Novel approaches for scaling up engineering-based inclusive innovation

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Abstract. Given their obvious need, why is it so hard for new pro-poor, engineering-based inclusive innovation (EII) to become more mainstream? Can new trajectories emerge that are more inclusive and environmentally sustainable? Those interested in these questions have studied the role of science and engineering in development but have been brought up short by a range of constraints. These include the poverty of those who might benefit most but also institutional barriers to the inclusion of some actors with knowledge and experience of scaling innovations towards the mainstream. This paper presents new theories and a set of case studies of attempts to scale and mainstream innovations. We have gathered data from and analysed scaling up case studies from different sectors and geographies, including the UK, China, India, Bangladesh, Uganda. The paper advocates for the advantages of evolutionary approaches to development engineering that take account of institutional variety over static, neo-classical and one-size-fits-all approaches. We show that one size fits all does not apply to scaling up for engineering-based inclusive innovations. We illustrate that engineering innovations that have not been replicated on a large scale have not necessarily failed. We conclude by arguing that it is possible to go beyond market failure approaches towards a more agile framework for the delivery of innovations and suggest that our results resonate with broader changes in the greening of the global economy.

Keywords. Scaling up, Development engineering, Transdisciplinary engineering, Engineering-based inclusive innovation, Evolutionary approaches

Introduction

Engineering for Development (E4D) links global development and engineering by building solutions for societal challenges for people who are generally left out of the development process [1]. Previously, E4D was considered a marginal and 'appropriate' solution that often failed to integrate into the mainstream economy and society. Huge efforts by well-meaning, talented, and hard-working individuals and small teams are put into designing and building prototypes that aim at solving poverty and inequality but fail to be widely taken up, remaining utopian and often forgotten inventions. However, previous research analysing the Research Excellence Framework (REF) 2014 impact case studies of E4D shows signs of socially and institutionally aware engineering that extend to complex and uncertain where these solutions are applied [2]. This also highlighted the beginnings of scale-up and the integration of networks and communities to solve pressing societal challenges. Building on this work on E4D and their attempts to scale, in this paper, we conceptualise serious efforts applying science and engineering to address societal challenges as engineering-based inclusive innovations (EII) rather than just being technofixes.

Given the increased focus on scaling up, our aim is to understand what scaling means and investigate the pathways to scale-up and mainstreaming of EII across sectors and geographies. Scaling up is generally associated with expanding interventions or innovations into new contexts, which is crucial for ensuring a broader societal impact of innovation. Improving understanding of scaling involves assessing impact, typically transitioning from the pilot phase, where innovation is the key process, to scaling, where diffusion becomes paramount, and wider stakeholder involvement is critical [3]. Various contexts and research areas delve into these two aspects of scaling, including social innovation [4-6], pro-poor initiatives focusing on the bottom of the pyramid [3, 7-10], and

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more recently, development engineering [11] and inclusive innovation [12-14]. The paper has three sections. In section 1, we review extant literature to develop conceptual underpinnings of scaling EII, frameworks and their underlying assumptions. In section 2, we follow up on the case studies from previous work [2] along with recent cases across sectors and geographies (e.g. the UK, China, India, Bangladesh, Uganda) by reviewing extant literature and content analysis of academic and policy publications. That is, case studies discussed in this paper are high-tech engineering solutions - and not merely cheaper alternatives - designed with an understanding of institutional contexts, exhibiting signs of scalability by involving various actors, networks, and communities to address societal challenges in local settings. Our analysis of case scenarios showcases a variety of scaling-up strategies for EII based on sector and geographies that go beyond replication and wider adoption. In section 3, we conclude by highlighting insights to develop more agile frameworks to theorise scale in EII across sectors and geographies rather than market failure-based and standard economic approaches.

1. Conceptual underpinnings of scaling up engineering-based inclusive innovations (EII)

1.1. Dominant frameworks to scale in the realm of development engineering

In this section, we critique a framework for scaling EII based on narrow narratives, integrating theories and methods of standard development economics and social sciences with engineering practice, advocating the co-design of engineering advances with social and economic innovations for real-world impact [11]. The practical framework offered to develop scalable development engineering solutions involves the following iterative activities - innovation, implementation, evaluation, and adaptation – that enable researchers to anticipate and design solutions for common challenges associated with technology for development. It defines development engineering as ‘process of discovering and characterizing a problem and then developing a generalizable technological solution—one that can address the challenge at scale’ [11, pp70]. Moreover, it is based on the premise that development engineering is closely linked to the recent use of randomised controlled trials in public policy to address poverty, focusing on technological innovation as a tool for achieving sustainable development. Under this framework, scaling up is defined as taking an innovation that has positively impacted a limited number of users during the evaluation stage, modifying it to reach a larger number of users, and expanding its reach to users in new geographic locations [12]. To some extent, the framework emphasises parameters that confer long-term sustainability of scale-ups, including business models, market processes, managing deep supply chains, and navigating the political economy of institutions, government regulations, legal challenges, and the role of civil society in oversight. To operationalise this framework, the authors describe ‘hypothesised constraints’, ‘common’ for many ‘developing countries and low-resource communities’ that posit as design requirements and direct targets for technological innovation:

(i) Market constraints, such as a lack of insurance (risk transfer) markets, capital constraints and weak credit markets, missing information, high transport costs and shallow markets, labour market failures, etc.
(ii) Institutional constraints, such as elite capture, intermediaries, a weak contracting environment, high transaction costs, principal-agent problems within government and citizens, and asymmetric information.
(iii) Behavioural/ social norms, such as cognitive bias, intra-household bargaining, social norms, mood disorders, etc.

The authors describe the means to overcome these constraints for engineers as ‘diagnostic and design tools’ to understand the user base and explain why technologies that work in developed settings may fail when applied to a new setting [11]. However, despite starting innovation efforts as ‘iterative’ and ‘non-linear’, our argument is that this is not enough. We argue that approaches need to go beyond the heavy reliance on microeconomic depictions of developmental issues and market failure-based framings, which provide a neoclassical perspective on scaling up.

1.2. Dangers of using a microeconomic lens to theorise scaling up of EII

This framework provides a straightforward approach to scale and implement engineering innovation, but despite stating innovation efforts to be ‘iterative’ and ‘non-linear’, it forms its basis on static and neoclassical assumptions, which are impractical for real-world innovation efforts. We discuss some of the reasons:

(i) The representation of constraints faced by developing countries or low-resource communities as uniform and common can be misleading due to diversities within and among the countries. Such an approach brings a 'cookie-cutter' model for developing scaling measures. Moreover, market constraints overlook that the availability and accessibility of technologies are affected by factors beyond pricing and income, which the framework states are the main factors of uncertainty for people living in poverty. For instance, it is important to focus on both vertical inequalities (taking the population as a whole) and horizontal inequalities (within sub-groups, like gender, ethnicities, etc.) [15]. Although there are instances where the authors appreciate the wider context and challenges of adopting a top-down approach for innovation, the hypothesised constraints lack nuance and layers.

(ii) The framework posits ‘design requirements’ with a manual for 'development engineers’, who are assumed to be identified principal actors responsible for innovation in low-income countries. The framework undermines the plurality of actors and institutional variety that enables knowledge exchange, technological learning, and adoption. Second, the innovation process is an evolutionary approach involving various actors, knowledge and technologies, and institutions [16] and assuming a ‘development engineer’ can observe the market constraints and user behaviour to develop a suitable solution fails to acknowledge the complexities of the innovation process. While microeconomic principles have been widely used to study firm-level or industry-level dynamics, they cannot capture the complex dynamics through which engineering innovations evolve. They require the identification, involvement, and communication of actors specific to each sector to operationalise the scaling and diffusion process. For instance, a study explains insights on effective delivery platforms from actual field practices of sanitation entrepreneurs in India [7]:

> ‘...‘market-oriented or ‘market delivered’ innovation does not mean that the end-user effectuates all transactions associated with the diffusion through markets. Behind a market delivery, there is a complex network of actors comprising financiers, facilitators, service providers and field staff, the last interacting most closely with the target community’

In the post-COVID era, focusing on delivery platforms is crucial as it helps identify different actors and the significant role of LMICs as consumers and producers of innovation. This approach is necessary to recognise that LMICs are more than just an end market in global value chains [17].

(iii) The framework highlights evaluating and implementing scaling-up efforts closely and iteratively to achieve success. For instance, business models are critical in determining the long-term sustainability of scale-ups that rely on market processes. However, managing deep supply chains can present challenges that require strategies for mitigating risks posed by market frictions commonly found in developing countries. Alternatively, scaling up with government partners may require navigating the political economy of institutions, government regulations, legal challenges, and the role of civil society in oversight [12]. The framework presents a siloed discussion on constraints, which is difficult to apply to understand complex developmental challenges that undermine the complex institutions that enable knowledge exchange, technological learning, and adoption.

1.3. Going beyond the static framings of scaling EII

Given the above challenges, while scaling up EII to address societal challenges has gained prominence in policy discourse, the strategies and initiatives that are based on static framings tend to focus on quantity rather than quality, which overlooks important points of contention around the direction and nature of innovation [12]. The existing frameworks prescribe steps to achieve scaling seldom take into consideration the complexity or the unpredictability of the broader system they aim to change [18]. The lens of scale may vary in these different framings, which have different implications set, achieve, and assess goals associated with scaling [12]. Recent work has provided a wider range of frameworks to study the concept of scale and inclusivity in innovations. For instance, a recent review of 20 frameworks for scaling highlighted the importance of a more dynamic and systematic approach to scaling that considers marginalised groups and anticipates, addresses, and assesses the extent to which scaling is inclusive [14]. They identified three key aspects: phases, directions, and inclusions (see Figure 1). First, the generic pathways of the five scaling phases comprise identifying, planning, implementing, learning, and adapting. Second, there are four directions of scaling: up (changes in laws, policies, institutions, or norms), down (resource allocation to support implementation), in (ensuring organisations can deliver good practices required) and out (geographically replicating or broadening the range or scope of good practices). Third, multiple inclusive actions across the phases and all directions to take inclusive actions ensure that marginalised groups are not left behind. Using the above three aspects,scaling inclusive innovations occurs within the context of complex adaptive systems (CAS). The CAS approach can help understand scaling in complex systems and identify scaling failure. In such scenarios, CAS approach enables examining interactions among agents inside and outside the system to identify and address the root causes of exclusion or discrimination in the scaling process [14].

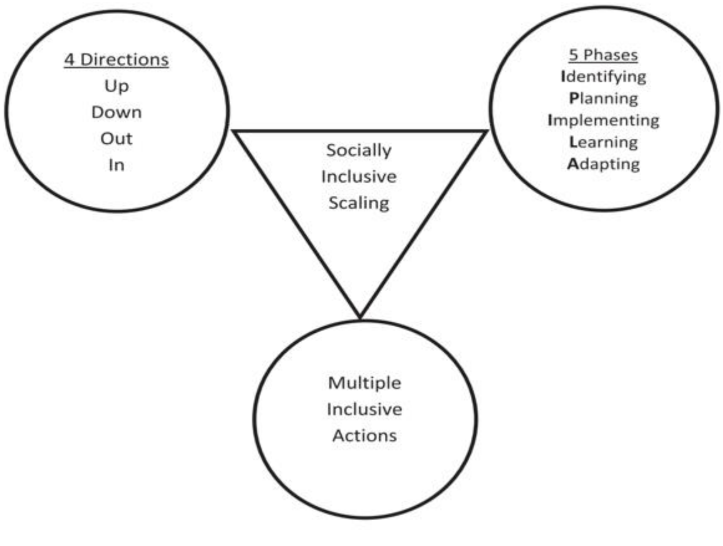

Figure 1: Approach for a socially inclusive framework
Source: Figure 3 from [14].

To conceptualise scale in EII, there is a need to delve deeper into appreciating scale as a more complex and diverse process than simply focusing on the wider 'diffusion' of the product [19, 20]. Engineering is a complex field that cannot be reduced to simply applying scientific principles or led solely by research and development. Static 'market failure' straightforward approach to engineering for development is ineffective as the diversity of engineering knowledge and practices makes it impossible to have a single concept of 'engineering for development. Some learning can be taken from evolutionary frameworks, which provide a realistic and dynamic way of understanding the innovation process compared to neoclassical models that treat technology as exogenous [21]. For instance, a study demonstrates scaling up R&D-intensive technologies while promoting local development is not just about replicating a product but creating a comprehensive system to build socio-technical adequacy [22]. This study employs a socio-technical analysis framework, combining heuristic tools from constructivist approaches to the Sociology of Technology [23, 24], learning conceptualisations from the economics of technological change [25], and a 'backwards mapping' approach to policy analysis [26]. It emphasises using a systemic problem-solving strategy instead of relying on a technology-fix public aid approach by drawing on intensive, interactive learning and diverse sources of knowledge and involving active users who contribute to product shaping and public policy [22]. This allowed the researchers to build an integrated approach from specific product technology to general, i.e., policy implementation and decision-making strategies, which provided insights on heterogeneous actors in the innovation process within knowledge-intensive technologies and scaling up through participatory technology development processes [22]. Another study highlights the merit of framing scaling within a wider sociotechnical context. It does so by combining the multi-level perspectives (MLP) from the sustainability transitions literature and the Ladder of Inclusivity (LII) from the inclusive innovation literature to explain the rapid transformation in the financial services sector in Kenya [27]. By combining these frameworks, researchers identify key aspects that drive a rapid transition in a socio-technical system and how it necessitates strong landscape pressures that motivate regime actors to act towards a common goal of M-Pesa's success resulting from various events and processes occurring over a long time in the financial services system, consisting of formal and informal regimes. Over time, multiple pressures from different levels, oriented towards social inclusion, were exerted on the incumbent system. These pressures were influenced by the microfinance movement, the millennium development goals, and the ICT revolution.

2. Case studies deciphering different scaling-up strategies across sectors and geographies

In this section, we explore scaling-up strategies using case studies of EII in different sectors and geographies. We use Table 1 to frame the developmental problem, the role of engineering and its impact, and the insights for scaling up to develop a broader understanding of how engineering innovations can be scaled up by different actors in different sectors and geographical contexts.

Table 1: Engineering-based inclusive innovations across sectors and geographies.

Case Study	**Problem / Challenge**	**Role of Engineering**	**Impact**	**Insights for scalability**
Technology to filter arsenic from groundwater	Arsenic contamination in water sources poses health risks	Chemical engineering, contextual knowledge	Provides chemical-free water treatment, scalable with solar/wind power	Funding and institutional support crucial for financial sustainability, potential role of state/intermediaries in creating markets
Disaster Monitoring Satellite spin-out company	Limitations of single satellite systems for global monitoring	Paradigm-shift engineering	Constellation of low-cost satellites for 24-hour global monitoring	Capacity building in space engineering, commercial and non-commercial applications, international cooperation frameworks
Sustainable water engineering services in Uganda	Challenges of providing piped water to poor urban settlements	Evaluation of delivery solutions for water	Improved water provision for over a million people, including urban settlements	Institutional partnerships crucial for scaling, new models for service delivery
Low-energy strategies for healthcare buildings	Lack of sustainable heating/cooling strategies for buildings	Engineering innovation	Adoption of low-energy ventilation and cooling techniques	Interdisciplinary collaboration, scalability through technology innovation and partnerships
Unified Payments	Access to digital finance, duplicity	Open-source software and	Interoperable platform supporting multiple	Scalability through open-source technology, adoption

Case Study	Problem / Challenge	Role of Engineering	Impact	Insights for scalability
Interface (UPI)	of payment applications	commodity hardware	banks and third-party apps	through all mobile devices, government regulation and potential for international partnerships
OralScan	Availability of affordable and objective oral cancer screening	Handheld device with machine learning software	Objective, non-invasive screening with reduced false negatives	Application of high-tech innovation to low-resource settings, affordable access through technology innovation using different business models

Source: Scenario building to draw insights for scaling up EII by the authors.

These cases involve identifying and framing problems and challenges, the role of engineering, and the desired societal impact. We identified how key indicators and metrics influencing their conceptions and adoption differ in different sectors and geographies, offering scenario building and exploring the meaning of scales and affordability in engineering-based innovations. For instance, in REF impact case studies of the UK [2], knowledge exchange and the development of new networks and partnerships are strong outcomes of interventions that resulted in spin-out and collaborations with governments showing signs of scale-up (horizontally and vertically, up and deep).

Chemical engineering innovation to filter arsenic from groundwater: A team of Indian and European engineers led by Bhaskar Sen Gupta developed the process of filtering arsenic from groundwater in 2004-06 [28, 29]. Their work involved utilising chemical engineering knowledge for arsenic remediation, which is crucial in addressing the toxicity of non-piped water. One of the key breakthroughs has been the successful implementation of pilot plants successfully in three countries, with learnings from each site being used to improve the technology. The success of this approach hinges upon financial sustainability for scaling up [2]. The engineers are trying to fund investment by having users of decontaminated water pay an affordable fee for the service, albeit also acknowledging that water should be provided free to poor users. There is no incentive or business model to attract private service delivery institutions because once the plant has been built and installed, there is nothing to sell. The approach to scale, in this case, provides insights into the challenges of scaling public goods (drinking water) and presents the potential role of state/intermediaries in demand generation, capacity building, and creating new markets.

Water engineering improves water service delivery in underserved areas: Providing piped water to poor, informal, urban settlements in developing countries is challenging due to financial and budgetary constraints and quality issues. National Water and Sewerage Corporation (NWSC) is Uganda's largest water authority, providing potable water and sewerage services in urban towns on a commercial and financially viable basis. The Water Engineering and Development Centre (WEDC) and the NWSC have collaborated to provide sustainable engineering services to these communities. They have conducted surveys, interviews, and focus groups to understand the users' needs and evaluate various delivery solutions for water through pipes [2]. The safety of water, assessment of utility meters, and shared connections at standpipes were also assessed. In terms of scaling, the WEDC and NWSC's strong ties began in 1988 through a World Bank infrastructure project, and they have developed new models to extend and improve water service delivery to underserved areas. NWSC has taken steps towards ensuring sustainable scaling and improving service delivery by signing a Memorandum of Understanding (MoU) with the WEDC, under which NWSC sponsors their staff to pursue MSc degrees in Water & Waste Engineering, Water and Environmental Management, and Sanitation. These programs offer in-person training in the UK and Uganda and self-study distance learning, which adds to the capacity development of employees and the organisation's sustainability. Many NWSC employees, including PhD, masters students, and those on short courses, were taught by WEDC academics. Over the years, they have built a shared discourse of water engineering networks. NWSC's corporate plan for 2021-2024 aligns with Uganda's national development plan (2021-2025), which identifies NWSC as one of the key actors ensuring improved urban safe water and waste management services and associated infrastructure for value addition and revenue generation in Uganda [30].

Space and electrical engineering to improve global disaster monitoring: The Surrey Satellite Technology Limited (SSTL), Surrey University's spin-out company, designed and built earth observation (EO) microsatellites, low-cost yet highly capable small satellites and imaging sensors using the latest `commercial-off-the-shelf' technologies and devices to create the international Disaster Monitoring Constellation (DMC). DMC presents a new set of knowledge by reconfiguring existing products based on constellation building and miniaturisation in electrical engineering with strong socio-economic components to fit satellite technology for developing countries [2]. The key innovation is the constellation of small, affordable satellites equipped with strong monitoring equipment into a powerful array to improve global disaster monitoring. The case presents a more evolutionary style of engineering practice with room for error as opposed to the risk-averse military model of satellite development. DMC International Imaging (DMCii), a commercial imaging company and a subsidiary of SSTL, was formed to coordinate first-generation microsatellites and stimulate EO applications. It is the only company in the world that can finance its own EO satellites without any government subsidies. The project strongly emphasises three key aspects for scaling up by commercial and non-commercial activities,

(i) replacing big and high technology with small and flexible technology,
(ii) network building through capacity building in space engineering for China, Algeria, Nigeria, Turkey, Spain, and the UK
(iii) affordable access to space technology for developing countries to improve disaster monitoring worldwide.
(iv) These engagements are also influenced by factors external to the technology deployment, e.g., national security, regulations for space technologies, etc.

Paradigm-changing building engineering for sustainable buildings: In this case, the innovation involves incorporating passive cooling (or heating) of hospital designs as a substitute for high-tech air conditioning systems and closed buildings. It builds on existing knowledge of what is present with new practices and strong networks of research, development, and use. The community of practice consists of two types of networks: Modelling of air flows in buildings and analysis of water and air usage by Alan Short's team in Cambridge, Andy Woods and colleagues from the BP Institute. Data collection and modelling of temperature, humidity, and airflow behaviour over extended periods of time by co-investigators at Loughborough University. Using this research, environmental design proposals are developed for various clinical and non-clinical spaces. These proposals are then catalogued and combined into a typical plan component. The ventilation and energy performance of these components are modelled and scaled to fit a 200-bed hospital, keeping in mind the current NHS service delivery policies. This unique approach has resulted in viable retrofit adaptation schemes for recurring building types, showing the potential for significant energy and carbon emission savings, the concept has been taken up in India and China [2, 31]:

(i) The Indian Ministry of Health and Family Welfare is developing a resilient prototype 200-300-bed hospital led by its Chief Architect, Professor Chandrashekhar.
(ii) Healthcare organisations and stakeholders in China's Hot Summer-Cold Winter region responding to government carbon reduction policy – in REF 2021 interdisciplinary research led by Architecture at the University of Cambridge in collaboration with Engineering, Geography and Applied Mathematics and Theoretical Physics in Cambridge and with Earth Sciences at Imperial College London and Chongqing and Zhejiang Universities in China focus on addressing challenges in building the existing stock's resilience – it has garnered interest from the Chinese construction companies.
(iii) The research has also created new forms of scaling/impact in form of a film (A Low Carbon Future for China's Furnace Cities) that showcases their above research on adapting China's existing building stock, which comprises over 9 billion square meters, without constructing new buildings.

State-led system-wide engineering innovation to enhance access to digital finance: The UPI platform, developed by the National Payments Corporation of India (NPCI), standardises payment platforms in India, allowing real-time fund transfers between bank accounts through a single mobile application [32]. It merges various banking features, fund routing, and payments into one platform, involving multiple participants such as payment service providers, banks, NPCI, account holders, and merchants. UPI IDs and pins enable cashless payments across various applications and wallets. NPCI launched a pilot in April 2016 with 21 member banks, subsequently expanding to more banks and third-party payment service provider apps. These apps pay NPCI a platform fee to utilise the UPI infrastructure. As of February 2024, the UPI ecosystem supports over 550 partner banks and third-party payment service provider apps, making it an attractive model for other countries [32]. This state-led innovation is widely adopted due to the following scaling strategies:

- (i) Utilising open source softwares like Java, TDB, and Cassandra, offers flexible APIs, enabling easy customisation, seamless integration with mobile devices, and convenient user interface innovations.
- (ii) Opting for commodity hardware, not a private cloud, allowed for enhanced scalability through interoperability and reliability, reduced costs, and dependency on specific vendors.
- (iii) Collaboration with banks ensured seamless functionality across multiple mobile banking apps and third-party UPI-compliant apps, increasing user accessibility.
- (iv) Accessibility across all mobile devices, including those without mobile data connections, ensured widespread adoption, particularly in remote and rural areas.
- (v) Regulated by the Reserve Bank of India, ensuring compliance with government regulations, promoting safe banking practices and tech diplomacy efforts by exporting UPI architecture.

AI-based MedTech innovation for early detection of oral cancer: Oral cancer is a leading cause of death in India. Presently, visual inspection of the oral cavity using torchlight is utilised to detect early-stage cancers of the oral cavity. However, this screening technique is subjective and often misses detecting oral potentially malignant lesions (OPMLs) in the early stages. Conventional oral examination often leads to multiple biopsies, increased expenses, and false-negative reports, causing delays in diagnosis and treatment. Even experienced clinicians find it challenging to locate the optimal biopsy site. Dr. Subhash Narayanan, a physicist by training, applied physics principles to biomedical engineering to find screening modalities for oral and cervical cancer screening. This technology was a culmination of 20-25 years of knowledge exchange and multidisciplinary collaborations of Dr Narayanan with researchers, dentists, and biomedical engineers [33]. These efforts resulted in scientific and instrumentation breakthroughs to screen and detect oral cancer by miniaturising instrument design. The research efforts were institutionalised to build technologies for early cancer detection by incubating OralScan under the start-up Sascan Meditech Private Limited using early-stage support of government policies and programmes [34]. OralScan is a handheld device with proprietary ML-based software to assist the healthcare provider in screening and guiding the surgeon in taking a biopsy from the most appropriate site to avoid multiple biopsies and false-negative reports. OralScan has been investigated in multicentric clinical trials covering six hospitals in India, granted an Indian patent, and a US patent has been filed, approved by regulatory approvals in India, and obtained CE mark. The objective of scaling this case has been to make this innovation reach as many people as possible. For instance, while government funding is available for the stages of innovation development, it has been challenging to secure constant funding at subsequent stages [35]. While bigger firms (like MNCs) can cover shocks like COVID-19 by other revenue streams, it is challenging for MedTech start-ups like Sascan, which also has only one or two innovations and significant operating expenses. Further, it takes time to influence clinical practice and policy. Since cancer screening is an underserved area, both from private and public provider perspectives., Sascan is leveraging technology to disrupt delivery models by lowering capex to disrupt healthcare delivery creation [35]:

- (i) the direct sale model, as a one-time investment (around INR 5.9 Lakhs or USD 7120) for hospitals and laboratories without additional consumables costs.

(ii) pay-per-use model for diagnostic chains, small clinics

(iii) large screening camps and demand creation efforts by engaging key stakeholders.

In summary, the scenarios underscore nuances of scaling strategies that cannot be discussed using a standard neo-classical economics framework. REF impact case studies demonstrate that scaling is not always widespread use or replication but rather a co-evolutionary trajectory of networks, communities, and institutions in sectors that led to broader developments and the adoption of technologies for societal impact. Introducing an engineering innovation for developmental challenges substantially differs from a standard product launch. This point is pivotal for engineering innovations with no visible markets, e.g., arsenic removal technologies. The arsenic removal plant has not been replicated on a large scale, which does not mean it has failed. In the Indian cases, engineering innovations supported by universities are not taking the standard and traditional pathways of starting with 'pilot' and scaling up by fitting into value chains. As a key pathway to innovation diffusion, the innovators opt for start-up formation, reacting, and evolving with the larger systemic change of evolving institutional support for 'start-ups', for instance, through Start-up India and Make in India policies. This is visible in the case of OralScan, in which the researchers chose to incubate and miniaturise lab-based technology based on the principles of optics using biomedical engineering after forming Sascan. The start-up formation helped institutionalise access to funding, incubators and accelerators, government programmes and schemes, and eventually, policy recognition. Since cancer screening is an underserved area in India case, both in terms of public and private interventions, this case also presented insights on demand generation and the creation of new markets by innovative approaches in the delivery mechanism. Such forward and backward linkages help in coming out of the 'round peg in a square hole' challenge faced by a range of well-intentioned development interventions. The Indian case of UPI's immense success in creating a large-scale impact on access to digital finance, for instance, by using open-source technology and hardware to enable scalability through interoperability and reliability.

3. Conclusions

The paper presents different framings and meanings of 'scaling up' EIIs and their implications in mainstreaming these innovations in society. Instead of adopting a generic approach to scale, we draw attention towards multiplicities of framings and how they influence scale and its impact. We also point out that current focus of scaling up in development engineering studies are based on frameworks that use economic assumptions providing a restricted perspective on actors, factors, and knowledge influencing scaling strategies. We also emphasise the significance of diverse frameworks rather than focusing on common 'hypothesised constraints'. We highlight the need for an agile framework to study the scaling up of EII with variables, including network building, socio-economic and political influences, institutional support, capacity creation and demand-generating mechanisms, which have a strong role in scaling up.

We use case scenarios of the REF impact case studies of UK universities and Indian state-led and private startups to demonstrate that one-size-fits-all doesn't apply to scaling-up strategies for EII emerging in different sectors and geographies. Scaling is not always widespread use or replication but a co-evolutionary trajectory of networks, communities, and institutions in sectors that have led to broader developments and the adoption of technologies for societal impact. Innovations in different sectors highlight the importance of identifying the different aspects of sectoral systems of innovations, including knowledge and technologies, actors and networks, and institutions scaling up in different sectors and geographies. This approach is particularly useful in deriving crucial insights into how various actors, including universities, spin-offs, and start-up firms, are innovating engineering solutions. This approach allows us to map the coevolution of technologies with actors, knowledge, networks, and institutional paradigms, e.g., by creating a matrix. To better understand impact of scaling, it's also important to consider variables that explain effective demand, value, and political economy of innovation. Further bifurcation of diffusion must include scaling up, alongside discussing the delivery mechanism, for a deeper exploration of efficiency, effectiveness, sustainability, and social equity measures. These insights will likely inform better delivery models, value chain advances, and the de-colonisation of development engineering by breaking off from ‘cookie-cutter’ models.

Our conclusions resonate beyond discussions concerning the role of E4D and conceptions of EIIs. At a broader level, they posit the recent growth in debates about industrialisation and the global economy. Although large-scale, capital-intensive mega projects still proliferate, there has perhaps been a shift to a less ‘productionist’ industrialisation. Service-led and consumer-led industrialisation is on the rise. The old debates on green vs growth, tomorrow’s technology vs today’s consumption, and so on are changing so that arguments are emerging strongly that green does not contradict growth and investment-led belt-tightening is not the only way to grow an industrial economy. The work that links health to industrial systems, fossil fuels to renewables, and local and shorter supply chains during COVID and post-COVID crises may be in their early days. However, the changes we have studied and the institutional variety they illuminate seem to fit close to these potential changes in the global economy and society.

References

[1] Robbins, P.T., Wield, D. and Wilson, G., Mapping engineering and development research excellence in the UK: An analysis of REF2014 impact case studies. Journal of International Development, 29(1), 2017, pp.89-105.

[2] Robbins, P.T., Wield, D. and Wilson, G., Engineering for Development as Borderland Activity. Engineering Studies, 12(1), 2020, pp.58-78.

[3] Foster, C, and Heeks, R. Innovation and scaling of ICT for the bottom-of-the-pyramid. *Journal of Information Technology* 28, 2013, pp 296-315.

[4] Moore, M.L., Riddell, D., and Vocisano, D.. Scaling out, scaling up, scaling deep: strategies of non-profits in advancing systemic social innovation. Journal of Corporate Citizenship 58, 2015,pp: 67-84.

[5] Morais-Da-Silva, R. L., Takahashi, A.R.W., and Segatto, A.P., Scaling up social innovation: a meta-synthesis. *RAM. Revista de Administração Mackenzie* 17, 2016, pp 134-163.

[6] Pittz, T. G., and Intindola, M.L, Scaling social innovation. In Scaling Social Innovation Through Cross-sector Social Partnerships: Driving Optimal Performance, Emerald Publishing Limited, 2021, pp 7-16.

[7] Ramani, S.V., SadreGhazi, S., and Duysters G. On the diffusion of toilets as bottom of the pyramid innovation: Lessons from sanitation entrepreneurs. Technological Forecasting and Social Change 79(4),2012,pp 676-687.

[8] Lecomte, C, Blanco, E. and Boissin, O. Base of the Pyramid on the Web: What Strategies for Scaling-Up. Working paper, 2012.

[9] Suurs, R., López, F.J.D., de Boer, J., Miedema,M., de Kamp, L and Mashelkar. R.A., A systems-based model for the successful scaling up of sustainable innovation at the bottom of the pyramid. In International Workshop: New Models of Innovation for Development. 2013.

[10] Kato, Hiroshi, and Akio Hosono. Meeting the demand of the poor: Two cases of business-led scaling up at the base of the pyramid. Getting to scale: How to bring development solutions to millions of poor people, 2013, pp 220-235.

[11] Madon, T., Agnihotri, A., and Gadgil, A.J., A Practical Framework for Research. In Introduction to Development Engineering: A Framework with Applications from the Field, Cham: Springer International Publishing, 2022. pp. 59-81.

[12] Smith, A, Scaling-up inclusive innovation: asking the right questions? OECD, Symposium On Innovation And Inclusive Growth, Paris, 2014

[13] Braund, P., and Schwittay, A. Scaling inclusive digital innovation successfully: the case of crowdfunding social enterprises. Innovation and Development 6(1), 2016, pp 15-29.

[14] Sanchez Rodriguez, A. M., MacLachlan, M. and Brus, A. The coordinates of scaling: Facilitating inclusive innovation. Systems research and behavioral science 38(6), 2021,pp 833-850.

[15] Cozzens, S. E., and Kaplinsky, R. "Innovation, poverty and inequality: cause, coincidence, or co-evolution?" In Handbook of innovation systems and developing countries. Edward Elgar Publishing, 2009.

[16] Lundvall, B. "National innovation systems—analytical concept and development tool." Industry and innovation 14(1), 2007, pp 95-119.

[17] Horner, R. "Global value chains, import orientation, and the state: South Africa's pharmaceutical industry." Journal of International Business Policy 5(1), 2022, pp 68-87.

[18] Paina, L., and Peters, D.H. Understanding pathways for scaling up health services through the lens of complex adaptive systems. Health policy and planning 27(5), 2012, pp 365-373.

[19] Moore, M.L, Riddell, D. and Vocisano, D.. Scaling out, scaling up, scaling deep: strategies of non-profits in advancing systemic social innovation. Journal of Corporate Citizenship 58 (2015): 67-84.

[20] Breaugh, J., McBride, K., Kleinaltenkamp, M, and Hammerschmid, G. "Beyond diffusion: a systematic literature review of innovation scaling. Sustainability 13(24), 2021,pp 13528.

[21] Edquist, C. "Systems of innovation: Technologies." Institutions and Organizations, Pinter, London.1997.

[22] Bortz, G., and Thomas, H. "Biotechnologies for inclusive development: scaling up, knowledge intensity and empowerment (the case of the probiotic yoghurt 'Yogurito' in Argentina)." Innovation and Development 7(1), 2017,pp 37-61.

[23] Callon, M. "Society in the making: The study of technology as a tool for sociological analysis." The social construction of technological systems: New directions in the sociology and history of technology, 1987, pp 83-103.

[24] Rip, A. "Introduction of new technology: making use of recent insights from sociology and economics of technology." Technology analysis & Strategic management 7(4),1995,pp 417-432.

[25] Lundvall, B.A., Dosi, G. and Freeman, C., Innovation as an interactive process: from user-producer interaction to the national system of innovation. 1988.

[26] Elmore, R.F. Forward and backwards mapping: Reversible logic in the analysis of public policy. In Policy implementation in federal and unitary systems: Questions of analysis and design, Dordrecht: Springer Netherlands, 1985, pp 33-70.

[27] Onsongo, E. K., and Schot, J. Inclusive innovation and rapid sociotechnical transitions: the case of mobile money in Kenya. 2017.

[28] World's first solar-powered arsenic treatment plant [retrieved from https://www.hw.ac.uk/news/articles/2017/world-s-first-solar-powered-arsenic.htm, last accessed on 5 March 2024]

[29] REF impact case study [retrieved from https://ref2014impact.azurewebsites.net/casestudies2/refservice.svc/GetCaseStudyPDF/38375, last accessed on 5 March 2024]

[30] NDP Uganda 2021-25 [retrieved from https://nationalplanning.gov.ng/wp-content/uploads/2021/12/NDP-2021-2025_AA_FINAL_PRINTING.pdf, last accessed on 5 March 2024]

[31] Adaptation of existing buildings to boost resilience in a changing climate, REF 2021, https://results2021.ref.ac.uk/impact/0c00c5c0-748f-4904-a30e-9b298efa8180?page=1, last accessed on 5 March 2024]

[32] United Payment Gateway for real-time interface [retrieved from https://www.npci.org.in/PDF/npci/upi/Product-Booklet.pdf, last accessed last accessed on 5 March 2024]

[33] Subhash, N., Anand, S., Prasanna, R., Managoli, S.P., Suvarnadas, R., Shyamsundar, V., Nagarajan, K., Mishra, S.K., Johnson, M., Dathurao Ramanand, M. and Jogigowda, S.C.. Bimodal multispectral imaging system with cloud-based machine learning algorithm for real-time screening and detection of oral potentially malignant lesions and biopsy guidance. Journal of Biomedical Optics, 26(8), 2021, pp.086003-086003.

[34] OralScan, a handy oral cancer screening tool launched [retrieved from https://dst.gov.in/oralscan-handy-oral-cancer-screening-tool-launched, last access on 5 March 2024]

[35] Joshi, P., Inclusive health: Medtech innovations for the early detection of cancer in India. PhD thesis., The Open University, UK, 2023.