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Review

Methodological Approach for the Sustainability Assessment of Development Cooperation Projects for Built Innovations Based on the SDGs and Life Cycle Thinking

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Abstract: This paper describes a methodological approach for a sustainability assessment of development cooperation projects. Between the scientific disciplines there is no agreement on the term of “sustainability”. Whereas the definition of sustainability within the context of development cooperation frequently highlights the long-term success of an intervention, the United Nations herald the inclusion of social, economic and environmental aspects. This paper proposes to bridge this gap by providing an analytical framework that uses nine impact category groups based on thematic priorities of sustainable development derived from the Sustainable Development Goals. Additionally, the long-term effectiveness of a project is taken into consideration. These impact category groups comprise the analytical framework, which is investigated by the Life Cycle Assessment and an indicator-based analysis. These data are obtained through empirical social research and the LCA inventory. The underlying concept is based on life cycle thinking. Taking up a multi-cycle model this study establishes two life cycles: first, the project management life cycle; and, second, the life cycle of a project’s innovation. The innovation’s life cycle is identified to have the greatest impact on the target region and the local people and is consequently of primary interest. This methodological approach enables an ex-post sustainability assessment of a built innovation of a development cooperation project and is tested on a case study on Improved Cooking Stoves in Bangladesh.

Keywords: sustainable development; sustainability; Sustainable Development Goals (SDGs); development cooperation; life cycle thinking; life cycle assessment

1. Introduction: Why Sustainability Is Important in the Development Sector

Our present age, the so-called Anthropocene [1,2], is defined by global anthropogenic climate change, rapid loss of biodiversity and over-exploitation of resources, including both sources and sinks. These prominent impacts cause environmental, societal and economic disruptions. As a response, the United Nations’ Millennium Declaration calls sustainable development to be the major solution to tackle these problems [3,4]. This political incentive has been encouraging development activities to devote more attention to the sustainability of their development projects. In addition, development cooperation projects are faced with resource scarcity and an increasing demand of stakeholders and investors to demonstrate the usefulness and effectiveness of the projects. Therefore, the need to come up with frugal innovations that reduce negative impacts on the environment is more urgent than ever. However, in order to evaluate whether a development project has been implemented in a sustainable way, it is crucial to conduct a sustainability assessment using standardized approaches and criteria. However, literature shows that so far only limited methodologies have been developed and applied for sustainability assessments [5], with only a small number of them tailored to the evaluation of projects in the development cooperation sector [6].

One main obstacle has been a lack of a common definition on what sustainability means. This, however, seems to be desirable since the term is widely used within industry, politics, research and society and is continuously gaining popularity. One of the most frequently cited concepts of sustainable development has been defined by the World Commission on Environment and Development within the so-called Brundtland Report, as: "[. . .] development that meets the needs of the present without compromising the ability of future generations to meet their own needs" [7]. This definition emphasizes the temporal aspect of sustainable development providing inter- and intra-generational equity. Rooted in these ideas and understanding, researchers developed a three-pillar model (also called three dimensions) which takes into account economic, social and environmental aspects (see cf. [8–12]). Within this notion, each of the three pillars is given an equal weight and it is only by considering all of them that an anthropogenic system can be sustained.

The eight Millennium Development Goals (MDGs) declared in 2000 at the Millennium Summit by the United Nations are in line with this notion and incorporate social, economic and environmental aspects. These goals aim at the improvement of health issues, poverty eradication, gender and social equity, as well as environmental sustainability in developing countries, though they have a clear focus on the social dimension [3]. At the Conference on Sustainable Development (Rio Earth Summit 2012), the international community agreed on keeping all three pillars of sustainability, while giving more weight to environmental concerns [4]. This led to the proposal of 17 Sustainable Development Goals (SDGs) that were globally adopted in September 2015 at the UN Summit in New York [13]. Compared to the MDGs, the SDGs improve upon the coverage and the balance among the social, economic and environmental dimensions. Although there are some major drawbacks, such as the great number of goals and targets, a lack of clearly defined goals and overlapping objectives [14,15] the SDGs represent a huge step forward towards a common definition of sustainability. The adoption and acknowledgment of the SDGs by all member states of the United Nations underscores the political will.

In addition, the development sector has experienced a paradigm change. Nowadays, development is described as not only a country's economic growth but also its improvement of different aspects of human well-being, such as health or social equality [16]. This notion is broader than the traditional concept of development aid which has been defined mainly by resource flows from donors to less developed countries [17,18]. This change also goes hand in hand with the definition promoted by the European Union, the world's most important development actor: "[. . .] the aim of development is to achieve sustainable economic progress and social equilibrium" [19]. Other definitions of sustainability build on this concept and further highlight the long-term aspect of an intervention. Thus, one of the most popular definitions of sustainability in the context of development cooperation is given by the OECD (2002) as: "The continuation of benefits from a development intervention after major development assistance has been completed" [20]. This definition is shared by development cooperation agencies such as USAID [21], KfW [22], and the GIZ [23]. As a consequence, Holtz recommends replacing the term sustainability as it is currently being used in the context of development cooperation with long-lasting effectiveness to avoid confusion between both terms [6].

Two major problems arise from this currently used definition of sustainability: first, mainly the positive effects or benefits are assessed while potential negative impacts or a shift of burden are often not assessed in depth [23,24]. A shift of burden can only be detected if the concept of life cycle thinking is applied which is seldom the case [25]. Also evaluations remain largely confined to observations of effects in the use phase of the products. Second, the environmental dimension is often not adequately accounted for although it is crucial for the long-term prosperous development of a country. Consequently, these concerns are addressed in this paper by taking up the three-pillar model promoted by the UN and agreed upon by the international community. The three pillars are considered to be equally important and positive as well as negative effects have to be evaluated in order to conduct a holistic analysis and to provide a comprehensive understanding of the effects of a development intervention.

Following this introduction, Section 2 reviews the state-of-the-art and highlights the associated challenges regarding existing sustainability assessment methods. Section 3 describes the herein proposed methodological approach for a sustainability assessment of development cooperation projects dealing with any type of built innovation. An innovation is defined as: "[. . .] an idea, practice, or object that is perceived as new by an individual or other unit of adoption" [26]. According to this definition we define a built innovation as a tangible object which may include buildings (e.g., schools, and hospitals), infrastructure (e.g., roads, and electricity grids), and manufactured goods (e.g., cooking stoves). The question whether other types of innovation such as business development projects (e.g., cash flow, and micro-credits), projects aiming at improving the social welfare or educational system can be assessed through the herein proposed methodological approach is unclear and makes further research necessary. Section 4 provides an application through a case study of a development cooperation project in Bangladesh. Section 5 discusses the advantages and drawbacks of the methodological approach and the subsequent Section 6 finishes with a short conclusion.

2. State-of-the-Art and Challenges

The ex-post assessment of an on-going or concluded development project is crucial for determining whether the set goals have been achieved and how the project design can be improved for future implementations. There are several options how to conduct an evaluation e.g., ex-ante versus ex-post, the analysis of short-term versus long-term effects, intended and unintended benefits, positive and negative impacts, among others. Furthermore, an evaluation can include monitoring, process evaluation, cost-benefit evaluation, and impact evaluation [2]. In general, the methods of evaluation differ depending on the aspects that should be evaluated and also depending on costs and time spent for retrieving the necessary data for the evaluation. Many development aid projects use the *OECD DAC* guideline for their project evaluation [27]. Still, the OECD's definition of sustainability focuses on the long term effectiveness of development cooperation projects which is included as the temporal aspect. The literature review reveals more methods to evaluate development projects, such as logical framework analysis, objectives-oriented evaluation, cost-benefit analysis, the interpretivism or constructivism approach or indicator-based assessments (cf., e.g., [28–31]).

This paper uses the concept of indicator-based assessments which is comparable to the approach of the LCA where indicators for the environmental impacts are used. The advantages of an indicator-based assessment compared to, e.g., a purely qualitative approach [32,33], is a more objective quantitative analyses which retrieves its data through tools of empirical social sciences. The results are compared to a reference system in order to reveal positive or negative impacts, thus, making an evaluation less subjective.

Some of the well-established methods using a reference system include the social experimentation model. This approach, also known as with-without approach [34], creates a counterfactual by using a control group without the innovation and by comparing it with the target group benefiting from the innovation. In order to compare both groups the control group should have similar attributes as the treatment group with the only difference that the former does not benefit from the intervention [35]. Another way to prove causality is the difference in difference method [36]. Here, a control group is being compared to the treatment group ex-ante and ex-post of the intervention. Many scientists consider this methodology to be ideal to assess the impact of a development project [29]. Other reference systems include the before-after approach [34,37], milestones set by the project management or benchmarks derived from national or international statistics. In addition to these methods, the LCA forms a key tool for the assessment of the environmental impact. It is a well-recognized methodology using the internationally accepted standards of the International Organization for Standardization (ISO) [38]. The concept of life cycle thinking has also increasingly gained popularity over the last years in politics and decision making [39]. As a result, it has been further developed towards a more holistic approach by also including economic and social aspects for the sustainability assessment of products and product systems. This approach is called life cycle sustainability assessment (LCSA) [40]. Such a life cycle sustainability assessment consists of the LCA, the life cycle costing (LCC) which focuses on the economic dimension and the social life cycle assessment (SLCA) (and its sub-method life cycle working environment (LCWE)) which deals with the social impact of a product [40,41]. However, there are drawbacks that make an application in the development sector not feasible; i.e., the SLCA is still being developed and discussed and there is no agreement on the social impact categories [40], while the LCC focuses on costs of products or product systems and therefore omits information relevant for development assistance such as poverty or employment [25]. As a consequence, the well-recognized LCA is used for the environmental (and some social) impact assessment whereas an indicator-based approach is being used for the analysis of the social and economic impacts. The LCA is able to provide indicators and large databases for the assessment of environmental impacts that otherwise are difficult to measure throughout all life cycle phases of an innovation (such as particulate matter formation, ecotoxicity or global warming), but that are also highlighted to be crucial within the SDGs [13,42].

Some recognized sustainability assessment methods of development cooperation projects focus on the long-term effectiveness and its measurement (cf., e.g., [23,32]). Therefore they mainly focus on the social and economic dimensions, whereas environmental aspects are only treated as cross-cutting topics or an unequal dimension. Some sustainability assessments that focus on the long-term effectiveness of benefits do not consider additional negative or positive impacts within the social, economic and environmental dimension [43]. Other methods take into account all three pillars of sustainability but in an unbalanced way by giving the social dimension more weight or by not using quantifiable indicators [25,44–46]. In contrast, other frameworks use indicators stemming from the three pillars of sustainability but do not take into account the long-term effectiveness of the project or the impacts during each life cycle phase of an innovation [24,37,38]. Often, the sustainability evaluation of a project does not take into account the whole life cycle of the project's innovation. As a result, the end of life or the manufacturing phases are excluded from an evaluation. Whereas existing sustainability assessments based on life cycle thinking take into account the overall life span but are, with few exceptions, not adapted for analyzing development cooperation projects [24,27,37]. Still, there is no single framework which provides guidance for projects on how to retrieve and assess data for a comprehensive sustainability assessment.

3. Methodological Framework

This section comprises the core of the paper as it describes the proposed methodological approach for a sustainability assessment for development cooperation projects. With the identified advantages and limitations of existing methodologies in Section 2, this paper combines several aspects of the above mentioned sustainability assessment approaches: it applies life cycle thinking and separates a development cooperation project into its different life cycle phases. This approach, therefore, accounts for the overall question whether the innovation proves frugal or not. If an innovation consumes fewer resources during the use-phase but a large amount of resources for its production, the overall life-cycle might prove resource intensive. The question of resources, however, comprises only one part within a sustainable development. Another benefit of this approach is the assessment of each life cycle phase in respect to the social, economic and environmental dimension. This is done using quantitative indicators. Since the three dimensions are regarded equally important there are three impact category groups for each dimension which are derived from the SDGs of the UN. Furthermore, another impact category group is introduced which takes into account the long-term aspect of the development cooperation project. The implementation of the method should ideally be used combining bottom-up approaches (e.g., data sampling and weighting) and expert knowledge (LCA). By including the results into a referential system, the assessment accounts for positive and negative impacts. For the overall sustainability assessment, the following structure is applied for the research framework following the life cycle assessment standards [38,39,47,48] (see Figure 1):

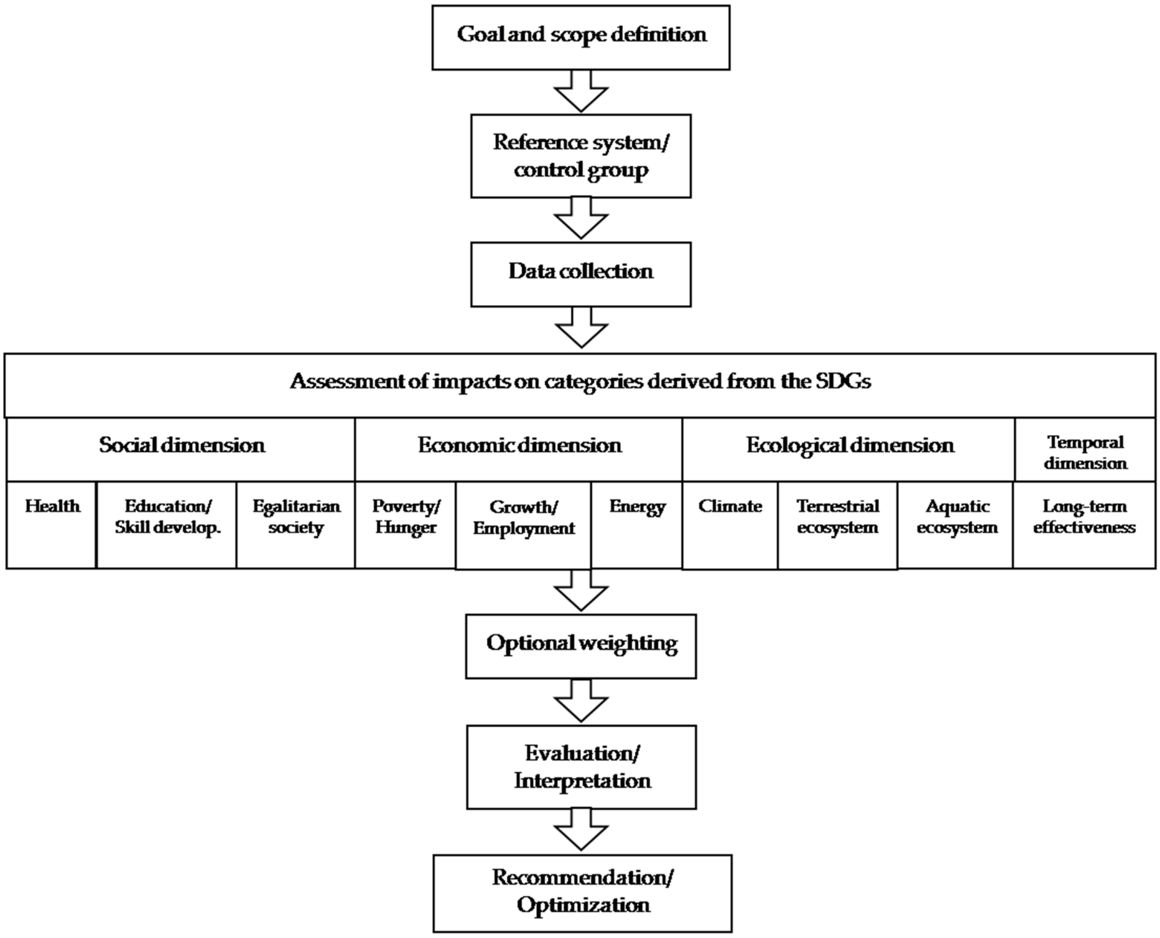


Figure 1. Sustainability assessment of development projects (modified after [39]).

3.1. Goal and Scope, Reference System and Data Collection

As the starting point of the investigation the goal and scope of the sustainability assessment has to be clarified. The goal is to conduct a sustainability assessment that accounts for social, economic and environmental impacts—positive and negative alike. This is done within the set system boundaries and in relation to the reference system [38].

In respect to the system boundaries the concept of life cycle thinking provides a suitable framework for a sustainability assessment. As it has been highlighted by the UNEP one major advantage of life cycle thinking is to take into account a balanced view from the beginning until the end of an innovation [49]. The question of how to investigate the impact of a development cooperation project has not yet being decided. One way is to divide the project into life cycle phases of the project management (conceptualizing, planning, implementing and closing phases) [44,50]. However, by only evaluating this life cycle one neglects additional impacts that take place during the manufacturing or the end of life of the project's innovation.Therefore, this paper takes up the suggestion of Brent and Labuschagne who propose a multi-cycle model [51–53]. Therefore, two life cycles can be distinguished:

the project management life cycle and the innovation life cycle which is supposed to continue beyond the first life cycle (people should still be able to use the innovation after the project management has come to an end). The second life cycle can be structured into three phases: manufacturing or establishing of the innovation, its use and operation, as well as its end of life phase which comprises recycling, disposal or other forms of waste management (see Figure 2). Ideally, both life cycles should be analyzed in order to grasp the full impact of the development cooperation project. In case of limited time and resources one should at least, however, focus on the innovation's life cycle which has the greatest impact on the target region [52].

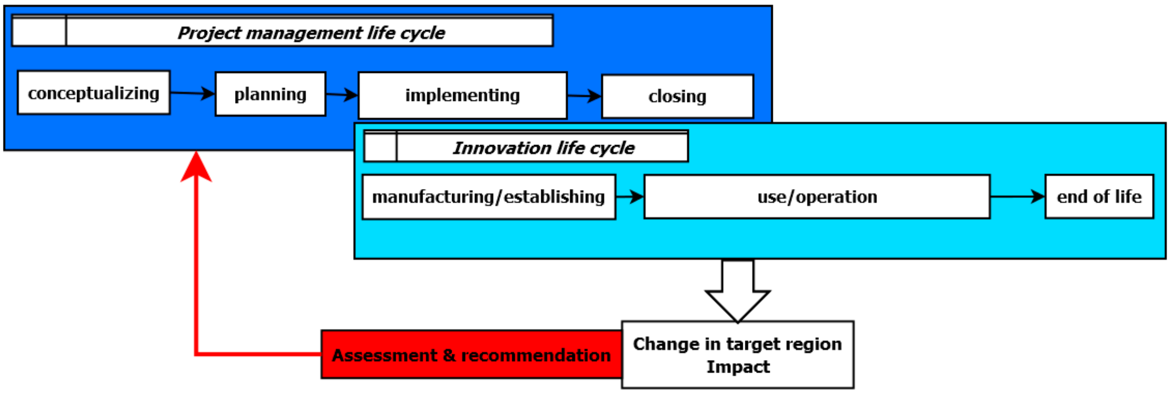


Figure 2. Two major life cycles of a development cooperation project to be considered within a sustainability assessment.

In respect to the reference system, there are several ways of measuring the effect of an innovation. Obviously, the reference system must be adjusted depending on the specific impact category that is to be analyzed. The necessary data are gathered through empirical social research and might be gained through a bottom-up participation. In general, it is important to randomize the study in order to avoid possible data bias [31]. The most favorable case is to rely on data triangulation so that data from different sources can be compared and double checked, hence increasing the quality of the data-based interpretation [54]. Some possible methods include participatory rural appraisal, household surveys, standardized tests, group discussions, spot check observations, official statistics and document analysis (e.g., project documents). Analogous to this data triangulation, an investigator triangulation, which involves different researchers, is useful for the transparency of the results and interpretation. The described sampling strategies can be applied for each selected indicator as they are described in this paper and in the annex.

3.2. Assessment of the Impacts

In order to conduct a sustainability assessment for the life cycle of development cooperation projects, impact categories with suitable indicators have to be defined. For this purpose the recently launched SDGs serve as a basis since the UN claims that these goals cover the global thematic priorities for sustainable development [13]. However, the 17 SDGs, showing priorities for sustainable development, have been criticized by scientists for their large number and indistinct objectives. Furthermore, all goals are multi-dimensional [15]. In this respect, the ICSU suggests to cluster the goals under so called meta themes in order to reduce overlaps and ambiguities [15].

An analysis of the 17 goals shows such inter-linkages: SDG 1 for instance addresses the reduction of poverty and is thus strongly interconnected with all the other 16 goals since the causes for poverty are multi-dimensional in their nature and linked to, e.g., hunger, health, jobs and employment, the degradation of ecosystems, etc. SDG 2 addresses the end of hunger, which is in turn directly linked to poverty alleviation (SDG 1), whereas the other concerns of SDG 2, food security and sustainable agriculture, are directly related to water management (SDG 6), the impact on terrestrial ecosystems

(SDG 15) and sustainable consumption and production (SDG 12). SDG 3 aims at improving health issues and is also interconnected besides poverty (SDG 1) with aspects dealing with water and sanitation (SDG 6), hunger and malnutrition (SDG 2) or the aspiration of an egalitarian society (addressed in SDG 5, SDG 10 and SDG 16). SDG 4 aims mainly at education and learning but is also interconnected with the development of an egalitarian society, which forms also part of SDG 5, SDG 10 and SDG 16 and is strongly interlinked with other goals dealing with health (SDG 3), poverty (SDG 1) or employment (SDG 8). SDG 6 addresses scarcities of water and sanitation problems and is deeply interconnected with aspects of poverty (SDG 1), sustainable agriculture and hunger (SDG 2) health aspects (SDG 3) or the management of aquatic resources (SDG 14). SDG 7, highlighting energy for all, is connected to the concept of an egalitarian society and is strongly linked to SDG 13 on the mitigation of climate change and SDG 9 emphasizing the importance of infrastructure and industrialization for economic development. SDG 8 takes into account growth and employment but also touches upon poverty and an egalitarian society. SDG 17 addresses partnerships for achieving the goals which is at the heart of development cooperation. Thus, implementing a cooperation project as a whole aims at the last SDG. For an overview of more interlinkages see Figure 3. As it is described, all development goals are strongly linked with each other and thematic priorities for sustainable development are not only addressed within one single goal. Some goals are even contradicting and contain trade-offs amongst each other. Thus, the methodological approach takes into account the suggestion of the ICSU and clusters the goals under so called meta-themes—here addressed as impact category groups [15]. This shall also help to make the methodological approach more simple and easier to apply for practitioners.

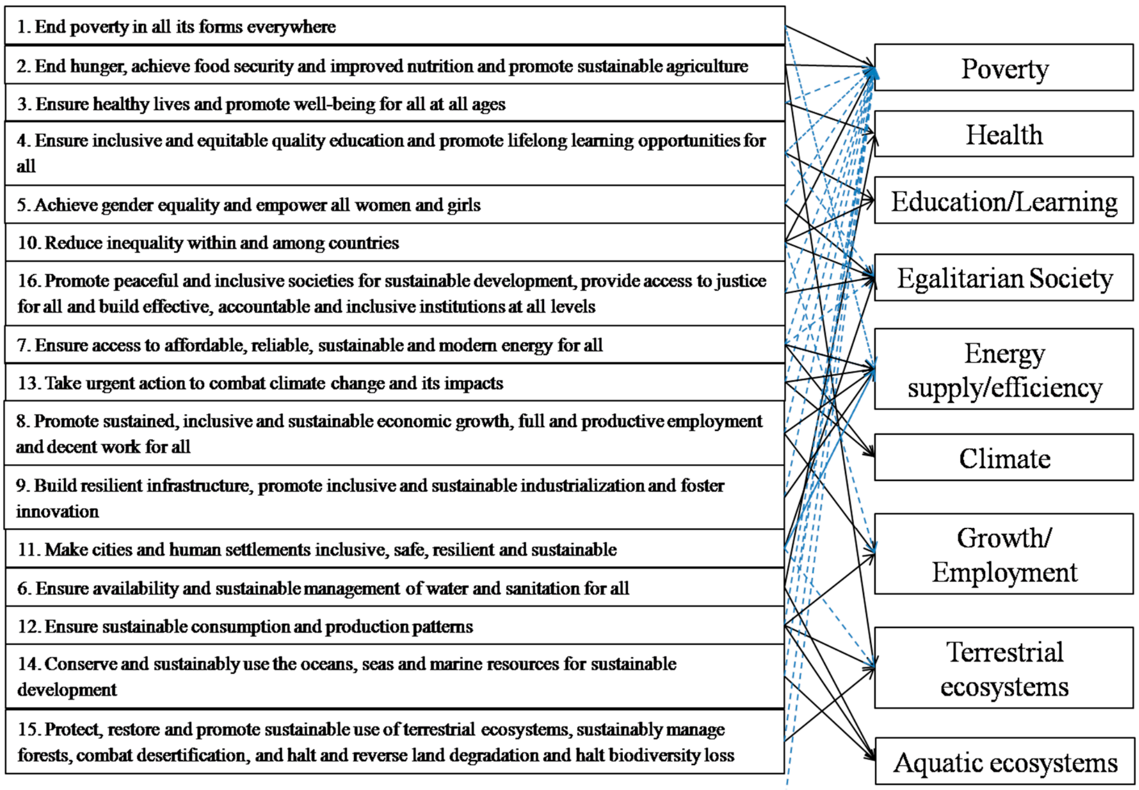


Figure 3. The Sustainable Development Goals and their relation to the impact category groups.

Therefore, for the sustainability assessment the goals are reduced to 9 impact category groups that are used to assess the sustainability of an innovation on a local and regional scale. Notwithstanding, the 17 SDGs are all addressed in the 9 impact category groups in such a way that they fit the scale of an innovation; SDG 11 highlights the need to make cities and settlements among other things inclusive and safe. These aspects can be dealt with through the impact category groups egalitarian society (e.g., indicator: number of handicapped people) and health (e.g., indicator: number of accidents). Each impact category group consists of several impact categories that address aspects of the corresponding group, e.g., the impact category group "health" is divided into impact categories such as "accidents" and "human toxicity".

The social dimension encompasses the impact category groups health, education and egalitarian society. The groups poverty, energy supply and consumption as well as growth and employment form part of the economic dimension. The groups climate, terrestrial and aquatic ecosystems are addressed within the environmental dimension. Indicators are necessary to obtain information on the innovation's repercussions of its specific impact categories. Hence, they must be tailored for each project depending on the type of innovation. In order to assess the impact categories within their group of terrestrial and aquatic ecosystems, climate, and to a certain extent health and energy indicators derived from LCA can be used. For the other impact categories, indicators are derived from relevant literature sources. A comprehensive catalogue of SDG indicators is provided by the UN [13,42]. However, though some of these indicators may prove helpful for the herein proposed assessment others cannot be used because they do not refer to innovations or regional projects (e.g., indicator 1.5.3 addressing SDG 1 "Number of countries with national and local disaster risk reduction strategies" or indicator 2.a.2 addressing SDG 2 "Total official flows (official development assistance plus other official flows) to the agriculture sector"). Even if SDG indicators are adopted they usually need modifications according to the scale of the project (e.g., indicator 1.1.1 addressing SDG 1 "Proportion of population below the international poverty line, by sex, age, employment status and geographical location (urban/rural)" has been modified in our case study to suit our needs; the modified indicator is "Proportion of beneficiaries below the international poverty line"). More potential impact categories and their indicators are provided in Appendix A to measure the development cooperation's contribution on each impact category group (see Table A1). The impact categories are formulated in a general manner to make it applicable to different types of innovations and can be specified as it fits. In order to evaluate the temporal aspect of the project, an additional impact category group is taken into account throughout the innovation's life cycle which is called long-term effectiveness. This group is not part of one of the three pillars of sustainability but highlights the temporal dimension and how external factors influence the development and, therefore, longevity of the innovation. Thus, it is treated as an impact category group that encompasses all of them (see Table 1).

Table 1. Priorities for sustainable development based on the three pillars and their corresponding impact category groups.

Society	Environment	Economy
Education/Skill development Egalitarian society Health	Climate Terrestrial ecosystem Aquatic ecosystem	Poverty Growth/Employment Energy supply/consumption
	Temporal dimension Long-term effectiveness	

3.2.1. The Social Dimension—Impact Category Groups and Impact Categories

The three impact category groups within the social dimension are health, egalitarian society and education and skill development. Their importance for a sustainable development is being highlighted in the following.

(1) Impact category group: health

This group is clearly mirrored in SDG 3 linked to SDG 2 and SDG 6 by addressing the improvement of health and of the well-being. Being in good health is one of the primary basic human needs and is considered to be crucial for a sustainable development. Many development cooperation projects focus on health improvement measures in least developed and other low income countries. However, the intended health benefits are usually accounted for solely for the use phase of the innovation. The herein proposed methodology sheds light on this blind spot by including the manufacturing phase and the end of life of the innovation. Impact categories within this group might encompass human toxicity, accidents and specific diseases.

(2) Impact category group: education and skill development

Education and skill development are an underlying driver for inclusive societies and sustainable development [55] and are addressed in SDG 4, directly linked to other goals such as SDG 1. By conducting educational or vocational training, opportunities can be created for people to actively participate within the development cooperation project. The ILO highlights the importance of training throughout all life cycle phases for the proper handling of an innovation for technology transfer between developing and developed countries [56]. Following the ICSU also aspects of awareness-raising for environmental concerns are taken into account as part of this group [15]. Some impact categories might be quality of training and application of knowledge.

(3) Impact category group: egalitarian society

An egalitarian society, including gender equality, is a crucial aspect of a modern and balanced development [57] linked to all SDGs [15] and addressed especially in SDG 1, SDG 5, SDG 10 and SDG 16. The inclusion of disadvantaged and marginalized groups within the society as well as the protection of children is an important part of the social dimension of sustainable development [58]. This has been especially highlighted by the definition of sustainability by the Brundtland Report [7]. In respect to the measurement of the impact categories of an egalitarian society with indicators it is possible to rely on the other impact categories of related impact category groups. By disaggregating the other social and economic indicators for health, income, employment or education and skill development by social vulnerable groups (e.g., gender, children, minorities, age, migrant status, ethnicity or disability) information is obtained about the innovation's impact for an egalitarian society.

3.2.2. The Economic Dimension—Impact Category Groups and Impact Categories

Within the economic dimension the three impact category groups poverty, growth and employment and energy are being described.

(4) Impact category group: poverty

Within a scientific review of the SDGs, poverty reduction addressed in SDG 1 is claimed to be one of the major goals for sustainable development and the basis for all of the SDGs [15]. Many of the other impact category groups address aspects of poverty, such as education, health, jobs and employment. This group therefore focuses on poverty with respect to impact categories income and monetary savings. There is a strong relationship between income and hunger especially for developing countries where large parts of the total income are spent for the acquisition of food [59], which links this impact category directly to SDG 2. In general, the reduction of poverty contributes to both the social and economic pillars of sustainability; since within this methodological approach income poverty is analyzed, this impact category group is assigned to the economic dimension.

(5) Impact category group: energy

Having access to energy has been addressed in SDG 7 directly linked to SDG 13. For a prosperous economy, energy is needed for almost all types of economic activities (jobs, productivity, and development). This is the reason for assigning this group to the economic dimension. There is a tradeoff between the mitigation of climate change and higher energy supply and consumption for economic activities. Within this methodological approach this trade-off is taken into account by valuing the energy supply through an innovation as positive within this respective impact category, as it touches upon economic concerns. The corresponding increase in greenhouse gas emissions is valued as negative in the impact category group climate. If there is a reduction in energy consumption due to the higher efficiency of the innovation, the impact is valued as positive within both impact categories, since higher energy efficiency does also benefit the economy.

(6) Impact category group: growth and employment

SDG 8 highlights the need for sustainable growth, and quality employment. Within the impact category group growth and employment, impact categories are used that assess, e.g., the creation of jobs and a boost of entrepreneurship. Other impact categories touch upon the type of jobs (e.g., skilled vs. unskilled, and long-term vs. short-term) and working conditions that are compared to nationally and internationally recognized labor standards (addressed in SDG 8). Jobs and employment are not only crucial for the people to be able to afford their basic needs as well as education or health services, but are also an important driver of the country's economic growth. The UN highlights the provision of jobs and employment as one major tool for the eradication of poverty. However, they also show that there is a direct linkage of well-being and employment in connection with sound ecosystems, an intact environment as well as a stable climate. This is why particularly "green" jobs have been promoted for a sustainable development [60].

3.2.3. The Environmental Dimension—Impact Category Groups and Impact Categories

Within the environmental dimension the three impact category groups terrestrial as well as aquatic ecosystems and climate are being described. In order to assess the innovations impact on these groups, impact categories and their indicators from a LCA can be used.

(7) Impact category group: terrestrial ecosystems

The impact on terrestrial ecosystems is directly addressed within SDG 2, SDG 12 and SDG 15. People from developing countries are particularly dependent on their environment and the provision of natural resources as well as ecosystem services [61]. However, 15 out of 24 crucial ecosystem services are currently being destructed by human activities [62]. This highlights the importance of the environment and its protection especially for the sustainable development of low income countries. In addition, for the economic growth, which is based on natural assets within developing countries, a healthy environment is important as a safety net for local communities [63,64]. The enhancement of the management of natural resources and ecosystems is therefore deeply connected with many of the SDGs tackling economic growth, poverty alleviation or an egalitarian society; it can be reached with an improvement of the education, skill development and awareness raising [63]. To assess the impact on terrestrial ecosystems, impact categories can be derived from the methodology of LCA such as terrestrial acidification, eco-toxicity and resource depletion [65].

(8) Impact category group: aquatic ecosystems

Access to clean water and therefore healthy aquatic ecosystems are not only of environmental concern but also essential for human health and survival; they are directly addressed in SDG 2, SDG 6, SDG 12 and SDG 14. Aquatic ecosystems, freshwater and marine ecosystems are interconnected by a global water cycle and therefore protecting one ecosystem also positively influences the others. Access to clean water and aquatic resources is an underlying driver of food security and the reduction of poverty. Since it is mainly women who are the ones responsible for collecting water for housework, e.g., cooking or washing, they are especially vulnerable to water borne diseases. Hence, access to safe water also touches upon the aspects of equality and an egalitarian society. The depletion of water supplies combined with the predicted demographic increase and water scarcities due to the effects of climate change will constitute one of the major human challenges on the planet [66]. Many of the economic sectors, such as agriculture or the manufacturing industries are very much depending on large water supplies. Since water scarcities, polluted drinking water and the resulting health problems particularly affect the poor, improving such aspects is often part of the development cooperation initiatives. The LCA provides impact categories and indicators that can be used to assess the impact of the innovation on aquatic ecosystems throughout all life cycle phases. Among the impact categories are, e.g., freshwater aquatic eco-toxicity, marine eutrophication and water depletion [67].

(9) Impact category group: climate

The impact on the global climate is directly addressed in SDG 13 and inter-linkages and trade offs are shown in aspects touching upon SDGs 1, 2, 3, 6 and 7. Climate change is not only strongly linked with other environmental problems but it also has social implications. This is because the burdens of climate change especially affect the extreme poor in developing countries, since their economy is dependent on the agricultural sector to a high degree. Water scarcities, inadequate health provision, the burden of tropical diseases, and their low incomes which will make adaptations to climate change especially challenging contribute even more to the great vulnerability of people from developing countries [68]. This highlights the importance of mitigating climate change for sustainable development, especially for developing countries. To assess the impact of the innovation on global warming, a life cycle assessment can be conducted.

3.2.4. The Temporal Dimension—Impact Category Group and Impact Categories

The impact category group long-term effectiveness ultimately influences the temporal aspect of the other three dimensions. Contrary to the other dimensions, we do not assess what kind of impact the innovation has on the three dimensions but how external factors (such as local acceptance or governance) contribute to the long-term effectiveness of the innovation. Of course, these two perspectives are intertwined and constantly influence each-other.

(10) Impact category group: long-term effectiveness

Within this group, impact categories such as local acceptance, governance and local conditions (e.g., climate) and manifestation of the innovation are assessed for all life cycle phases. The acceptance of the innovation by the people and local communities is crucial for the success and long-term effectiveness of the development cooperation project. For example, let us assume that the innovation (e.g., improved cooking stove) enjoys popularity and is sold and distributed successfully during the manufacturing phase. However, due to customs and local behavior it functions as a status symbol and is de facto not used during the use phase. As a consequence, customs and local behavior contribute to a positive impact during the manufacturing phase but have a negative impact during the use phase where the intended improvement of respiratory diseases is hindered (because the traditional stoves are still being used). The corresponding impact categories and indicators can be used from existing methodologies (e.g., [23,44,69]). The importance of achieving local acceptance cannot be stressed sufficiently if the innovation is to be manifested successfully in the target region. Historic investigations reveal the relevance of local and regional agency within a process of cultural transfer. This transfer is not unilateral but relies on a local wish for the innovation which can take a specific local and creative adaptation according to their needs [69,70].

3.3. Optional Weighting

This methodological approach enables a weighting option, which provides the opportunity to include stakeholders of the project. The stakeholders, such as project managers or beneficiaries (thus allowing for bottom-up participation), can provide different weighting factors ranging from 1 to 3, while indicating: no priority (1); a low priority (2); and a high priority (3), according to the importance of the specific impact category group to the overall development cooperation project. A value of 0 should only be given if one impact category group is not applicable at all for this type of project. Each weighting factor is multiplied with the final score of each corresponding impact category group (see the next subsection). The advantage of a weighting is the involvement of stakeholders who can express their priorities. This enables the interpretation of the results in the context of the development cooperation project highlighting the success and shortcomings within the targeted impact category groups. This is a communication-friendly way of illustrating whether the objectives of the project have been achieved. The weighting should be regarded as an optional step of the assessment but does not exclude a detailed analysis of all impact category groups and their corresponding impact categories prior to any weighting.

3.4. Evaluation and Interpretation

As a final step, the results of the impact assessment will be evaluated and interpreted for each impact category group. This is undertaken by retrieving data for each indicator, comparing them to the corresponding reference system and triangulating the results for a final score of the impact category. Herein, each indicator is evaluated: if the result of the indicator shows an improvement compared to the reference system, it will be scored with "+"; if it shows a deterioration it will be scored with "–" and if there is no change a "0" is given. As a next step, all results are added up and if the final result is positive, the impact category will be scored with "+1", if the final result is negative, there will be a "–1" and if the result is neutral, so is the impact category (0). Once all impact categories within an impact category group have their scores, they will be added up and divided by the total number of impact categories (see example in Table 2). Finally, the results can be visualized by a spider web for each life cycle phase, thus facilitating a better understanding.

Table 2. Evaluation matrix exemplarily for the impact category health during the use phase.

Social Dimension						
Impact category group: health			Final score: +0.33			
Life cycle phase:			Use and maintenance			
n°/Indicator	Measurement unit	Reference	Result of the reference	Result of the innovation	Resulting difference (%)	Score (+, –, 0)
Impact category: human toxicity			Final score: +1			
1.1/Dichlorobenzene equivalents	kg DCB eq./functional unit	...	...	...	...	+
1.2/ ...	...	...	...	...	...	+
Impact category: respiratory diseases			Final score: +1			
1.3/coughing	%	...	...	...	...	+
1.4/ ...	...	...	...	...	...	+
Impact category: accidents			Final score: –1			
1.5/N° of burns	n°/functional unit	...	...	...	...	–
1.6/ ...	...	...	...	...	...	0

Note: Abbreviation n° stands for "number"; Abbreviation eq. stands for "equivalent".

4. Case Study Improved Cooking Stove Project in Bangladesh

The herein proposed methodological approach has been inaugurated in Bangladesh where it assessed the level of sustainability of an improved cooking stoves (ICS) project. Due to its low demand on resources for its production, distribution and operation and its reduction of resources through substituting traditional cooking stoves, which consume more fuel-wood, this project is a good example for a frugal innovation [71–74].

This project started in 2005 and has been implemented by the GIZ [75]. About 5800 local manufacturers have been trained to produce improved cooking stoves and to sell them on the market. For the promotion of the stoves, 1200 female volunteers and 500 promoters have helped to successfully introduce it to the Bangladeshi market. Hitherto, more than 1.58 million ICS have been installed in households all over the country.

The reference system of this study is the traditional stove as a control group, which also displays the situation of the people before the implementation of the project. The data collection during the fieldwork took place in the Bogra Division, an administrational unit (also known as Upazila in

Bangladesh) of Shajahanpur, which is an urban area northwest from Dhaka. This area was chosen due to the high density of ICS users. Household interviews were conducted with both the manufacturers of the ICS and the traditional stoves as well as their users. In all cases, the traditional stove users were at the same time the ones who manufactured their own stoves. For a better comparison of the ICS households with the control group (traditional stove households), neighboring households were interviewed in order to avoid effects of urban gentrification, and to have comparable socio-economic and geographic conditions amongst both the target and control groups. The household surveys were conducted using semi-structured questionnaires.

For the impact assessment on the environmental dimension and health impacts during the manufacturing, use and end of life, the results of the life cycle assessment of a one-pot rice improved cooking stove was compared with the life cycle assessment of a one-pot traditional stove. The data for the material of the ICS were obtained by conducting interviews with the ICS producers and by referencing to additional literature data. Data for the production of the traditional stove was retrieved from literature sources (BCSIR 1984). Calculations were made for the quantities of material where no information could be found within the literature. Since all the ICS of the households were quite new and none of them has had dysfunctions yet, a scenario has been assumed in which the broken stoves will be dumped at a landfill area. This enables the modeling of the end of life phases. For the broken ICS the assumption was made that all parts of the broken stove will be dumped except for the iron grate, which usually has a longer durability than the stoves and which can be recycled and reused for a new stove. In total, 36 different indicators were used within the ten impact category groups under investigation. Each indicator was first scored individually and then added up to one general score for the overall impact category which in turn were added up for a final score of the impact category group. The major benefits of these stoves are their greater energy efficiency by saving between 30 to 50 percent of fuel wood. Additional positive outcomes are supposed to be the improvement of health due to a chimney which leads harmful smoke away from the stove users [76].

The large-scale implementation of the ICS project mirrors the societal relevance and justifies the need to assess its degree of sustainability. Nonetheless, the conducted case study does not claim to grasp the full impact, but rather represents a pilot study with which the herein proposed methodological approach has been field tested. Due to the small amount of data that have been used to demonstrate the application, these results should not be seen as a complete assessment of the GIZ project. In the next subsection, an example is given for the impact category group (1) health.

4.1. Results of the Case Study—Health

In the following, we present some results touching upon human health during the three phases of the life cycle of the innovation. For the manufacturing phase, no accidents during the manufacturing process have been reported. This shows that there is a good occupational health and safety conditions for the ICS production and can therefore be evaluated as positive (Indicator 1.6). However, the processing and use of material for the ICS production shows a greater potential risk for human health related to the higher toxicity potential during the production of the ICS (Indicator 1.1). The human health risks due to particulate matter formation attributable to the ICS production are greater than for the traditional stove (Indicator 1.5). Thus, the manufacturing phase of the ICS can be evaluated for one impact category out of three as being positive.

For the usage phase, both the household interviews and the results of the LCA show an improvement in health incidences due to the use of the ICS. However, in the results of the interviews, none of the ICS respondents claimed to be suffering from any symptoms of respiratory diseases, smoke and tears while cooking, being therefore in contrast to the observational data. For example it was observed during the interview that the husband of one interviewee was making fire. During this process smoke was produced and his eyes were red and tearing. Nonetheless, the interviewee responded that there was no smoke with the new ICS. Additionally, some of the ICS showed a blackening of the stove walls which is another sign for smoke production. Hence, the number of all of the ICS respondents without any smoke and tears while cooking seems to be too high and therefore not reliable. Moreover, the local project partners as well as an ICS producer were present during the interviews. Under the presence of the local project partner the ICS users might give answers that will satisfy the attendants. However, triangulating the results of the interviews with the results of the LCA for particulate matter formation (Indicator 1.5), there is still an improvement in health incidences related to respiratory diseases due to the use of the ICS (Indicators 1.2–1.5). The result of the LCA for particulate matter formation and its corresponding DALYs are even better because only the combustion process and its emissions have been modeled. Since the chimney of the ICS is channeling the smoke away from the users the positive impact on human health is higher. This also highlights the importance of the skill development for a proper usage and maintenance of the ICS, especially of the chimney. Even so, there is a clear improvement in health aspects regarding respiratory diseases attributable to the use of the ICS which justifies a positive evaluation. Moreover, a second positive impact on human health could be documented such as the decrease in accidents (burns) related to the better safety of the ICS while cooking (Indicator 1.6). Additionally, the use of the ICS decreases the human toxicity potential (Indicator 1.1). Therefore the usage phase scores positive health improvements for all impact categories under investigation (see Table 3). However, these results stand in contrast with the findings of some literature where authors reported no significant health improvements related to the use of another type of improved stove in India. Furthermore, they claimed that the positive impact on human health due to the ICS use had decreased already after one year, mainly due to the improper usage and maintenance of the stoves [77]. The average stove age of the ICS households in Bangladesh that took part in the interview was about 15.43 months, which is only some months above one year. Even though the stoves are technically different still, it is recommended to carry out another household survey after a given time to assess the long-term effectiveness of the ICS's health improvements.

Table 3. Results of the case study within the impact category group health.

Social Dimension						
Impact category group: health			Final score: +1			
Life cycle phase:			Use and maintenance			
n°/Indicator	Measurement unit	Reference	Result of the reference	Result of the innovation	Resulting difference (%)	Score (+, −, 0)
Impact category: human toxicity			Final score: +1			
1.1/Dichlorobenzene equivalents	kg DCB eq./functional unit	Trad. stove	0.011/ pot rice	0.006/ pot rice	45	+
Impact category: respiratory diseases			Final score: +1			
1.2/occurrence of symptoms: coughing, headache, . . .	%	Trad. User	90	0	90	+
1.3/smoke while cooking	%	Trad. User	100	0	100	+
1.4/tears while cooking	%	Trad. User	90	0	90	+
1.5/Particulate matter formation	kg PM 10 eq./functional unit	Trad. stove	0.062/ pot rice	0.058/ pot rice	15	+
Impact category: accidents			Final score: +1			
1.6/N° of burns	n°/functional unit	Trad. stove	20/last 3 weeks	0/last 3 weeks	80	+

Note: Abbreviation n° stands for "number"; Abbreviation trad. stands for "traditional"; Abbreviation eq. stands for "equivalent".

Regarding the end of life phase of the stoves the ICS shows a higher negative impact on human health related to particulate matter formation and human toxicity. The health impacts are especially related to the waste of the concrete and the landfill of other inert matter, such as the iron wire. Thus the impact on human health for the end of life scores two negative health effects, with the assumption that the stoves will be dumped at a landfill area after it has broken down. For the end of life, it is recommended to provide information and awareness-raising about risks for human health if all parts of the broken stoves will be dumped at a landfill area.

4.2. Results

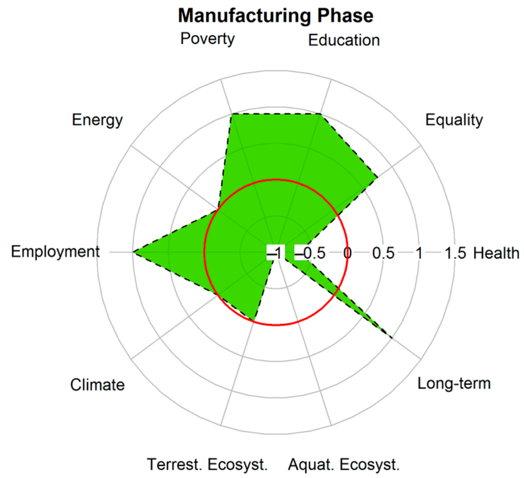
The three different spider webs (see Figure 4) illustrate the results for all ten impact category groups of the three different life cycle phases. The red circle indicates no impact or not applicable to the specific group, the impact category groups within the red circle show no success or deterioration, whereas the groups outside the red circle indicate an improvement.

The manufacturing phase of the ICS project shows a clear focus on the social and economic dimension such as poverty reduction, education and skill development, equality and employment. All these impact category groups show improvements within the ICS production phase. There are negative effects for the group energy efficiency and supply as well as climate change and terrestrial ecosystems due to the manufacturing of the ICS. However, these negative impacts could be offset by the positive impact of the usage phase which led to a neutral evaluation. The only impact category group that lies within the red circle in the spider-web, thus indicating deterioration, concerns the aquatic ecosystems. A recommendation to mitigate these negative impacts could be to use recycled materials for the production, as long as it is not negatively impacting the durability of the new ICS.

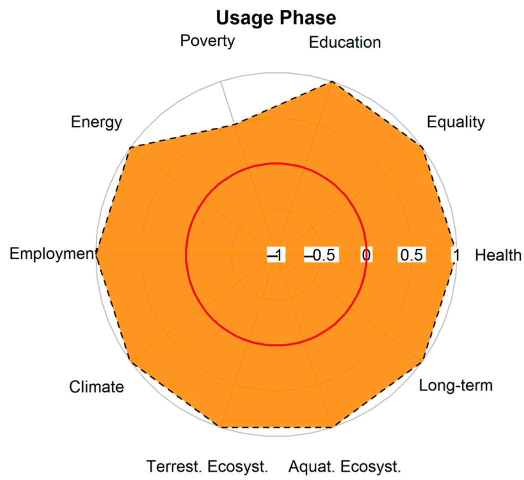
The use and maintenance phase of the ICS has a strong focus on the social dimension by showing good results in the impact category groups education, egalitarian society, health and also in the economic field of energy efficiency. Other positive outcomes of the project that were not the focus of the use phase touch upon the groups employment, as well as the environmental dimension. The reduction of poverty that was reported to be highly important for the overall success of the project shows potential of improvement. At least for the research area of Bogra the majority of the beneficiaries had already an income above the international and national poverty lines. That is why the ICS project does not contribute to poverty reduction for the majority of people within this area. Nonetheless, the project has an overall good potential to contribute to the fight against poverty. In order to determine the impact of the ICS on poverty reduction in Bangladesh, more data should be sampled within other areas of the country. Proposed recommendations are an intensified promotion of the ICS or a smaller or portable version of the ICS, etc.

The impact of the end of life on employment, egalitarian society or local acceptance could not be investigated. Therefore, it is recommended to carry out a second survey at a later time period to assess these impacts. The analysis shows that poverty was positively influenced by the long durability of the ICS, since the short amortization rate does not negatively affect income and savings of the people. The education had to be scored as negative because no information was given on waste management. Providing such information in future might cushion the impact on human health and aquatic ecosystems. This assessment has assumed a scenario in which parts of broken stoves are being dumped at a landfill area. This might not reflect the real situation and makes additional research in the future necessary.

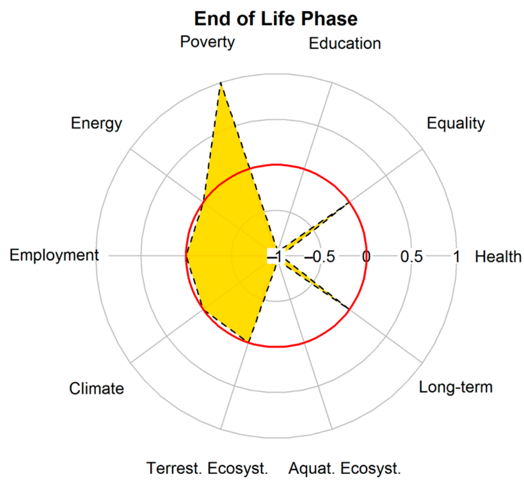
In general, it has to be highlighted that it is almost impossible to have positive contributions of the innovation for each impact category group within all life cycle phases. This is not the claim of this methodological approach. The goal is to point out the impact of the innovation for important topics of sustainable development and to give suggestions and recommendations for the optimization of potential negative impacts.



(**a**)



(**b**)



(**c**)

Figure 4. Evaluation of the different impact category groups: (**a**) manufacturing phase; (**b**) usage and maintenance phase; and (**c**) end of life phase of the innovation.

4.3. Recommendations Case Study

This subsection provides a short summary of recommendations that are given for potential improvements within the analyzed impact category groups:

- *Health:* It is recommended to provide information and awareness-raising about risks for human health if the broken stoves are dumped at a landfill area.
- *Education and skill development:* (Regular) user knowledge refreshment could help make the ICS more effective and efficient.
- *Egalitarian society:* ICS shop owners could be made aware of the advantages of equal salaries for their female employees to reduce the gender wage gap. The ICS shop owners could be encouraged to employ more women or disabled people to increase the labor participation rate of socially disadvantaged groups. Despite potential socio-cultural barriers more female ICS entrepreneurs could be trained for the ICS production.
- *Poverty:* An intensified promotion of the ICS within areas of Bangladesh where more than half of the population is living below the poverty line can be considered. Stimuli, such as subsidies for the (extreme) poor for buying and maintaining the ICS can help incentivize people that otherwise do not have direct monetary savings.
- *Growth and employment:* Jobs and economic growth could be achieved by refurbishing old ICS into a reusable form or by recycling old ICS parts and components and reusing them as useful parts or raw material. A win-win opportunity for the ICS owners and producers could be created by offering a return system for broken stoves.
- *Aquatic ecosystems:* Recycling and reusing of broken ICS parts can reduce the negative impact on aquatic ecosystems.
- *Local acceptance:* The design of smaller types or portable versions of ICS might attract households that do not have enough space for the existing model. Alternatively, a service for the households to fill up the unused holes of the traditional stoves and to install the ICS within this unused area could be provided. Awareness-raising about health issues related to indoor air pollution could be given, since only the minority of the users reported health improvements to be the reason for potentially buying an ICS.

5. Discussion

This study proposes a new methodological approach for assessing sustainability aspects of development cooperation projects. It does so by referring to priority topics of the SDGs which have been recently accepted by the international member states. Evidently, public and private organizations are still in the process of rethinking and reorientating their approaches in order to account for current political events. The UN goals serve as a basis for identifying impact category groups but are simplified in number and tailored towards development cooperation. In doing so, the method sets up an analytical framework of ten groups that should be evaluated regardless of the type of innovation.

These universal impact category groups facilitate the comparability of the success of development cooperation projects and match the balance between social, economic and environmental demands which lies at the core of the SDGs. As a desirable by-product, every sustainability assessment accounts for intended but also occurring, unintended negative impacts in all three societal pillars that are caused by the introduced innovation.

The assessment of these ten groups is conducted through a combination of well-established methodologies. Among the contributions of natural science are the LCA and life cycle thinking. The LCA offers a well-recognized assessment tool for the impact categories "health", "energy" and the environmental dimension. Whereas life cycle thinking serves as starting point for the structural division of an innovation into its life cycle phases. These phases and their subsequent assessment are not yet common in development assistance evaluations but of utmost importance if one is to avoid a shift of burden. The social sciences provide social research methods of quantitative and qualitative designs using among other elements household surveys, spot-check observation, focus group interview or qualitative document analyses. Their common interdisciplinary ground includes well-known procedures, such as randomization and indicator-based investigations.

Since this methodology represents an ex-post analysis further research might shed light on its potential for an ex-ante assessment in order to identify alternative innovations. Still, this might prove difficult because information about the innovations in question is needed and there might be no data for comparable impact categories. Furthermore, regional factors such as availability of resources and human habits influence the impact of each project significantly.

Having highlighted the benefits of the herein proposed methodology, its limitations should be discussed. The first concerns the scope of the assessment. This study has only investigated the life cycle of the innovation. This is usually of primary importance for the contracting authority since the establishment of an innovation usually takes place in the target country where its impact is taking place. Nonetheless, there is also a life cycle of the project management, which always precedes the implementation of the innovation, and which usually ends while the life cycle of the innovation is still continuing. If one is to analyze the sustainability of the overall project both life cycles must be assessed thoroughly. Further research should be conducted for including the life cycle of the project management. Since this methodology only takes into account built-innovations, it must be also further investigated whether these life cycle phases are adaptable for assessing projects with non-built innovations. This touches upon the questions whether two life cycles are applicable and the corresponding life cycle phases have to be modified. Additionally, the nature of the innovation has to be reconsidered and how the impact category groups have to be changed in order to make them accessible.

The second limitation deals with the application of the LCA in developing countries. It could be demonstrated that it is possible to reconcile the methodology of life cycle assessment with additional analytical tools to assess the impact of development projects. However, the LCA has been developed for meeting the needs of an environmental assessment within developed countries. This becomes a concern if the LCA is applied to developing countries while still using data for developed countries. Therefore, further research could be conducted to sample more country specific data for developing countries and thus to improve the application of an LCA for developing countries.

Thirdly, the proposed methodological approach for a sustainability assessment proposes a framework universally applicable to different types of innovation. This flexibility has its limits—it is not possible to define a universal set of impact categories which would be applicable to any innovation. Therefore, if one is to apply this methodological approach to other types of innovation, the ten impact category groups would need customized impact categories depending on the specific innovation.

Additionally, the approach presents a final score for each life cycle phase of each impact category group by using an additive index. The major drawback is a loss of the absolute value information of the results. However, the advantages are that a final score can be easily communicated to other stakeholders. It can also be visualized for each impact category group and life cycle to demonstrate the respective positive or negative impacts. Moreover, by using an additive index negative impacts within one life cycle phase could be offset by positive results within the same impact category, e.g., the reduction of the same amount of emissions, within another phase. In offering this tool, development cooperation projects have the opportunity to compensate for negative effects that cannot be completely avoided. This in turn might incentivize project managers to perform further actions (such as planting trees for the compensation of GHG emissions) for the offsetting of negative scores so they can achieve a final positive score in the respective impact category group.

6. Conclusions

The herein proposed methodological framework aims at determining the degree of sustainability of a built innovation. In the light of global change and high pressure on resources it is of paramount importance to account for these developments and stress the need for frugal innovations. Yet, no innovation is an isolated project but rather an integrated part of the society where it is implemented. It develops geographical entanglements (local, regional and, to some extent, global) as well as dimensional entanglements with the social, economic and environmental sectors. The international community has recognized this inter-connectedness and expects cooperation projects between developed and developing countries to be well balanced. Most importantly a full-scale sustainability assessment does not limit itself at focusing on unintended negative effects of the innovation. Rather it outlines ways of how to reduce them efficiently so the innovation's contribution to the targeted society might improve.

Therefore, this study concludes with the main purpose of the herein proposed methodological approach for assessing development cooperation projects. It is hardly possible to get positive results for all ten impact category groups because every innovation creates geographic and dimensional entanglements that were intended and unintended by the project management. Assessing the level of sustainability of the project, by analyzing the impacts on the ten groups, should be therefore seen as an incentive. On the one hand, the positive impacts highlight the relevance of the innovation and provide reasons to keep supporting it. On the other hand, the negative impacts reveal the categories that need to be addressed and offer solutions so future projects of the same innovation might be improved upon. The purpose of this method is to support the project management to help optimize the impact of the different life cycle phases of its innovation in order to continuously improve its overall sustainability—for the sake of the local people, their economic development and their future environment.

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

Appendix A

Table A1. Impact category groups and potential indicators for the sustainability assessment.

Dimension	Impact Category Group	Impact Category	Possible Indicator	Sources	Measurement Unit	Reference System
Social	1. Health	Accidents	Number/ratio of accidents (including occupational health incidences and accidents)	[15,78,79]	Number/ratio of accidents per time period or number of DALYs	Control group or traditional technology, statistical data of similar sectors in target country
		Specific type of disease	Number of health incidences	[15,78,79]	Number/ratio of incidences per time period or change in DALYs	Comparison with the situation of people prior to the introduction of the innovation, statistical data of similar sectors in target country
			Tears while cooking (for respiratory diseases)	[80]	Tears while cooking (TWC) per time period	control group or the situation of the people before the implementation of the project
			Particulate matter formation (for respiratory diseases)	[65]	kg PM 10 eq./functional unit	Traditional technology
		Human toxicity	Human toxicity potential	[65]	(kg DCB eq.)	Traditional technology
	2. Education & Skill Development	Training/education	(Tertiary) enrollment rates disaggregated by sex	[13]	Number/ratio	control group or the situation of the people before the implementation of the project
		Quality of education/training	Satisfaction of the people with their training		Grading system	No reference system needed, proxy for quality of training
			School or training completion rates	[13]	Number/ratio	Total number of people taking part in the training/school
		Effectiveness of education/training	No of people applying knowledge		Number/ratio	Compared to total number of people taking part in the training
	3. Egalitarian society	Health equity Income equity Gender equity Inclusion	Disaggregating the indicators of the other impact categories such as health, education, poverty, (paid/unpaid) employment according to the above mentioned socially disadvantaged groups	[13] [81,82] [15,79,80]	Number, ratio, share	Total number of people with benefits/detriments due to health, education, income, employment; situation of disadvantaged people or groups before the implementation of the project; situation within a control group. national and/or international databases about minimum wage, vulnerable employments, education, income of socially disadvantaged groups, etc.

Table A1. *Cont.*

Dimension	Impact Category Group	Impact Category	Possible Indicator	Sources	Measurement Unit	Reference System
Economic	4. Poverty	Absolute poverty	Proportion of people benefiting from innovation with an income below $1.90 (PPP) per day (MDG Indicator)	Modified after [13]	Number, share; Local currency and then converted into international dollars (PPP)	Income of total of number of people
			Proportion of people benefiting from innovation living below national poverty line, by urban/rural (modified MDG Indicator)	Modified after [13]	Number, share; Local currency and then converted into international dollars (PPP)	Total number of people
		Inequality	GINI coefficient	[13]	From 0 to 1	Baseline data
		Income/savings	Change in income/savings above national and/or international poverty lines	Modified after [13]	Local currency and then converted into international dollars (PPP)	average previous income; national and the international poverty lines
			Change in income/savings for people living below national and/or international poverty lines	modified after [13]	Number, share	average previous income; national and the international poverty lines
	5. Energy supply and efficiency	Energy intensity	Change in energy intensity of different life cycle phases	[65]	(MJ)	Traditional technology, product, situation before
		Energy usage	Net energy balance throughout the life cycle	[65]	(MJ)	Traditional technology, product, situation before
			Primary energy, renewable and fossil energy sources (on the input side)	[65]	(MJ)	Traditional technology, product, situation before
	6. Growth and employment	Job creation Quality of jobs	Net job creation total and disaggregated (if possible): -skilled/unskilled, -temporary/indefinite	[79]	Number, ratio	Situation before, total number of people involved in project
		Job creation Working conditions	Total number of jobs (percentage adhering to nationally recognized labor standards, e.g., ILO Declaration on Fundamental Principles and Rights at work)	[83]	Number, ratio	Situation before, total number of people involved in project, ILO labour standards, international and national standards
		Working conditions	Reduction in vulnerable employment	[84]	Hours, ratio	Situation before

Table A1. *Cont.*

Dimension	Impact Category Group	Impact Category	Possible Indicator	Sources	Measurement Unit	Reference System
	7. Terrestrial ecosystems	Terrestrial acidification	Terrestrial acidification threatening species per time period	[65]	(species.yr.)	Results for traditional technology or alternative product
		Terrestrial Ecotoxicty Potential	Terrestrial Ecotoxicity Potential in Dichlorobenzene Equivalents	[65]	(kg DCB eq.)	Results for traditional technology or alternative product
		Land transformation	Natural land transformation threatening species per time period	[85]	(species.yr.)	Results for traditional technology or alternative product
			Area of natural land transformation	[85]	(m^2)	Results for traditional technology or alternative product
		Ozone layer depletion	Ozone Layer Depletion Potential (ODP, steady state) in R11-equivalents	[65]	(kg R11 eq.)	Results for traditional technology or alternative product
	8. Aquatic ecosystems	Freshwater aquatic ecotoxicity	Freshwater Aquatic Ecotoxicity pot. as DCB–Equivalents	[65]	(kg DCB eq.)	Results for traditional technology or alternative product
		Marine aquatic ecotoxicty	Marine Aquatic Ecotoxicity pot. as DCB-Equivalents	[65]	(kg DCB eq.)	Results for traditional technology or alternative product
		Freshwater eutrophication	Freshwater eutrophication as phosphor equivalents	[85]	(kg P eq.)	Results for traditional technology or alternative product
		Water depletion	Quantity of water depletion	[85]	(m^3)	Results for traditional technology or alternative product
		Marine eutrophication	Marine eutrophication as nitrogen equivalents	[85]	(kg N eq.)	Results for traditional technology or alternative product
	9. Climate	Global warming	Greenhouse gas emissions	[65]	(kg CO_2 eq.)	Results for traditional technology or alternative product
Temporal	10. Long-term effectiveness	Local acceptance	penetration rate/sales rate of innovation	[23]	(percentage)	If applicable traditional product
			usage and maintenance rate of innovation	[23]	(percentage)	If applicable traditional product
			disposal and replacement rate of innovation	[23]	(percentage)	If applicable traditional product
			Willingness to pay		(monetary values)	If applicable traditional product

Note: Abbreviation eq. stands for “equivalent”; Abbreviation yr. stands for “year”.

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