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Infrastructure at the Crossroads–Beyond Sustainability

Rehan Sadiq, Kh Md Nahiduzzaman* and Kasun Hewage*

School of Engineering, The University of British Columbia, Okanagan Campus, Kelowna, BC, Canada

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INTRODUCTION

Infrastructure systems are multifaceted entities and inherently complex which not only limited to engineering systems but also encompass numerous other dimensions, notably governance, service delivery, human and social interactions, and asset management. Infrastructure systems may include urban and rural water systems, energy, transportation, telecommunication, sanitation, and urban built environment with a sustainability focus on governance, socio-demographic, cultural, financial/ economic and environmental domains. However, given the current nature of increasing complexities, many of which are climate change driven, the thought process demands to be addressed beyond the sustainability and/ or resilience praxis.

In this status quo, think-tanks and policy experts on infrastructure planning and management are at the crossroads—the contemporary research directives are dynamic and management practices are under constant transformation due to mounting pressure of urbanization and regular but uncertain disruptive forces, e.g., climate induced natural disasters, anthropogenic threats, and global pandemics, among others. The Great Recession of 2008 taught us the benefits of having robust infrastructure while the current COVID-19 is revealing how ready-to-adopt green and clean technologies can promote prudent infrastructural foundation that would be inclusive and responsive to the future changes. Sustainable development goals (SDGs), such as #11 "Sustainable Cities and Communities" is also reflective to this dynamic transformation. It necessitates the significance of adaptation to the changing dynamics and hoists the need for integrated infrastructure systems to equip the urban and surrounding regions with enhanced resilience (United Nations, 2019). Although "beyond sustainability" seems to be a newly indoctrinated paradigm shift in managing infrastructure systems, advancement of the pertinent think tanks along this path is still far from being adequate.

Modern well-designed infrastructure systems play a significant role in the socio-economic well-being of a population as factors such as traffic jams and energy inefficient buildings strongly dictate the level of social inequity and poverty. Addressing these challenges demands innovative urban planning, technology adaptation, and governance models that enable cities to become more sustainable (Berawi, 2018). It is clear that while the trend toward densified urbanization influences the quality of urban landscape ensures greater opportunities for economic growth and better quality of life, integrated management of infrastructure serves as an impetus to make the cities truly sustainable and resilient.

While achieving sustainable economic growth is of paramount importance, continued and additional investments on infrastructure is understood to be the strategic way to battle against the forthcoming challenges. The criteria for what can be included in the investment spectrum of various infrastructure types can vary across geography and depend on host of factors such as differences in existing infrastructure, built form, climate challenges as well as the nature and availability of local resources and/ or talent. Against this backdrop, this overview attempts to formulate a trajectory for the renewed need of investments, while identifying the current state of infrastructure deficit across four major economies, including Canada, the United Kingdom, China, and the United States. At

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Lakehead University, Canada

****Correspondence:***
Rehan Sadiq
rehan.sadiq@ubc.ca
Kh Md Nahiduzzaman
kh.nahiduzzaman@ubc.ca

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the same time, the overview takes into account the nature of technological and non-technological innovations, and what that means to the renewed needs beyond the sustainability paradigm.

SUSTAINABILITY OF INFRASTRUCTURE SYSTEMS

Sustainability commonly considers three elements, namely, social, economic, and environmental attributes. Its concerns also extends to "maintaining, repairing and upgrading the infrastructure that sustains our quality of life" (Fisk, 2010). State-of-the-art technological innovations have changed human lives in a number of ways, but the infrastructure should develop in a sustainable manner, focusing on the prevention of unnecessary consumption of natural resources, mitigation of harmful emissions/ effluents, and adaptation to the changing environmental conditions (Zavrl and Zeren, 2010; Ahsan, 2018). As per the Triple Bottom Line (TBL), every project and intervention must be evaluated against three attributes, where the integration and optimal balance have to be maintained in favor of an integrated welfare (Zavrl and Zeren, 2010). The urban infrastructure systems must have functional capacities to facilitate various socioeconomic affairs to perform. Urban Infrastructure Carrying Capacity (UICC) refers to the capacities to carryout essential urban socioeconomic and environmental functions, including water supply, urban metabolism, and provisions of living, educational, and medical services (Wang et al., 2020). It is set to guide the local governments to promote infrastructure for sustainable development (Zhang and Li, 2018).

Over the last decade, green infrastructure have witnessed growing acceptance as a viable means of reducing environmental impacts. Green infrastructure consists of a network of natural and semi-natural landscape and feature which incorporates four categories: (i) energy and environment, (ii) ecological planning, (iii) water resource management, and (iv) methods and tools (Du et al., 2019). For instance, continued investment on electric vehicle charging infrastructure both for private and public vehicles (e.g., buses) would be a key recovery package against the deteriorating urban environment. Charging infrastructure need to take into consideration the opportunity cost for other alternatives and public space used.

In case of urban water management, there is a substantial deficit in infrastructure investments. One prominent example is the estimated C$50 billion deficit in the Canada's water infrastructure, despite being a key pillar of the country's green infrastructure (Arsenault, 2020). There is also a C$300 billion gap in the investment of building retrofits, which is considered to be among the cost efficient and green solutions to mitigate the rising greenhouse gas emissions from Canadian homes and buildings. Similarly, bridges and tunnels face challenges requiring immediate attention and additional investment worth C$21 billion (Arsenault, 2020).

Globally, there is an annual deficit of infrastructure investment worth US$ 3.3 trillion through 2030 in order to keep pace with the projected economic growth (McKinsey Global Institute, 2016). **Figure 1** shows the investment gap of specific infrastructure that needs to be bridged up through a consistent investment in the next decade.

STATE OF URBAN INFRASTRUCTURE

This section portrays an overview of the status of infrastructure across few major economies of the world.

China

Climate change coupled with natural disasters exert immense strain on China's infrastructure (Wei et al., 2015). Climate change has been found to accelerate the deterioration rate of infrastructure (Peng and Stewart, 2016). Studies (Xiong et al., 2018) have also demonstrated that, owing to the changing climate, drainage infrastructure will be incapable of handling future increases rainfall, exposing urban areas to flooding. These findings represent a growing number of studies that have underscored the future challenges likely to be faced by China in safeguarding its infrastructure them against climate change and natural disasters, thus highlighting the need for better planning in preparing for and addressing the impending climate-related challenges.

The rapid economic development in China over the past years has taken a negative toll on its environment. In order to address these challenges, China has introduced a number of "green initiatives," including the reduction in coal consumption, improved regulations, green investment, and the establishment of sustainable development zones (van der Putten, 2020). Further, China has since 2017 realigned its Belt and Road Initiative (BRI) activities in the favor of environmentally sustainable infrastructure systems. The BRI is an initiative designed to strengthen the integration of international economies *via* energy and infrastructural projects investment (van der Putten, 2020). This China-led initiative, estimated to be worth more than US$1 trillion, consists of projects in transportation, as well as energy and other infrastructure across at least 70 countries (UOP, 2019). The enormity of annual infrastructure investment has put China on top of the countries, totaling to a sum more than North America and Western Europe combined (McKinsey Global Institute, 2016). **Figure 2** provides infrastructure investment deficits across the major economies where China stands out to be only country with a high margin of surplus.

However, the recent COVID-19 pandemic has added new challenges to China's economic development. Accordingly, in an effort to combat the economic impact brought by the pandemic, China continues to invest in new infrastructure projects, including 5G networks, big data centers, electric-vehicle charging stations and industrial internet, modern transportation such as urban subways and inter-city high speed rail, and ultra-high voltage (UHV) power-transmission projects (FR, 2020).

The United States

An extensive network of infrastructure drives the US economy. However, because several decades have passed since the existing infrastructure systems were first constructed, the economic performance of the country falls short of where it could be had the infrastructure been more modern (McBride, 2018). The current

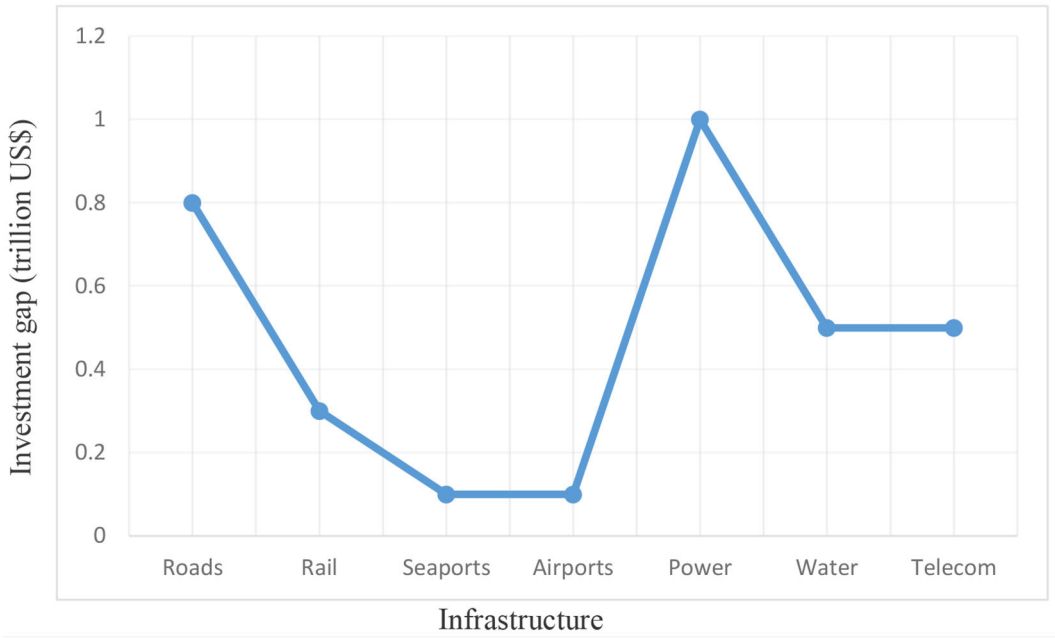

FIGURE 1 | Global investment gap in infrastructure systems; Source: McKinsey Global Institute (2016).

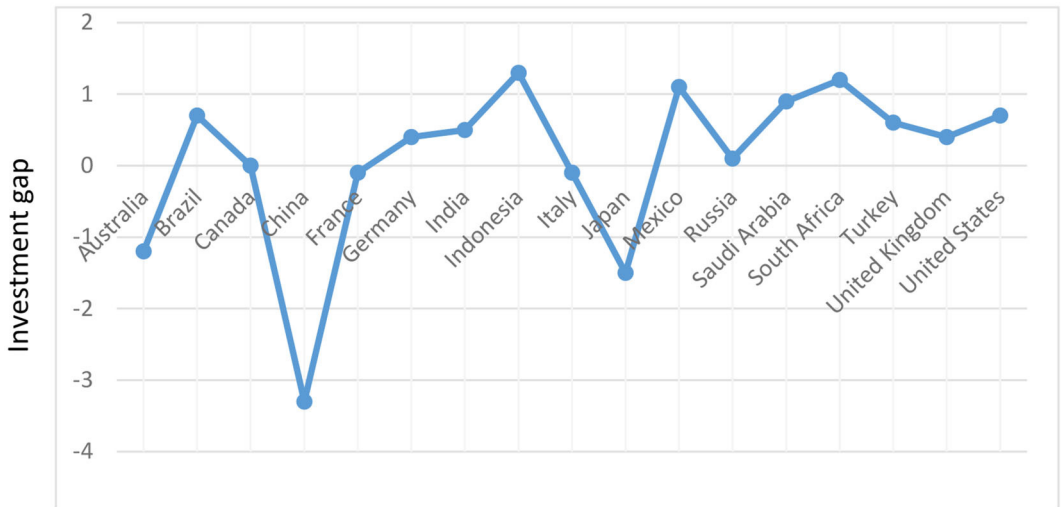

FIGURE 2 | Infrastructure investment gap (Need 2016–30 vs. actual 2008–13, percentage points of GDP); Source: McKinsey Global Institute (2016).

deficit of infrastructure investment in the US is about 1.1 trillion US$ where surface transportation and water/wastewater suffer the major shortfall than what is currently needed (Wang, 2017). Underinvestment in infrastructure projects has contributed to the inadequate services, with only 2.5% of the GDP invested in infrastructure in 2019, compared to 4.3% during the 1930's (ASCE, 2020). Moreover, safety concerns and poorly maintained infrastructure systems lead to loss in productivity that translates to billions of dollars' worth of cost (McBride, 2018).

The COVID-19 pandemic has further deteriorated the already dire situation. In particular, a major source of funding of the country's infrastructure is based on revenues generated by users of these infrastructure systems. Since the pandemic has virtually brought the country to a standstill in terms of greatly reducing the level of transportation, this revenue source has been severely curtailed, thereby limiting the support to these infrastructure systems (ASCE, 2020).

The United Kingdom

As a consequence for severe infrastructure deficit in the UK, rapidly changing climate is posing major challenges to the socio-economic well-being including the threat of flooding to properties and the risk of insufficient water supply to homes/buildings located in densely populated areas (NIC, 2018). Past climatic disasters have laid bare the level to which the UK infrastructure is vulnerable. A case in point was the aftermath of the 2013 and 2014 storms which left more than 50,000 homes without power, necessitated the closure of an airport, caused disruptions to rail and road transportation, and resulted in building and infrastructure damage (Dawson et al., 2018). While climate change stretches current infrastructure systems, the recent COVID-19 pandemic has made it difficult to deliver UK infrastructure projects effectively (Jallow et al., 2020), potentially leading to far-reaching implications on future infrastructure projects.

The UK government recognizes the significance of having sustainable infrastructure for its future socio-economic development. For example, the National Planning Policy Framework (NPPF, 2012) proposes a careful development plan that ensures proper risk management by incorporating adaptable measures, such as green infrastructure systems. It also puts forward the need for careful planning of infrastructure that facilitates the mitigation of greenhouse emissions through the design, location, and orientation decisions (MHCL, 2012).

Canada

The current infrastructure deficit in Canada exceeds a staggering C$150 billion. Estimates from The Federation of Canadian Municipalities indicate that water and wastewater facilities controlled by municipals require an investment of more than C$50 billion in order to upgrade deficient infrastructure to appropriate standards (CUPE, 2019). These numbers reveal the extent of problems faced by the Canadian governments at various levels. To make matter worse, climate change has magnified the infrastructural challenges by imposing further financial burden on the maintenance of infrastructure. An example of climate induced damages include the 2013 floods borne by Province of Alberta (Boyle et al., 2013; CUPE, 2019). Moreover, the current COVID-19 pandemic has brought to the fore the country's infrastructure insufficiency in accommodating the ongoing demands (Koch, 2020).

Canada recognizes the significance of green infrastructure systems in engendering an environment that is conducive to both health and productivity. This commitment is reflected by several initiatives that aim to establish green infrastructure systems (GOC, 2020). Budget 2016, e.g., allocated C$5 billion spread across a span of 5 years to green infrastructure systems (GOC, 2016). Budget 2017 was even more aggressive in pushing for the construction of green infrastructure, allocating C$21.9 billion in green infrastructure, contributing to Canada's goal of realizing a green economy (GOC, 2017a).

The new and innovative infrastructure solutions (such as building greener and longer lasting infrastructure systems) stimulated for the global marketplace. The Government of Canada's sustainable development goals and targets, short-term milestones, and actions for sustainable environment are presented in the 2016–2019 Federal Sustainable Development Strategy. Canada duly emphasizes the surging need for public transit systems to help the country build a green economy. Because investments in public transit will not only reduce GHG emissions, but also shift away to promote sustainable urban mobility choices, including active transportation from single-car usage. By the end of 2025–2026, Canada plans to allocate C$20 billion for green infrastructure initiatives that will yield significant reduction in GHG emissions and improve climate resilience as well as environmental quality (GOC, 2017b). The government has announced C$130 million in funding toward developing a national recharging network. Besides making funding available through Federal infrastructure programs, Canada plans to keep on taking necessary steps that improve the sustainability of its workplace and reduce its operational impact on the environment.

CONCLUSIONS

The recent literature paints relatively a bleak future, whereby the efficiency and capacity of infrastructure systems are compromised severely because of adverse conditions under climate change and the current pandemic challenges. It is thus imperative that appropriate resources are dedicated to the proper planning of these infrastructure systems. Failure to do so will only result in costly ramifications and dire consequences. Moreover, given the fact that infrastructure projects require significant capital and are expected to have a long lifespans, which cannot be easily modified once constructed.

Infrastructure is key to the sustained development of a country. Countries undertake activities in response to their national priorities. It is anticipated that greater pressures will be placed on infrastructure systems as a result of population and economic growth (NIC, 2018). Governments in both developed and developing world should act in pragmatic but strategic way in order to overcome the immediate and long-term challenges of urban infrastructure systems. Measures such as promoting electric vehicle charging stations; improving efficiency and capacity of water systems; building energy efficient homes through energy-saving retrofits; introducing green building certification programs; rebuilding/ retrofitting bridges; roads and tunnels to promote quality of key transportation links; cleaning up old mines, wells in abandoned sites that cause enormous environmental contamination and degradation which may pose health and safety risks etc.; should promote modern and resilient and sustainable infrastructure systems.

More technological adoption and high-levels of corporate financing are needed to cope with new normal period that demands a "beyond sustainability" approach to address the immediate and long-term needs. Mobilization of communities are required to make resilient infrastructure systems that can meet goals from sustainability perspective. Involving various government stakeholders and local communities can boost up theoretical and practical knowledge. The "Sustainable

Infrastructure" platform intellectually sheds lights on such empirical (situational) knowledge, emerging challenges, financial and institutional capacities in the public sector, new technologies, models and approaches, state of the art innovations and best practices with all tiers of governance by incorporating native and global perspectives. Realizing the urgency for creating dialogues among the scientific communities and effective communication among the entire spectrum of stakeholders, "Sustainable Infrastructure" offer a forum that triangulates new knowledge, innovations and transformational change dynamics in order to make the cities truly sustainable.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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