

Sociotechnical systems and sustainability: current and future perspectives for inclusive development

Afreen Siddiqi^{1,2} and Ross D Collins¹



Sociotechnical systems – for example, telecommunication networks, electric grids, large-scale manufacturing systems – are interacting ensembles of engineered artifacts embedded in society, linked with economies, and connected with ecology. Such systems have been analyzed through the lenses of sustainability (largely along the dimensions of environmental protection and affordability), carrying influence in the literatures of technology innovation, product design, infrastructure planning, and service delivery. Sustainability concerns along the environmental and financial dimensions have motivated focus on waste and emissions reduction, new technology development, and greening of industrial ecosystems. The concept of inclusive development, however, has not yet permeated the research or conceptualization of sociotechnical systems. Two streams of on-going work in inclusive innovation and in inclusive wealth analysis offer meaningful avenues for future connections. We discuss how the literature on sociotechnical systems and their constituent elements of engineered products and processes has evolved on the topic of sustainability, how the emerging concept of inclusive innovation bridges dimensions of environment and social inclusivity, and how inclusive wealth may inform system-level planning and analysis of sociotechnical systems moving forward.

Addresses

¹ Massachusetts Institute of Technology, USA

² Harvard Kennedy School, USA

Corresponding author: Siddiqi, Afreen (siddiqi@mit.edu)

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Introduction

Inclusive development, with its explicit agenda for attending to the distributional aspects of societal well-being, inclusion of un-served groups, and the internalization of environmental impacts, is a major policy challenge for

world leaders [1^{*}] and is the subject of this Special Issue. Inclusive growth (that entails broad-based economic growth across population groups and sectors and is related to but also different from inclusive development due to its primary focus on economic aspects) has been advocated for almost a decade [2]. While socio-political and economic forces have shaped disparities, technology and modern engineered systems (typically capital intensive, large in scale, and environmentally damaging [3^{*}]) are also considered to have contributed simultaneously to a growing divide and uncoupling of economic growth and social development. A variety of lenses from economics, sociology, and development studies have been brought to bear on the issue of increasing disparity in access to modern technologies and industrial economies (and the consequent differences in social opportunities and quality of life). Here, we examine the literature on engineered sociotechnical systems to add a distinct perspective for inclusive development.

Sociotechnical systems (also referred to as engineering systems) – including air transportation systems, electric grids, telecommunication systems, water supply networks, and healthcare systems – underpin socio-economic development and well-being [4]. They are ensembles of technical artifacts embedded in society, connected with natural ecosystems, functioning within regulatory frameworks and markets, and exhibiting a high degree of complexity and dynamics that are not fully understood. Research on sociotechnical systems intersects classic systems engineering [4,5] with technology innovation and management, economics, and policy. A focus of this stream of research has been on the architecture [6], technical design and performance analysis [4,7], and is different from the literature on sociotechnical regimes and sociotechnical transitions [8] wherein the emphasis has been on social complexity with questions of inquiry mostly focused on social and institutional processes.

In the following sections, we first discuss the literature of sociotechnical systems, specifically with regard to the constituent elements of engineered products and processes. We highlight past and recent literature on green innovation stemming from concerns of environmental sustainability. We explore the emerging concept of *Inclusive Innovation* that aims at expanding access to and benefits from technologies. We summarize definitions and discuss connections of inclusive innovation to inclusive growth, inclusive development, and sustainable development. Finally, we summarize the recent literature on *Inclusive Wealth* (see also Kumar, this Special Issue)

along with its prospects for shaping research on socio-technical systems in the context of inclusive development.

Technology innovation: from environmental sustainability to social inclusivity

In the past two decades, a significant amount of literature has emerged in the technology and design domains of engineered products and processes (constituting socio-technical systems) motivated by sustainable development (Table 1). While the principles of sustainable development were generally described as the integration of economic, environmental and social dimensions [9], the greatest thrust of research (and subsequent practice) was on environmental impacts and affordability. Ranging from new consumer products, materials, manufacturing processes, modeling and assessment methods [10,11], a variety of innovations have emerged under the paradigm of green innovation [12,13^{*}]. Some of this was demand driven by environmentally conscious customers, while other developments were driven by business motivations with the recognition that green product design and green practices could improve profitability. Approaches such as Lean Manufacturing and Engineering [14] – that reduced material waste and increased efficiency – have been advocated and adopted in industry since the 1990s. The movement towards green processes thus had a strong correlation and complementarity with these past practices [15]. However, in contrast to cost reduction motivations, the ‘green-labeled’ approaches were driven in part by social pressures and environmental impact considerations. Beyond the product and process level, research in industrial ecology [16] drew upon concepts from natural ecosystems to focus on system-level questions of the environmental impacts of flows of materials and energy in industrial and consumer activities with the objective of integrating environmental concerns into economic activities [17].

The social dimension of sustainability and concerns for equity have been comparatively less dominant in engineering literature. However, a few streams of research

have such emphasis, most notably in *inclusive design* and *inclusive innovation*. Inclusive design seeks to design for the widest possible number of people (particularly the elderly and people with disabilities). The motivation is not just about offering equality of social opportunity, but also about increasingly promising business catering to a growing aging population and a wider user base of previously un-served groups [18]. The concept of inclusive innovation emerged from the notion that mainstream innovation had produced goods, services, and processes traditionally aimed for middle and high-income consumers and formal producers [19^{*}], and that most of the technological advances catered to the rich [20]. In contrast to inclusive design (that seeks to cater to groups with limitations on physical and cognitive abilities), inclusive innovation aims for distributional access of technologies for the socio-economically disadvantaged.

Proponents of inclusive innovation observe that formal scientific, technological and productive structures and organizations have rarely produced innovations that address the needs of the poor [20], and innovations at times reinforce inequalities. Inequality here refers to unequal distribution of anything people value, which is not just wealth, but also health outcomes, educational experiences and so on. For instance, when product design is aimed at particular income groups, for example, drug development for relatively rare-diseases in high-income countries as compared to drug development for diseases prevalent in low-income nations [21].

While innovation may at times contribute to inequalities, it can also help overcome them [21]. Inclusive innovation – of products and processes along with the inclusion of roles of poor as both producers and consumers – seeks to play an important role in overcoming exclusion [3^{*}] and creating opportunities to improve the wellbeing of disenfranchised individuals and communities trapped in poverty [22]. Inclusive innovation (noting that while some inequalities cannot be completely eliminated, they should be narrowing rather than widening [21]) has increasingly gained scholarly attention [23]. With growing momentum, it will likely inform policy and development-based practice in the Post-2015 development agenda [19^{*}].

Linked with inclusive innovation are concepts of grassroots innovation, reverse innovation, and frugal innovation discussed in development studies and business literature, but less so in engineering literature to date. Grassroots innovations are bottom-up, community-level innovation solutions responding to local needs, interests, and values [24]. The notion of reverse innovation (employed by several multinational corporations including GE, Procter and Gamble, Unilever, Nestles, Philips, and Siemens) is about redirecting innovation activities from high-income to low-income markets to that of

Table 1

Number of publications (including journal articles and conference papers) listed in Compendex (Engineering) database with search words ‘sustainable development’, ‘inclusive development’, ‘inclusive growth’ in title, subject, or abstract

Year	Sustainable development	Inclusive development	Inclusive growth
1991	72	0	0
1995	173	0	0
2001	1067	0	0
2005	3770	0	0
2011	7707	3	9
2015	7406	10	5

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