Mini-review

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Sustainable intensification: a multifaceted, systemic approach to international development

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Abstract

Sustainable intensification (SI) is a term increasingly used to describe a type of approach applied to international agricultural projects. Despite its widespread use, there is still little understanding or knowledge of the various facets of this composite paradigm. A review of the literature has led to the formalization of three principles that convey the current characterization of SI, comprising a whole system, participatory, agroecological approach. Specific examples of potential bottlenecks to the SI approach are cited, in addition to various technologies and techniques that can be applied to overcome these obstacles. Models of similar, succcessful approaches to agricultural development are examined, along with higher level processes. Additionally, this review explores the desired end points of SI and argues for the inclusion of gender and nutrition throughout the process. To properly apply the SI approach, its various aspects need to be understood and adapted to different cultural and geographic situations. New modeling systems and examples of the effective execution of SI strategies can assist with the successful application of the SI paradigm within complex developing communities.

Keywords: sustainable intensification; international development; agroecological, resilience

SUSTAINABLE INTENSIFICATION DEFINED

The definition of sustainable intensification (SI) has previously been qualified as somewhat nebulous, taking shape and evolving over time.[1,2] Jules Pretty is credited with establishing one of the most accepted definitions of SI. Pretty characterizes SI as a concept that entails a whole-system and agroecological approach to increasing agricultural outputs and decreasing negative environmental effects (i.e. building natural capital).[3–5] Previous, as well as some subsequent, definitions of SI are often more one-dimensional than Pretty's conceptualization, lacking the systemic element.[6,7]

Sustainable intensification has been misinterpreted as a screen for the escalation of industrial agriculture: a variant of the green revolution that emphasizes the use of fertilizer, other chemical inputs, large farm equipment and tillage.[6,8] However, this depiction of SI is contrary to Pretty's definition, which integrates the principes of the ecological intensification and agrobiodiversity approaches, two earlier conceptualizations of SI.[9] Both the ecological intensification and the agrobiodiversity approach emphasize a decrease in chemical/anthropogenic inputs through the use of biological practices such as fallows, integrated pest management (IPM), crop-livestock integration, and soil and water conservation.[6] Sustainable intensification itself promotes a balance that maximizes the efficiency of external inputs (i.e. inorganic fertilizer, pesticides) and restores internal resources (environmental goods and processes). To balance these inputs and facilitate resilience, this paradigm necessitates a diversification of livelihoods, land-use and marketing practices.

Often, when describing SI, there is a narrowed focus on the various technological options that can be employed in this process, whereas necessary socio-economic changes that may also need to be addressed, as part of the 'system', are ignored.[10–12] Although Pretty cites the use of participatory methodologies as one of the key attributes that was observed across 30 African SI case studies, it is not emphasized as a primary component of his definition.[4] Jacqueline Loos argues that the SI definition, and the process itself, needs to engage with variables that are external to production, integrating inclusivity and empowerment of individuals.[1]

Sustainable intensification is typified as a process or system.[4] However, factors that should characterize this process have not been comprehensively outlined or expanded upon. The present review considers the SI process in the context of international development communities and its potential employment by international development projects or programs. Below, three interconnected approaches that are essential to and integrated within the SI approach are outlined: the (1) whole systems approach; (2) the participatory approach; and (3) the agroecological approach. The importance of adapting SI to cultural and geographic factors is also emphasized. Although the various definitions of SI differ in a number of different ways, a prominent, cross-cutting aspect of SI is that no set suite of technologies, management practices or solutions is intrinsically linked to the SI concept; instead, these techniques must be adapted to the local context.[4,12,13] The intended goals and

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future pathways of SI, along with potential obstacles to SI implementation, are also examined.

THE PRINCIPLES OF SUSTAINABLE INTENSIFICATION

A whole system approach: limiting factors and connectivity

Despite the divergent pathways taken to international agricultural development, there is an overwhelming consensus that a one-dimensional stratagem will not succeed in advancing food security in developing countries.[14–16] The Foresight Project's Final report and Godfray and Garnett insist that SI cannot solely be production driven but, instead, should be considered within a broader context of variables that influence the food system, such as waste, diet, and governance.[17,18]

According to Liebig's Law of the Minimum, agricultural growth is determined not by aggregate resource availability, but by the most scarce/limiting resource.[19] These limiting factors are variables that are dependent upon other variables. A system is composed of a multitude of factors, many of which are connected to (and dependent upon) other factors. Agricultural intensification needs to be approached in a holistic manner, with various societal, infrastructural, and resource limiting factors taken into account. For example, even if a crop receives the appropriate amount of fertilizer, harvest could still be limited by the amount of water supplied. This law also applies to societies in developing countries as a whole. If the purchasing of on-farm inputs is not limited by grower access to monetary funds, there might still be a shortage in the market availability of quality fertilizer. Another example is that of an agricultural development intervention of cross-breeding local cattle with exotic dairy breeds, in Bhutan, with the purpose of producing higher-yielding offspring. Despite this intercession, dairy yields did not increase because farmers could not afford or access quality feed, the introduced exotic breeds were susceptible to local diseases, there was a widespread lack of veterinary care, and culturally desirable livestock characteristics were ignored.[20] Siloed initiatives that do not consider the local context and interconnected variables can fail to achieve the desired objective(s) or curtail the intended impact. Achieving food security in developing communities requires a systemic methodology that takes into consideration a multitude of interconnected economic, social, political, and agroecological variables. The SI paradigm acknowledges this by promoting a whole system approach.

The subsequent discussion focuses on a few limiting factors that frequently encumber developing communities: inadequate infrastructure, human and institutional capacity development (HICD), and networks that transfer information and physical resources. All of these factors succinctly condense and encompass the seven key requirements that Pretty cites as necessary for the scale-up of SI.[4]

In the previously mentioned example, dysfunctional and unstable rural market infrastructure contributed to the failure of the exotic livestock integration. Poor market infrastructure is commonly named as an obstacle to the expansion of sustainable agriculture.[21,22] Although growers might have supplemental income, the market might not offer inputs that are optimal in terms of quality or price. Additionally, markets might be too far or too difficult to access. The development of rural markets through interventions such as monetary loans, price incentives, market diversification or improved transportation networks is dependent upon infrastructural strengthening.[22,23] Much of this infrastructural strengthening is contingent on the formation and reinforcement of human and institutional networks.

HICD is particularly important for SI because effective implementation of sustainable agricultural technologies requires an understanding of the system as a whole, and often necessitates the application of a number of different management techniques. For example, the Capacity to Improve Agriculture and Food Security (CIAFS) is a project in Ethiopia that works with key government officials, particularly those in the Ministry of Agriculture, to raise awareness of best agricultural development practices, as well as furthering knowledge of policy options. The CIAFS project focuses on supporting the empowerment of these decision-makers in implementing policy reform and enhancing program management efficacy. This empowerment is achieved through training in topics like institutional management, coordination, and communication.[24] Government support via informed policy making (e.g. the removal of trade barriers) and funding can be integral to building an infrastructure that is SI enabling.

Farmer education levels can also be a major constraint for SI.[25,26] In the USA, farmers with a high school education are able to adopt conservation agriculture (CA) much more rapidly (2.2 years faster) than those without a high school education. Growers with a college education adopt IPM significantly faster (6.5 years faster) than those with a high school education.[25] Enhancing the capacity of university and state agricultural systems in performing quality research, education, and extension activities is essential to effective distribution and application of SI.[27]

Improved access to technologies and innovations is often not effective in supplementing grower income without both HICD and infrastructural strengthening. For example, the availability and quality of plant genetic material cannot be improved without infrastructural growth and HICD. Advancements are needed to build networks that link farmers with high-quality plant varieties. This can be achieved through increased funding of public plant breeding activities, the formation of policies that encourage local seed enterprises or reliable certification programs for disease-free seed.[27] In addition to being connected to these technology networks, growers need to be trained in the use of these technologies (human capacity building) so that they can utilize them to their full potential.

The practice of performing a thorough examination of societal and agroecological variables of the focal development communities is an important component of the SI paradigm. Such assessments help development projects determine what interconnected components of that system will potentially influence the primary limiting factors of SI, allowing for strategic programmatic planning.

A participatory approach: multistakeholder and multidisciplinary

The necessity for a participatory element, which characterizes the SI approach, has been made evident through the many previous SI definitions emphasizing that multi-stakeholder inclusivity, empowerment, and the consideration of social dynamics (i.e. networks) are required to achieve sustainable change.[1,4] The participatory approach is particularly important within the framework of international development projects, which are frequently transient in nature and funded for only a specific period of time. A successful SI process will be led by local stakeholders so that mechanisms and solutions continue to function and remain in place over time, despite the absence of the development program.

A participatory approach involves multiple stakeholders and experts from different disciplines. Previous development projects that have successfully employed participatory multi-stakeholder, multidisciplinary methodologies can serve as models for developing a progressive SI strategy. A few of these successful development project interventions, as well as the various participatory paradigms that they employ, are discussed below.

Adaptive co-management, which integrates both the scientific knowledge of academic professionals and the ecological insight and experience of farmers, can provide a richer understanding of local agroecosystems.[26] The effective use of adaptive co-management is described in a study of Honduran farmer biological control of the fall army worm (*Spodoptera frugiperda*), a wide spread pest of maize. Initially, an international development project disseminated IPM recommendations for dealing with the fall army worm that were not in line with local practices, climatic conditions, and norms.[26] Subsequently, the project adapted its management practices and facilitated a more concerted effort, where farmers contributed local knowledge and helped identify information gaps, whereas scientists assisted in closing these gaps. The resulting cohesive outreach materials and trainings were then disseminated through local farmer networks, resolving non-adoption and IPM efficiency issues.[26] This type of participatory learning system can result in development activities that are well adapted to the local needs and opportunities of development landscapes.

Another paradigm that prioritizes a participatory approach is sustainable governance of natural resources. This method employs communicative action via collaboration of transdisciplinary groups (local experts, scientists, and non-scientific actors) to solve ecological, social, and cultural issues related to sustainable development.[28] The reasoning is that these cooperatively generated solutions take into account the differences in norms and values that exist within the societal strata and therefore have a higher impact in terms of magnitude and longevity. A 3-week sustainable governance workshop on ‘Social Learning for Sustainability’ held in India, West Africa, and South America involved a diverse participant consortium, from growers to scientists, politicians, experts, and other local actors, aiming to encourage multi-actor dialogue and collective decision-making. The workshop incited changes in preconceptions, decreased hierarchal communication, and promopted a shift to more equitable decision-making.[28] Most critically, this workshop facilitated the generation of solutions and actions that might not have come about without the inclusivity of differential stakeholders, encouraging dialogue around the various needs, knowledge and available resources of the workshops participants, and allowing for the formation of personal connections that could incentivize further action and collaboration.

The CoS-SIS program (Convergence of Sciences and Strengthening Innovations), funded by the Dutch Ministry of Foreign Affairs, and managed by a Wageningen led university/research center consortium, embraced the hypothesis proposing that the answer to a successful food security program is a participatory process that leads to institutional change.[29] Groups referred to as Concertation Innovation Groups (CIGs) were formed at local levels and were assigned a group facilitator.[29] The CIGs contained a variety of relevant stakeholders. CIG members identified the specific issues that they wanted to address within a particular theme and then worked together to implement institutional changes that would help solve these problems. For example, the rice CIG concluded that it was pointless to wait for government interventions and instead formed a system where the growers managed the primary canals themselves, instituting a rotation for canal cleaning.[29] This inclusive, problem-solving approach targeted institutions at various scales and was extremely successful for CIGs in all three countries.[29] Ultimately, the CoS-SIS program used an innovation platform that integrated multiple stakeholders with a range of expertise to incite institutional change.

Platforms that are farmer-centered, allowing for active participation in the planning process, feedback, and the development of personal ownership, are more likely to last. Programs that use food-for-work or subsidies to acquire farmer participation often do not instill lasting change, with the activities or practices fading quickly once the project is closed.[3] An intrinsic characteristic of an SI project is that its accomplishments and goals persist or spread to other communities (scaling-up) long after the project is finished.[3]

An agroecological approach: sustainable intensification technologies

Sustainable intensification espouses agricultural technologies and cultural management practices that enhance production efficiency, as well as natural capital.[4,10,11] A comprehensive report, conducted by Elliot *et al.*, describes a range of production techniques that effectively increased yields and elevated input efficiency, at the same time as reducing or mitigating negative environmental effects.[30] Many of the critical indicators used to measure the efficacy of the SI approach are carbon sequestration, amount of soil organic matter, farmer income, soil structure, and crop yield.[27,31]

Sustainable intensification technologies and management practices are often said to be exemplified in the CA and IPM systems, which promote the use of multiple agricultural management techniques (e.g. using multiple cultural and biological pest management techniques).[3,27] SI production necessitates a complement of different technologies and practices, such as efficient water and nutrient management, or the use of environmentally adapted, disease-resistant cultivars that can withstand abiotic and biotic stressors.[27]

One sustainable agricultural technology that is often cited as key to SI implemented programs is the use of environmentally and culturally appropriate improved seeds. However, these genetic materials often do not engender yield gains without the addition of sufficient organic matter and nutrient inputs, particularly where continual soil degradation increasingly impedes plant performance.[8] Also, as discussed previously, appropriate skills for the proper utilization of these materials, as well as infrastructural networks that allow access to and promote the growth of these technologies, are needed for optimal application of these tools.

The SI approach should also take into account water and sanitation issues. Crop and livestock security are highly dependent on access to water. Resiliency of rain-fed systems can be greatly enhanced through improved irrigation techniques. Water efficient technologies, such as drip irrigation, can play a role in conserving natural capital, at the same time as increasing yields. Improving access to water and enhanced water sanitation education also has the potential to improve nutrition and food security. In northern Mali, farmers in villages with access to irrigation demonstrate higher levels of production, consumption, and caloric intake than farmers who rely on rainfed agriculture or a lake-recession system.[15] On the other hand, poor water quality and lack of sanitation leads to water borne diseases and limited nutritional uptake. Malaria, which is often linked to irrigation development and landuse changes brought about by agriculture, reduces the labor productivity of farmers.

Climatic conditions are considered a limiting factor to agricultural production. The climate of a region sets a limit on a crops production potential.[32] According to meteorological predictions, climate change in many developing countries, and sub-Saharan Africa in particular, will lower this limit, decreasing the grower's conceivable crop output[33] and creating a climate 'ceiling'. New technologies and innovations (e.g. new crop varieties, irrigation techniques, soil quality building methodologies) are needed to address this limiting factor.

The SI process should also facilitate livelihood diversification. Supplemental grower income from diverse livelihood activities such as aquaculture or product manufacturing is most often used to purchase on-farm inputs, thereby enhancing revenue received from agricultural yields.[34] In Mali, farmers both harvest and process shea tree nuts, roasting or pounding the nuts to create a butter, which is used in a variety of products and can be sold for a much higher price than the unprocessed nuts.[35] The introduction of specific technologies and innovations enhanced this on-farm processing and enabled farmers to significantly supplement their income, with little extra labor. It is also important to note that diversified sources of income can serve as a form of insurance against crop failure, promoting resilience in farming systems. Additionally, growers with diversified livelihoods are often more open to adopting new sustainable agricultural management methodologies, furthering this interconnected cycle.[9,34]

ADAPTABILITY OF SUSTAINABLE INTENSIFICATION

It is essential that SI is flexible and situation-dependent. The methodology depends upon an adaptation of various development techniques for different types of communities. An obstacle to SI in one community might not be an impediment in another. For certain regions, the absence of clear land tenure rights could discourage growers from employing and investing in sustainable agricultural techniques, whereas, in other regions, devoting time and labor to SI implementation is a means of asserting land ownership.[20] Additionally, the success of specific technologies might be culturally or regionally dependent. Cultivar choices in sub-Saharan Africa are influenced by local food habits, traditions, and markets.[37] For example, local low-yielding corn varieties in Kenya are still greatly appreciated because they supply an early harvest at a time when food is scarce.[37] Together, all of three of the SI principles enable the adaptability of the SI approach, ultimately contributing to the success of the primary objectives of SI paradigms.

PRIMARY OBJECTIVES OF THE SI APPROACH

There are a number of key objectives and associated outcomes that are aligned with the SI approach. Many have constructed formulas, developed sets of metrics or conducted meta-analyses that attempt to measure the efficacy of different methods used within an SI process.[10,30,31] These key objectives, as well as some of the potential methods that can be used to achieve them, through an SI process, are described below.

Resilience and increased natural capital

The integration of the ecological intensification approach into the SI paradigm is meant to lead to the development of complex agroecosystems that are spatially heterogeneous, dynamic, and possess self-regulatory mechanisms, providing a buffer from change or shocks such as climatic events or disease epidemics.[38] The whole systems methodology of SI should promote a diversity of wildlife species, as well as an assortment of livelihood, marketing, and land management practices. These hierarchies of diversification all serve to safeguard grower livelihoods and food security.[38] The involvement of relevant stakeholders (i.e. pertinent citizens, community groups, private industry and non-governmental organization representatives, government officials, etc.) through participatory methodologies, such as facilitating thematic learning forums or establishing diverse working groups, should assist in the maintenance and fostering of natural resources, which are crucial to the resilience of growers and the survival of developing communities as a whole, particularly in the face of climate change. A primary illustration of this comprises the participatory methods that the CoS-SIS program employed with the rice CIGs, described above, which resulted in the cleaning and management of their water canal system.

Maximizing outputs and minimizing costs

Closing yield gaps refers to reducing differences in actual yield versus the maximum potential attainable yield per a cropping area.[38] Sustainable intensification, as a result of the application of both the agroecological approach and the whole systems perspective, supports maximal utilization (employing the proper rates, timing, and methods for application) of agricultural inputs (i.e. fertilizer, water, hybrid seed, pesticides, etc.), as well as other available resources or practices (beneficial insects, mechanization, land, intercropping, trap crops, etc.), in conjunction with mindfulness of environmental impact. This can be extremely difficult because individuals' incentives for neglecting the maintainance of ones own ecological assets can be high, especially in light of potential immediate increases in land production.[39] This issue can occasionally be addressed through various incentive schemes (i.e. product certifications that garner higher prices, loan programs, subsidies, etc.) to promote sustainable agricultural practices, preferably supported by the market and consumers, as well as the buy-in of stakeholders via participatory processes.

Although unsustainable agricultural practices might produce a higher immediate yield than sustainable ones these management techniques will, over time, result in land degradation, limiting the land yield potential. Improved environmental performance of farm units through soil health building practices and the promotion of biological diversity to manage pests are key elements of the agroecological approach and SI.[3,5] These techniques increase resource use efficiency and assist in eliminating costs that may otherwise be associated with intensive agricultural production. A variety of new and existing manuals and technological programs and tools focus on enabling this maximization of resources in farm management, many tailored specifically to the developing country context.[40,41] Such mechanisms can be extremely valuable to the SI application, particularly as telephones, Internet connectivity and technological literacy become more widespread in the developing world. These materials can assist in farm system modeling, visualizing increases in income, and optimizing yields and the use of inputs and natural resources, as well as enhancing farmer connectivity to resources and markets.[40,41]

Agricultural extensification, involving the use of more land (i.e. land that was not previously used for agriculture, such as forested/fallow areas), is often employed to elevate overall crop production.[12] Extensification is not in line with the agroecological approach because it is not maximizing the use of land that is already in production and results in decreased ecological services.[3,5]

Bridging the yield gap can also be achieved through reduced food waste, which represents another method for optimizing the use of existing resources. A third of the food that is harvested globally is thrown away, whereas, in developing countries, approximately 40% of crop losses occur after harvest or during processing.[27] Improvements in post-harvest technologies could greatly enhance developing country food security.[16]

Many agricultural extension and development project activities involve training, instruction materials or loan packages that recommend the use of expensive inputs and labor intensive practices, such as mechanical tillage, pesticide application, and cover crop cultivation. If these inputs or practices are not appropriate to the growers environment or socio-economic conditions (i.e. cover crop seeds are not competitively priced or easily sourced for timely planting, varieties are not well adapted to the climate or soil conditions, or cannot be utilized for as an additional means of income), considered in a holistic, agroecological manner and allowing for grower feedback, their use could even negatively influence farmer revenue. Sustainable intensification intends to strengthen infrastructure and create linkages that enable growers to increase their incomes, either by decreasing costs, increasing the availability of inputs or supporting direct connections between buyers and sellers (i.e. with these recommendations, the development interventions should concurrently facilitate availability of suitable, affordable cover crops and competitive markets for cover crop seed or product acquisition, thereby promoting value-add).

Decreased malnourishment and enhanced nutrition

In developing countries, SI is fundamentally linked with two interconnected outcomes: improved agriculture and nutrition. The doubling of developing country agricultural per capita, as a proportion of the aggregate gross domestic product, can be correlated with a 21% decline in the stunting of human growth.[42]Agricultural programs that lead to changes in diets with respect to vitamin A, zinc, iodine, and iron deficiencies can have major benefits for human health. For example, in Mozambique, a bioforitified orange fleshed sweet potato has been widely adopted in target populations and successful in improving vitamin A intakes among children.[7] The consumption of cow's milk can decrease the probability of childhood stunting and malnutrition.[43] Horticulture is another area where SI approaches can address nutrition. The benefits of homestead gardens are well documented: the increase in the consumption of fruits and vegetables can improve dietary diversity, nutritional status, and income.[44]

Childhood malnutrition is also associated with chronic diarrhea that often results from consuming contaminated water or spoiled food. Health issues can also result from the consumption of mycotoxins, which are often found in disease infested produce. Therefore, as described in the three key approaches outlined above, an SI approach that enhances community nutrition should be holistic, and inclusive of practices that promote women's education (key to positive nutrition outcomes) and female participation in household income generating practices, as well as agroecological methodologies that preserve clean water, stored food, and disease management.[44,45]

Sustainable intensification and gender

Women farmers are often not able to benefit from agricultural technologies and programs as a result of their lack of access to labor, land, and inputs.[46] Studies from around the world show that women's preferences, needs, and roles are often not taken into account when designing new technologies or agricultural programs, a factor that has limited their potential benefits. A sustainable intensification approach, comprising a holistic and participatory approach, would consider the constraints that women face in adopting new technologies and also pay attention to the household dynamics and gender roles that shape women's preferences and motivations. This can be particularly important for Sustainable Agricultural Practices (SAPs) technologies, which can decidedly vary in the extent to which they are labor-saving.[5] In Ethiopia, the adoption of SAPs led to a significantly larger increase in female farm labor compared to male labor.[47] In Bangladesh, as a result of cultural dynamics, treadle pumps designed for male operation were used by women, causing women pain, exhaustion, and a decline in time spent and quality of domestic activities.[35]

One suggested strategy for closing the yield gap in developing countries is improving women's access to agricultural inputs.[45] The fact that plots managed by women have lower yields than those managed by men is attributed to unequal access to agricultural inputs.[46] Improving access to agricultural resources for women could result in large increases of on-farm outputs, with an estimated growth in agricultural production of 2.5–4%, and with a greater escalation in countries where the gender gap is more pronounced and women play a larger role in agriculture.[45] It is also important to note that these increased agricultural outputs often result in an augmentation of female income. A significant amount of this increased income would likely go towards child health and education, reducing the number of undernourished people by a projected 12–17%.[45,46]

Human and institutional capacity development activities that target women can have a substantial impact on the adoption of sustainable agriculture technologies. A positive correlation between female spousal education and the adoption of SAPs has been established.[47] Moreover, female growers in general are more likely to implement CA practices than males.[48] Based on all of these factors, an SI program that is at least gender aware, if not gender transformative, is likely to have higher benefits than gender-neutral programs.

CONCLUSIONS

Implementing an SI process through an international development project can be challenging. This is particularly evident in light of the necessity to employ a whole-system, participatory and agroecological approach that is culturally and geographically appropriate to building natural capital, resilience, and food security, with the aim of achieving the described objectives of the SI. The present review has noted many of the issues that the SI approach potentially has to address (weak infrastructure, HICD, networks, soil degradation, cultural barriers, climate change, poor or non-existent access to inputs, water, incentives for natural resource management, and improper sanitation) to achieve positive change. Many examples of development projects that have effectively applied the three SI principles have been given. Modeling future development programs after previous projects that have successfully utilized innovation platforms and integrated the principles of SI into their methodologies is a promising strategy for achieving the objectives of the SI paradigm and addressing these barriers to change. The effective monitoring and evaluation of SI projects and their outcomes can facilitate the advent of improved

SI stratagem, ultimately advancing SI implementation, which has yet to be perfected.[31]

It is important to emphasize that the SI approach needs to be applied within and between the individual food security projects that are on-going in developing countries. Coordination between projects and a sharing of resources, knowledge, and connections could be central to the success of SI efforts. It is quite possible that the definition of SI will transform again, taking on a new meaning or aspect. In this process, adaptability and continual development are fundamental to facilitating societal change.

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