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More than Target 6.3: A Systems Approach to Rethinking Sustainable Development Goals in a Resource-Scarce World

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ABSTRACT

The 2030 Agenda for Sustainable Development outlines 17 individual Sustainable Development Goals (SDGs) that guide the needs of practice for many professional disciplines around the world, including engineering, research, policy, and development. The SDGs represent commitments to reduce poverty, hunger, ill health, gender inequality, environmental degradation, and lack of access to clean water and sanitation. If a typical reductionist approach is employed to address and optimize individual goals, it may lead to a failure in technological, policy, or managerial development interventions through unintended consequences in other goals. This study uses a systems approach to understand the fundamental dynamics between the SDGs in order to identify potential synergies and antagonisms. A conceptual system model was constructed to illustrate the causal relationships between SDGs, examine system structures using generic system archetypes, and identify leverage points to effectively influence intentional and minimize unintentional changes in the system. The structure of interactions among the SDGs reflects three archetypes of system behavior: Reinforcing Growth, Limits to Growth, and Growth and Underinvestment. The leverage points identified from the conceptual model are gender equality, sustainable management of water and sanitation, alternative resources, sustainable livelihood standards, and global partnerships. Such a conceptual system analysis of SDGs can enhance the likelihood that the development community will broaden its understanding of the potential synergistic benefits of their projects on resource management, environmental sustainability, and climate change. By linking the interactions and feedbacks of those projects with economic gains, women's empowerment, and educational equality, stakeholders can recognize holistic improvements that can be made to the quality of life of many of the world's poor.

1. Introduction

In 1987, *Our Common Future* [1] was released by the United Nations (UN). This report defined sustainable development as "development which meets the needs of the present without compromising the ability of the future to meets its needs." In 2000, world leaders reaffirmed the principles of sustainable development by creating the Millennium Development Goals (MDGs), which guided international development efforts over the past 15 years to reduce poverty, hunger, ill health, gender inequality, environmental degradation, and lack of access to clean water and sanitation [2]. Great progress was made toward achieving many of the MDGs; for example, 95 countries have met the 2015 target for improved sanitation and 147 countries have met the 2015 target for access to improved water [3]. Unfortunately, many problems still remain; for example, 946 million people practice open defecation, 2.4 billion lack access to improved sanitation, 663 million people live without improved water, and 1.5 billion use

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sewer-collection systems without treatment [3,4]. *The 2030 Agenda for Sustainable Development* [5] was approved by the global community on September 25, 2015, replacing the MDGs, which expired in 2015. Like the MDGs, *the 2030 Agenda for Sustainable Development* contains specific targets that are categorized under 17 Sustainable Development Goals (SDGs) (Table 1).

One important SDG for environmental protection is SDG 6: "ensure availability and sustainable management of water and sanitation for all" [5]. Under this goal, Target 6.2 aims to provide access to adequate and equitable sanitation for all by 2030 and Target 6.3 aims to improve water quality by reducing pollution, halving the proportion of untreated wastewater, and increasing recycling and safe reuse globally. If environmental protection is to become more sustainable, so that it "ensures that humankind's use of natural resources and cycles do not lead to diminished quality of life due either to losses in future economic opportunities or to adverse impacts on social conditions, human health and the environment" [6], improving access to sanitation and promoting improved water quality must be integrated with resource recovery. For example, a large source of the total available global phosphorus (about 3.4 million metric tons of phosphorus) is in the excreted human waste that is produced in developing regions such as Asia and Sub-Saharan Africa, which have large populations that are currently unserved by improved sanitation [7]. Providing sanitation to these populations can be achieved in a sustainable manner by using sanitation-based resource recovery systems. Such systems are capable of recovering phosphorus, nitrogen, energy, and other resources embedded in human waste, and would offset the environmental impacts associated with the fossil-based production of these resources as they are used to support other development goals, such as food security.

Addressing sanitation provision and environmental protection (Targets 6.2 and 6.3) in a sustainable way can also have a beneficial impact on other SDGs and targets. For example, implementing appropriate sanitation-based resource recovery systems [8] (Targets 6.2 and 6.3) will simultaneously address Target 2.4, which aims to improve food security through increased productivity and production from resilient agriculture practices that help maintain ecosystems; Target 12.2, which aims to achieve the sustainable management and efficient use of natural resources; and Target 12.5, which aims to reduce waste generation through prevention, reduction, recycling, and reuse. The interconnectedness of various SDGs and targets is further exemplified when implementing such sanitation systems in public schools, as this helps to achieve targets within SDG 4 such as Target 4.5, which aims to improve access to education for girls by eliminating gender disparities [9], and Target 4.7a, which aims to ensure safe, equal access to gender-sensitive learning environments [10]. Furthermore, achieving improved equity in educational settings should also positively impact SDG 5, which aims to empower all women and girls [10].

Unfortunately, the traditional approach in most development agendas to achieve water quality and sanitation-related targets such as Targets 6.2 and 6.3 of the SDGs has been a reductionist one, compartmentalizing and individually optimizing single targets. The reductionist approach breaks down a large and complex system into components, assuming that the sum of the isolated components is able to describe the whole system. The primary benefit of reductionism is that components of a complex system are easier to investigate when they have been disaggregated [11]. In this study, the reductionist approach is described as "typical" or "traditional" because it has customarily been used in engineering and science disciplines in order to simplify problems, and has been dominant since the industrial revolution in explanations of the physical and chemical basis of numerous processes [11,12]. Within the sphere of international development, this approach continues to be applied by international organizations such as the UN, where delegates' shared values are organized and translated into specific targets, and siloed into a set of measurable goals such as the MDGs or SDGs [13,14]. On its own, reductionism is not a robust research approach in the area of sustainable development because it does not consider the many critical linkages and feedbacks that are inherent among multiple SDGs, potentially leading to a failure in technological, policy, or managerial interventions due to unintended consequences [15]. Understanding the critical linkages among components within systems requires systems thinking; that is, a way of considering the whole system, and especially the interactions between its parts, rather than viewing the system as a mere assembly of isolated parts [12].

Table 1
The 17 Sustainable Development Goals (SDGs).

No.	SDGs
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
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

Therefore, the objective of this manuscript is to use a systems approach to demonstrate and understand the fundamental dynamics, linkages, and feedbacks between the individual SDGs. Once the causal relationships within the system are defined, it is possible to align the overall system structure using generic archetypes in order to identify leverage points from which to effectively influence changes in the system. The identification of leverage points is especially important in the case of SDGs, because this new development agenda will undoubtedly drive implementation and innovation in engineering practice, research, policy, and development around the world for several decades [16]. However, addressing the identified leverage points requires an understanding of power dynamics (e.g., unequal power balances, lack of political will) and system heterogeneity (e.g., geopolitical imbalances, social and cultural context of technology implementation and operation), which is beyond the scope of this study.

2. Methods

In this study, the causal loop diagram, a tool in systems thinking that links factors based on their foundational relationships, is used to construct the conceptual system model. Fig. 1(a) illustrates the steps involved in the overall methodology.

Step 1 produces a conceptual model (i.e., a causal loop diagram) by using arrows to link each of the SDGs and, when necessary, intermediate factors (italicized text in Fig. 1(c) and 1(d)). The intermediate factors are added to improve the clarity of the model by avoiding inadequate or indirect links. It must be noted that the intermediate factors used in this study are subjective at a certain level; however, well-cited literature is used to define and support their use. The links between factors are characterized with positive or negative signs to indicate whether the changes occur in the same or opposite directions. For example, a positive sign between two factors means that an increase in the factor at the tail of the arrow will cause an increase to the factor at the arrow's head, while the opposite is true for a link marked with a negative sign.

In Step 2, the conceptual model created in Step 1 is compared to existing system archetypes in order to identify the archetypes that are represented within the model. System archetypes are the generic structures that are responsible for different types of well-described behavior trends produced in nature, business, and political systems [12,17]. It is important to identify and recognize these archetypes because their structures are used as references to guide modelers in determining missing or ill-defined links. Thus, a system's structure (i.e., the network of factors, interactions, feedbacks, and delays) dictates its behavior, which is described by the system's performance over time [18]. For example, the Reinforcing Loop (Fig. 1(b)), sometimes called Reinforcing Growth, is one of the most fundamental archetypes. When system performance changes, the growing action is stimulated (positive sign), which further changes the system performance in the same direction (positive sign). Such a structure of relationships results in exponential growth or decay of the system performance. A system that contains only reinforcing loops will experience vicious circles and eventually collapse. Another archetype, called Fixes that Fail, contains a balancing loop and a reinforcing loop. In the balancing loop, when a problem symptom increases, a "fix" will be implemented that temporarily alleviates the symptom; however, in the long term, the problem symptom will increase due to unintended consequences that are present in the reinforcing loop and perpetuated by the "fix."

Aside from guiding modelers in constructing a system structure and justifying the observed behavior, system archetypes are used to identify the leverage point(s) where root causes of the system's behavior can be addressed in order to effectively achieve the desired system performance. For example, for the previously described Fixes that Fail archetype, the reason for the counterintuitive behavior (i.e., an increased problem symptom due to the delayed increase of the unintended consequence) is a result of the nature of the "fix." In this archetype, rather than addressing the root problem that leads to the undesired system behavior, the solution ("fix") mitigates the problem's symptom without addressing the institutional or structural causes. Therefore, an effective strategy to improve the system's behavior is a two-tier approach that implements solutions that address the short-term problem symptom while simultaneously focusing on finding a long-term fundamental solution that addresses the root systemic issue [17].

The comparison results are also used to guide the refinement of the conceptual model (Step 3) as an iterative process. The conceptual model is considered final when the relationships within the model are aligned with existing knowledge (literature, logic, and the authors' experiences) and conform to the structure of the system archetype(s) that fits best.

3. Results and discussion

Fig. 1(c) depicts the final conceptual system model illustrating the causal relationships between the 17 SDGs. This model is the first attempt to understand the direct and indirect linkages between the SDGs and the potential positive or negative influences they have on each other. For example, increasing equality within and among countries (Goal 10) will directly promote peaceful and inclusive societies for sustainable development (Goal 16) (direct positive linkage). Achieving food security and improved nutrition (Goal 2) will reduce malnutrition and consequently promote healthy lives and well-being (Goal 3) (indirect positive linkage). Such understanding can help stakeholders and others in the development community to gain insight into the potential implications of addressing an individual goal through its broader network of connections. In particular, the model helps to identify leverage points where development efforts should be focused in order to influence positive, synergistic, and systemic change most effectively.

When the conceptual model is analyzed for known system archetypes, three archetypes that guide the system's behavior can be identified: ① Reinforcing Growth, ② Limits to Growth, and ③ Growth and Underinvestment. The portions of the conceptual model related to each of the three identified archetypes are illustrated in Fig. 1(d)–3. To better understand the conceptual model, the following subsections discuss the three archetypes first, followed by a discussion of the overall conceptual model. We then explore the linkages between the SDGs, identify leverage points, and suggest strategies to influence systemic change.

3.1. Reinforcing Growth

One of the fundamental archetypes identified in the conceptual model is Reinforcing Growth, as shown in Fig. 1(d). The expected behavior for this archetype is an exponential growth of system performance over time [18]. The three reinforcing loops shown in Fig. 1(d) are discussed in this section. We consider reinforcing loop 1 (R1) and reinforcing loop 2 (R2) together because they form the resilient water and sanitation infrastructure loop; also reinforcing loop 3 (R3), which forms the reliable energy infrastructure loop.

3.1.1. Reinforcing loops (R1 and R2): Resilient water and sanitation infrastructure

As shown in Fig. 1(d), building resilient infrastructure (as

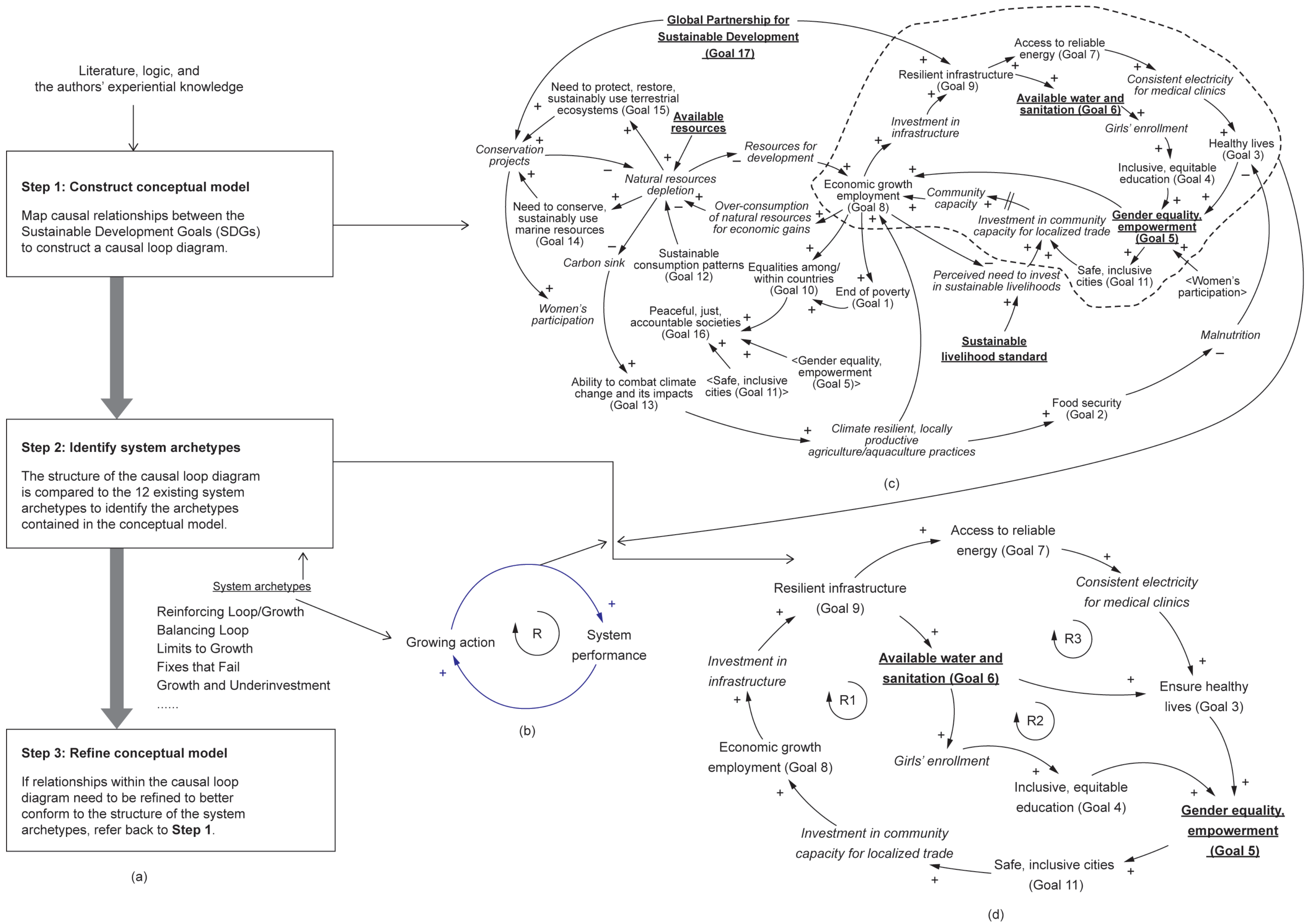

Fig. 1. (a) Steps involved in constructing the conceptual system model for this study. (b) Generic structure of "Reinforcing Loop" system archetype. (c) The conceptual model developed in this study. The model relates all 17 SDGs, intermediate factors (italicized) between SDGs, shadow variables (grey in bracket, used to ensure the readability and clarity of the figure), and identified leverage points (in bold font and underlined). A positive sign represents a reinforcing causal relationship, and a negative sign represents a balancing causal relationship. The double bar represents the time delay between one factor's impact on another. (d) The Reinforcing Growth archetype identified in the conceptual model in relation to the SGDs. R1, R2, and R3 refers to the reinforcing loops.

called for in Goal 9) will improve access to water and sanitation infrastructure (Goal 6), which can increase school enrollment of both sexes, but especially that of young girls (Goal 4). This is because girls are more likely to attend school when adequate sanitation is available and when the sanitation infrastructure is separated for boys and girls [10]. In addition, women are more likely to utilize and maintain infrastructure systems if they are incorporated into the design and implementation of a project [19]. In most developing world societies, women's traditional role is that of leader of the household, cook, and water collector; thus, women should have significant input into decisions related to the design and management of societal infrastructure that protects health and the environment [20]. Improved access to water can reduce the time and labor required to collect water at the expense of pursuing an education and income-generating activities [21–26]. In addition, improving access to water and sanitation can ensure healthy lives (Goal 3), promote gender equality, and empower women (Goal 5) through the reduction of water-borne diseases [27]. Furthermore, women (and children) are more vulnerable to harassment and assault when they are forced to walk away from their home for excreta disposal. Achieving these health-related water and sanitation goals should facilitate safety and empowerment for women and communities and make cities more inclusive and safe (Goal 11). Thus, people are more willing to reside and invest in community capacity for localized trade in cities that are inclusive, safe, resilient, and sustainable, thereby increasing community capacity and facilitating economic growth (Goal 8) and further investment in resilient infrastructure (Goal 9) [28].

3.1.2. Reinforcing loop (R3): Reliable energy infrastructure

Further consideration of Fig. 1(d) shows that building resilient infrastructure (Goal 9) will also improve access to reliable energy infrastructure (Goal 7). This can lead to more consistent energy that can be used for medical clinics, expanding some medical services offered to pregnant women, and thus leading to better maternal health. Medical projects can also bring together multidisciplinary teams of health workers, educators, and engineers, which may increase the rate of live births attended by skilled health personnel, also ensuring healthy lives (Goal 3) [29]. Healthier mothers will be more empowered in terms of gender equality (Goal 5) and, ultimately, are more likely to participate in income-generating activities that contribute to economic growth (Goal 8).

3.1.3. Leverage points for Reinforcing Growth

To promote sustained, inclusive, and sustainable economic growth and to build resilient infrastructure (Goals 8 and 9, respectively), the analysis suggests Goal 5 (achieve gender equality and empower all women and girls) and Goal 6 (ensure availability and sustainable management of water and sanitation for all) as leverage points. This suggestion is based on the involvement of Goal 5 in all three reinforcing loops and that of Goal 6 in both R1 and R2 in Fig. 1(d). One strategy to promote gender equality and women's empowerment is to cultivate active stakeholder engagement, especially for water and sanitation projects. Stakeholder engagement recognizes the importance of community-based social engagement as a critical theme that is necessary throughout a project's life cycle, due to the influence of local perspectives on project sustainability [30–32]. Specific means of stakeholder engagement include public presentations, focus groups for individual sectors, and community participation in decision making.

Many water and sanitation projects in developing countries are constructed by international donors and development agencies. Once construction is completed, ownership and management responsibilities are transferred to the community itself, in a process that is referred to as the "community management model" [33–35]. It is critical to build community capacity to manage the systems, and particularly women's capacity; otherwise, these systems are characterized by high rates of tariff payment delinquency, lack of maintenance and, too often, even failure [36,37]. In a resource-scarce world, as local decision makers deliberate about the limited financial resources available for various projects, these leverage points are instructive in determining valuable investment for sustained development.

3.2. Limits to Growth

Fig. 2 shows the Limits to Growth archetype identified in this study in relation to SDGs. This archetype consists of one reinforcing and one balancing loop that have opposing effects on the performance of the system—growth over time. For example, the reinforcing loop causes a continuous increase in efforts that perpetuate an improvement in the system's performance. On the other hand, the balancing loop slows down improvement under the constraint of a limiting condition. The expected behavior for a system operating under the Limits to Growth archetype is a bounded, S-shaped growth curve [18].

3.2.1. Balancing loop: Natural resources depletion

In the balancing loop in Fig. 2, economic growth (Goal 8) requires resources from nature, potentially resulting in over-consumption of natural resources and leading to natural resource depletion. With fewer available resources, depletion will occur more rapidly, reducing the resources available for economic development and decreasing economic growth. The depletion of natural resources can be slowed down through the practice of sustainable consumption patterns (Goal 12). Targets under Goal 12 seek to improve the efficiency of resource use and to reduce waste generation throughout product life cycles. Maximizing material and energy efficiency, which is one of the principles of green engineering [38], will reduce resource use and waste generation simultaneously. With less waste, fewer treatment and disposal efforts are needed, reducing the natural and financial resources required for treatment and disposal. By moving from treatment to source reduction in the pollution prevention hierarchy, engineering communities contribute not only to Goal 12 but also to Goal 8 through the indirect linkages illustrated in Fig. 2.

3.2.2. Reinforcing loops: Resource conservation

With increasing depletion of natural resources, the need to conserve and sustainably use marine resources (Goal 14) and to protect, restore, and sustainably use terrestrial ecosystems (Goal 15) is realized, driving the implementation of conservation projects aimed at reversing resource depletion. Such projects will increase the resources available for development and lead to increased economic growth (Goal 8). On the other hand, women are typically more involved in conservation projects that protect the environment [19,27]. Such projects will therefore promote gender equality and women's empowerment (Goal 5) as well, leading to increased community capacity for localized trade and increased economic growth (Goal 8) [39].

3.2.3. Leverage point for Limits to Growth

For the Limits to Growth archetype, the leverage point is to remove the limiting condition, an approach that is sometimes referred to as "removing the bottleneck." In this case, the limiting condition is the available resources (Fig. 2). One strategy to address this leverage point is to increase available resources by

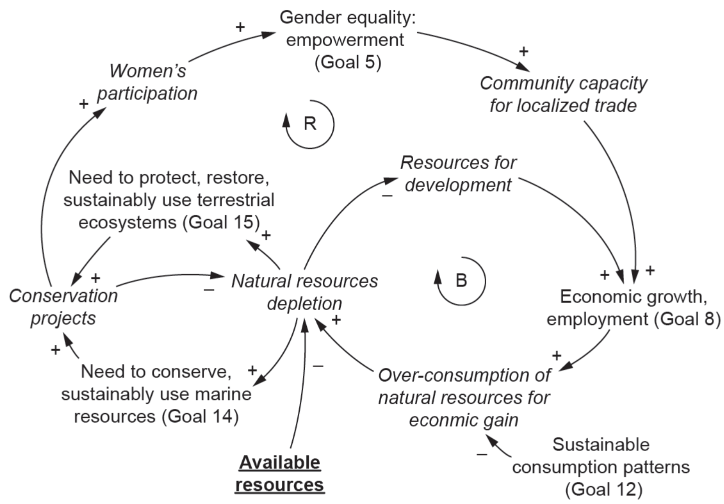

Fig. 2. The Limits to Growth archetype identified in the conceptual model in relation to the SDGs. The intermediate factors between SDGs are italicized and the leverage point is in bold font and underlined. The positive and negative signs represent reinforcing and balancing causal relationships, respectively. R refers to the reinforcing loop and B refers to the balancing loop.

incorporating renewable and locally accessible resources. To be specific, the implementation of geographically appropriate wastewater-based resource recovery systems can increase available resources because such systems provide alternative sources for water, energy, and nutrients, other than virgin sources. Technology innovations are promoted in order to synergize the recovery of resources, including water, energy, and nutrients with the treatment of human-generated wastewater [8,40–43]. The use of reclaimed wastewater for agriculture irrigation is a strategy that is now implemented worldwide: 2.0×10^5–4.5×10^5 km^2 in the world are now irrigated with reclaimed wastewater [16]. Wastewater also contains nitrogen and phosphorus from human waste and food [7,44]. Small cities in developing regions surrounded by agricultural zones provide great opportunities for reclaiming both water and the nutrients embedded in wastewater [44]. In terms of energy, the embedded energy content of typical municipal sewage in the US has been estimated to be 1.74–1.93 $kW{\cdot}h{\cdot}m^{-3}$ or 0.45–0.50 kW·h per 1000 gallons (assuming 500 $mg{\cdot}L^{-1}$ chemical oxygen demand (COD)) [45,46]; this value is several factors greater than the energy expenditure values reported for the conventional treatment of wastewater (0.3–0.6 $kW{\cdot}h{\cdot}m^{-3}$) [47,48]. Thus, it may be possible for municipal wastewater treatment to achieve energy neutrality or even net energy production through onsite energy generation technologies [46,49] and continued use of sanitation technologies that make use of photosynthesis [44].

3.3. Growth and Underinvestment

The balancing loop in the Limits to Growth diagram (Fig. 2) and the reinforcing loops that characterize the Reinforcing Growth diagram (Fig. 1(d)) are also contained within the Growth and Underinvestment archetype shown in Fig. 3. However, this archetype includes an additional balancing loop (B2).

The additional balancing loop (B2) in Fig. 3 represents the performance measure of the system, which reduces the perceived need to invest. In turn, this perceived need drives the investment in the system's capacity. As the investment in capacity increases, there is a delayed increase in the actual capacity, and, ultimately, in the performance of the system. As such, the result is that the system improvement will experience a time lag, increase modestly, and eventually level off.

3.3.1. Balancing loop: Need, investment, community capacity, and economy

In Fig. 3, the perceived need to invest in sustainable livelihoods is driven by the economic growth and performance standard. The perceived need thus drives the investment in community capacity for localized trade. As the investment in capacity increases, there is a delayed increase in the actual community capacity and, ultimately, in the economic growth and employment (Goal 8). The dichotomous balancing and reinforcing loops shown in this figure reflect the same behavioral pattern as mentioned for Limits to Growth; however, in this archetype, the presence of the external performance standard is the leverage point that offers an opportunity to influence a change in the system. The sustainable livelihood performance standard encompasses the economic, health, social, and environmental aspects of livelihood improvement. Without this external performance standard, the additional balancing loop would eventually reduce the perceived need to invest in community capacity completely, causing the livelihood improvement to plateau.

3.3.2. Strategy for Growth and Underinvestment

The leverage point for the archetype of Growth and Underinvestment is the external standard and, in this case, the sustainable livelihood standard. The potential strategy to address this leverage point is to increase the exposure of community members to the benefits other communities have experienced and the successful adaptations other communities have made to sustainable livelihoods through affordable training courses or multimedia venues. Furthermore, this strategy would benefit from having communities establish their own perspectives of what rigorous standards mean to them.

3.4. Overall conceptual system model

The discussion of the three system archetypes identified in this study has provided a detailed explanation of the majority of the linkages between SDGs in the overall conceptual model shown previously in Fig. 1(c). The additional linkages and leveraged points in Fig. 1(c) are discussed below.

3.4.1. Additional linkages

Several of the additional links in Fig. 1(c) are worth discussing.

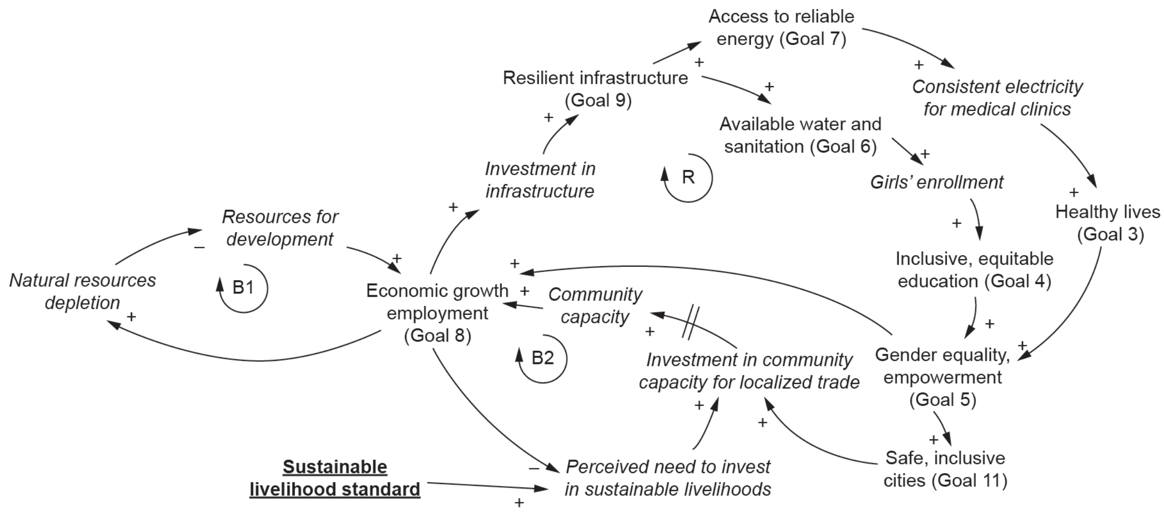

Fig. 3. The Growth and Underinvestment archetype identified in the conceptual model in relation to the SDGs. The intermediate factors between SDGs are italicized and the leverage point is in bold font and underlined. The positive and negative signs represent reinforcing and balancing causal relationships, respectively. R refers to the reinforcing loop and B refers to the balancing loops. The double bar represents the time delay between one factor's impact on another.

Natural resources depletion will not only reduce the resources required for development but also reduce terrestrial and marine resources that currently serve as carbon sinks by absorbing and storing global carbon emissions. As a result, development projects that tend to reduce resource depletion such as resource conservation or recovery projects will also increase society's ability to combat climate change and its impacts (Goal 13). This will facilitate more climate-resilient and locally productive agriculture/aquaculture practices, leading to advances in other SDGs such as food security (Goal 2), reducing malnutrition, and healthy lives (Goal 3). More productive management of agriculture, fisheries, and forests will result in more employment opportunities (Goal 8) in an employment sector that currently represents approximately half of all global jobs [50,51]. In addition, sustainable consumption patterns (Goal 12) are critical if the world is to reduce natural resource depletion. The IPAT equation can be used to explain why, by showing how environmental impact (I) is a product of population (P), affluence (A), and technology (T) [52]. Although environmental impacts cannot be determined by the simple product of population, affluence, and technology, and although there is ongoing debate about the utility of the IPAT equation [53,54], this equation conceptually shows that without changes in the consumption pattern (A), environmental impact (I) will inevitably increase with the increase of population (P), even as engineers try to incrementally improve the environmental performance and efficiency of particular technologies (T). Sustainable economic growth (Goal 8) will also lead to the advancement of Goal 1 (end of poverty) and Goal 16 (peaceful, just, and accountable societies) through advances in Goal 10 (equalities among/within countries). Goal 5 (gender equality and empowerment) and Goal 11 (safe and inclusive cities) will also contribute to achieving Goal 16 (peaceful, just, and accountable societies).

3.4.2. Additional leverage points

As discussed here and in the previous sections, changes in conservation projects (e.g., marine and terrestrial resource restoration) and designing and constructing resilient infrastructures will cause changes in several feedback loops. Goal 17 (Global Partnership for Sustainable Development) typically results in investments in resource conservation and local infrastructure facilities (e.g., water and sanitation infrastructure). Therefore, a strategy that addresses Goal 17 will be another leverage point to advance several SDGs. One way this can be achieved is by lobbying for financial resources from global lending institutions or regional lenders. However, as discussed previously, building community capacity through stakeholder engagement that focuses on women is the key for the long-term success of development projects.

4. Conclusions

This study used a systems approach to examine linkages between the 17 SDGs. A causal loop diagram integrating all of the SDGs was developed, and three main system archetypes emerged from an analysis of the structure: Reinforcing Growth, Limits to Growth, and Growth and Underinvestment. These archetypes guide the overall changes of SDGs. Leverage points were identified in terms of gender equality, sustainable management of water and sanitation, alternative perspectives to manage resources that include resource recovery from wastes, sustainable livelihood standards, and global partnerships. Such a conceptual system analysis of SDGs has implications for environmental protection, resource management, environmental sustainability, and climate change, as well as for significantly improving the quality of life for many of the world's poor.

It is thus important to consider the broader impacts of the SDG-aligned solutions and to acknowledge the larger system into which these solutions are placed. This is particularly critical for the engineering community because engineers are often engaged in SDG-related projects and may implement solutions without considering the larger context, leading to the failure of the projects. They must also understand the critical role women play in implementing environment-related projects, particularly in developing countries. An awareness of the interactions and feedbacks among the SDGs should drive interdisciplinary collaborations and enable development professionals to recognize the power and potential of using their knowledge and skills to implement appropriate solutions that impact more than one SDG at a time (directly and indirectly). Such an expanded mission provides additional innovation space to design the next generation of solutions that not only benefit economic development but also make strides in improving environmental and human conditions. It also expands the definition of "project success" by allowing the engineering community to rightfully claim contributions beyond the narrow scope of engineering challenges, while improving the current track record of unsustained projects due to unintended consequences. Furthermore, an awareness of the connection of environmental sustainability to all of these other challenges reinforces the call for interdisciplinary and multidisciplinary work. Similarly, the development community can benefit by being recognized as a critical and urgent part of the solution to all of the SDGs, making a case for an expanding role in global sustainable development discussions and for increased funding to support efforts in addressing SDGs beyond Goal 6 and Target 6.3.

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Compliance with ethics guidelines

Qiong Zhang, Christine Prouty, Julie B. Zimmerman, and James R. Mihelcic declare that they have no conflict of interest or financial conflicts to disclose.

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