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Review

Environmental Impacts of Infrastructure Development under the Belt and Road Initiative

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Abstract: China's Belt and Road Initiative (BRI) is the largest infrastructure scheme in our lifetime, bringing unprecedented geopolitical and economic shifts far larger than previous rising powers. Concerns about its environmental impacts are legitimate and threaten to thwart China's ambitions, especially since there is little precedent for analysing and planning for environmental impacts of massive infrastructure development at the scale of BRI. In this paper, we review infrastructure development under BRI to characterise the nature and types of environmental impacts and demonstrate how social, economic and political factors can shape these impacts. We first address the ambiguity around how BRI is defined. Then we describe our interdisciplinary framework for considering the nature of its environmental impacts, showing how impacts interact and aggregate across multiple spatiotemporal scales creating cumulative impacts. We also propose a typology of BRI infrastructure, and describe how economic and socio-political drivers influence BRI infrastructure and the nature of its environmental impacts. Increasingly, environmental policies associated with BRI are being designed and implemented, although there are concerns about how these will translate effectively into practice. Planning and addressing environmental issues associated with the BRI is immensely complex and multi-scaled. Understanding BRI and its environment impacts is the first step for China and countries along the routes to ensure the assumed positive socio-economic impacts associated with BRI are sustainable.

Keywords: China; Belt and Road Initiative; BRI; One Belt One Road; infrastructure; environmental impacts; environmental impact assessment; transboundary conservation; silk road

1. Introduction

China's "Going Out" strategy has culminated in what will be the largest infrastructure scheme in our lifetime—the Belt and Road Initiative (BRI; initially known as "One Belt One Road" or OBOR), announced by President Xi Jinping in 2013 [1]. The BRI comprises six overland and one maritime economic cooperation corridors, which are expected to connect around half of the world's population and over 60 countries [2]. Infrastructure projects are the most prominent component of BRI, which will feature various cooperation mechanisms under the "Five Connectivities" of policy, infrastructure, trade, finance and socio-cultural connectivity [3]. BRI has been heralded as a new phase of globalisation, which will integrate inland and maritime economies, unlike the previous phases of globalisation which were primarily maritime-based [4]. Consequently, it will carve out a Eurasian continental and maritime geostrategic realm for China [5]. Although BRI is trumpeted as fulfilling the Chinese dream of national revitalisation and the creation of a regional "community of common destiny" [4], it indubitably serves strategic and domestic goals, such as developing the Western and Central parts of China and creating overseas investment opportunities for state-owned enterprises [6].

Chinese BRI investments are projected to exceed $1 trillion, dwarfing all previous geopolitically-motivated American and Soviet spending [7]. The economic effects of these investments are rapidly being seen. For instance, Liu et al. [8] found that BRI mechanisms have stimulated more Chinese outward investments to BRI countries than non-BRI countries. However, concerns about the environmental impacts of BRI are rife [9–12], which Chinese academics have recognised as a possible hindrance to China's BRI ambitions [13,14]. In response, four Chinese ministries released a circular "Guidance on Promoting Green Belt and Road" to all government departments in 2017, followed by another circular from the Ministry of Ecology and Environment entitled "Plan for Cooperation in Ecological and Environmental Protection for the Belt and Road Initiative" [15]. Since then, hundreds of papers have been published in Chinese academic journals on environmental law, policy and financing for BRI [16], mostly theoretical rather than empirical. The research on the environmental impacts of BRI especially in English language international peer-reviewed scientific journals is sparse. Given the importance of a scientific evidence-based approach, which the Chinese government and academics have also recognised [17], it is necessary to understand the environmental impacts of BRI as a prerequisite for effective policy-making which encourages environmental and social sustainability.

There is little precedent for addressing environmental impacts of massive infrastructure development at the scale of BRI. Most environmental research and policy on development impacts such as mining or dams or regional development is still confined along disciplinary lines and to specific sites, although there is increasingly an emphasis on adopting a systemic perspective [18], taking into account characteristics of complex and interconnected systems [19,20] such as cumulative impacts [21,22]. For example, Chinese economists have attempted to model economic variables and national-level environmental indicators for BRI countries [23–25]. However, data is often lacking for most BRI routes, so far research has been focused on regions in China where data is available (e.g., [26]). China has recognised this and is pushing for 'big data' information-sharing platforms for BRI [13]. There is a need to assess the key social, political and environmental dimensions [27–29] of BRI impacts, whilst recognising the data limitations and methodological challenges inherent in reconciling the natural and social sciences [30].

In this paper, we review infrastructure development under BRI to characterise the nature and types of environmental impacts and demonstrate how social, economic and political factors can shape these impacts. Drawing on environmental and geographical approaches, our objectives are to: (1) define what BRI is and what makes an infrastructure project part of it, (2) define the different types of infrastructure development associated with BRI and the associated environmental impacts on different components of the Earth systems, (3) provide a typology of BRI infrastructure according to key impact dimensions, (4) describe the role of social and economic drivers on BRI's environmental impacts and sustainability policies and (5) provide a framework to characterise BRI's environmental impacts using an interdisciplinary and multi-scale approach. The paper aims to address some of the ambiguity regarding the nature and impacts of the BRI and lay the groundwork for further interdisciplinary study and planning on the BRI that accounts for the multi-scale nature of this trans-boundary initiative. This is critical as the impacts of BRI are likely to be felt for many generations after the construction and development of BRI projects are completed across the globe.

2. What is BRI?

BRI is driven primarily by infrastructure development along spatial corridors linking China with various regions of Eurasia, motivated by geostrategic and economic development priorities [11,31]. Infrastructure is often defined and constrained by geopolitics [32–34]. Through spatial linkages of people, goods, energy, and information, infrastructure can facilitate geopolitical aims such as conquest, competition or cooperation [35]. This infrastructure is supported by, and facilitates, other cooperation mechanisms such as policy coordination, trade, financial and socio-cultural linkages [3]. Other development programmes undertaken by other powers such as the US, Russia or Japan have been often geopolitically-motivated as well [36], but BRI differs from these investments by being spatially concentrated along corridors designed with the express aim of facilitating trans-Eurasian transport connectivity and integration with China. As such, the spatial dimensions of BRI impacts are more notable than other distributed forms of globalisation or development and thus need to be assessed as a whole rather than on a project by project basis.

A problem with much of the literature on the BRI is that the line between an infrastructure project funded by China and a BRI project per se is often unclear. Projects with Chinese assistance take many forms, such as investments, turnkey projects, technical cooperation, grants, aid and concessional loans, with varying degrees of involvement from different Chinese actors [37,38]. Although the term 'BRI' is often applied loosely to just about any Chinese project in BRI countries [39], here we consider BRI projects from a primarily spatial perspective as those supported by, or facilitating, clearly-defined infrastructure corridors linking BRI countries with China. Projects not explicitly connected to a BRI corridor in such a way are not considered to be BRI within this paper, regardless of financing or motivation. Some of these projects may have started as independent projects and were later recognised as BRI projects, but were located in those infrastructure corridors. Given our definition, Table 1 provides an example of the range of projects that have been characterised under the banner of BRI.

Table 1. Examples and characteristics of infrastructure built for Belt and Road Initiative (BRI) for a range of BRI corridors.

Infrastructure Type	Country	Route	Examples	Construction	Area (sq km)	Total Length (km) [1]	Intensity	Type [2]	Ref
Transport									
Road	Kazakhstan	New Eurasia Land Bridge	Western Europe–Western China Highway	2008–2018	8445	8445	Med	Linear	[40]
	Cambodia	China–Indochina Peninsula Economic Corridor	Phnom Penh–Sihanoukville highway	2019–2023	190	190	Med	Linear	[41]
Rail	Kyrgyzstan	China–Central Asia–West Asia Corridor	Uzbekistan–Kyrgyzstan-China railway	TBC	250	500	Low	Linear	[42]
	Laos, Thailand	China–Indochina Peninsula Economic Corridor	Kunming–Vientiane railway; Vientiane–Bangkok high speed rail	2015–2022	908	1816	Low	Linear	[43,44]
Airport	Pakistan	China–Pakistan Economic Corridor	Gwadar	2019–2022	17.4	4.2	Med	Nodal	[45]
Seaport [3]	Kazakhstan	New Eurasia Land Bridge	Kuryk	2017–2022	1	1	Med	Nodal	[46]
	Malaysia	China–Indochina Peninsula Economic Corridor	Malacca	2014–2019	5.5	2.4	Med	Nodal	[47]
	Sri Lanka	Maritime Silk Road	Hambantota	2008–2014	60.7	7.8	Med	Nodal	[48]
Energy									
Power lines	Pakistan	China–Pakistan Economic Corridor	Matiari–Lahore, Matiari–Faisalabad	2017–2021	203	2030	Low	Linear	[49]
Pipeline	Mongolia	China–Mongolia–Russia Economic Corridor	Russia–Mongolia–China pipeline	TBC	500	1000	Med	Linear	[50]
	Central Asia	China–Central Asia–West Asia Corridor	Pan-Central Asia pipeline: Kazakhstan, Kyrgyzstan, Tajikistan, Turkmenistan, Uzbekistan to China	2008	920	1840	Med	Linear	[51]
	Myanmar	Bangladesh–China–India-Myanmar Economic Corridor	Kyaukpyu–Kunming pipeline	2010–2017	385	770	Med	Linear	[52]
Coal plants	Tajikistan	China–Central Asia–West Asia Corridor	Dushanbe	2012–2016	0.04	0.2	High	Nodal	[53]
Hydropower	Pakistan	China–Pakistan Economic Corridor	Diamer–Bhasha dam (Indus River)	2011–2029	1200	140	High	Nodal	[49]
Wind farms	Pakistan	China–Pakistan Economic Corridor	Gharo, Jhimpir, Cacho	2017	60	7.7	Low	Nodal	[49]
Solar farms	Pakistan	China–Pakistan Economic Corridor	Quaid-e-Azam Bahawalpur	2014–2015	26	5.1	Low	Nodal	[49]
Economic									
Special Economic zone	Kazakhstan	New Eurasia Land Bridge	China–Kazakhstan Khorgos International Border Cooperation Center	2010	5.6	2.4	Med	Concentrated	[54]
	Pakistan	China–Pakistan Economic Corridor	Gwadar Free Trade Zone	2016–2018	25	5	Med	Concentrated	[55]

[1] Linear infrastructure impact area was estimated based on infrastructure type—A 1 km-wide for road, 500 m wide band for rail and pipeline and 100 m for power lines. These values allow for comparisons between infrastructure, but cumulative impacts of infrastructure can vary between 10 km and 80 km or more and can even cross nations [56,57]; [2] See Section 4.1 for a more detailed discussion on linear, nodal and concentrated typologies; [3] Indicative values for area and length of impact derived from land-based footprint of port and associated developments.

3. Nature of BRI Environmental Impacts

In this section, we define the different types of development associated with BRI and the range of environmental impacts associated with each development type. Environmental impacts of infrastructure projects are the product of interactions between the infrastructure and the receiving environment. Using an Earth systems approach [58,59], we characterised how different types of infrastructure development affect different components of the Earth systems: atmosphere, hydrosphere, geosphere and biosphere (Table 2). Land-use changes, landscape connectivity, and emissions are the primary impact pathways through which BRI infrastructure will impact a wide variety of natural systems across Eurasia, across various spatiotemporal scales. Although human activities already perturb most of Earth's ecosystems directly [60,61], when natural processes are disrupted to the extent that their inherent abilities to restore equilibrium are compromised—whether at the catchment level [62], at the planetary level [63], or anything in between—Earth systems risk being substantially and irreversibly destabilised. BRI infrastructure risks extending the human footprint into pristine regions and aggravating the existing footprints [10], destabilising Earth systems at various scales.

The Earth systems approach illustrates BRI environmental impacts at and between multiple scales. Atmospheric systems such as the East and South Asian monsoons [64] and the Central Asian dust storms [65] have complex teleconnections across the globe, but are closely coupled with human activities on land. For example, large-scale agricultural intensification and urbanisation in India were shown to cause a reduction in rainfall during the South Asian monsoon [66,67]. On continental belt routes, however, the degree of coupling between different spatial levels of the hydrosphere is weaker, so river systems are often studied at the catchment-scale or reach-scale [68]. BRI infrastructure will affect almost all of Eurasia's largest river systems, such as the Mekong [69], and may exacerbate water stress in regions like Central Asia [70]. The geosphere, comprising soils and rocks, serves as buffers, filters, sources and sinks, but has a finite carrying capacity often exceeded by human activities [71,72]. Additionally, many BRI routes such as the Karakoram Highway pass through geodynamically active areas, posing landslide risks [73]. Impacts on the biosphere, such as habitat degradation, fragmentation and loss, affect the health and survival of organisms and ecosystems [74,75]. Direct impacts give rise to a slew of secondary or indirect impacts. Apart from direct impacts, infrastructure development facilitates successive indirect effects like poaching, logging, settlement and other human invasions; it is thus imperative to "avoid the first cut", especially for pristine regions [76]. One such threat from BRI is the Russia–China Amur Bridge transport corridor, which dissects two nature reserves with old-growth forests [12]. Crucially, many environmental systems exhibit threshold behaviour, absorbing impacts before the threshold but destabilising rapidly once the threshold is exceeded, introducing additional uncertainty [63,77].

Table 2. A summarised review of key direct impacts associated with a range of infrastructure development.

Infrastructure Type	Impact on Earth Systems				e.g., Ref
	Atmosphere	Hydrosphere	Geosphere	Biosphere	
Transport					
Road	Air pollution; dust; microclimatic effects from warming; noise	Impede drainage; pollution and sediments in runoff; littering	Soil erosion; landslides especially in mountainous terrain	Habitat loss; edge and barrier effects, particularly wider clearings; roadkills; fragmentation; human and exotic species invasions	[78,79]
Rail	Less local pollution as pollution generated at power plant for electric trains; noise	Contaminants in runoff	Less than road but still present; soil pollution	Similar to roads, including fragmentation and barrier effects. Generally, less severe than roads; limited stops reduce human footprint	[79,80]
Airport	Air pollution; acid rain; noise	Impede drainage; chemical contaminants in runoff; solid and hazardous waste	Soil pollution	Often affects floodplains, wetlands and coasts; noise and light disturbance	[81–83]
Seaport	Local air pollution from ships and refineries	Direct discharge of pollutants	Dredging and reclamation	Exotic species invasions from ballast discharge; algal blooms from nutrient runoff; mortality from ship strikes and entanglement in waste	[84,85]
Energy					
Pipelines	Air pollution; noise	Contaminants in runoff; risk of accidents	Soil pollution	Habitat loss; fragmentation; human and exotic species invasions	[86]
Power lines	Electromagnetic disturbance; redistribution of pollution to power source	Contaminants in runoff (mainly during construction)	Soil pollution, compaction (mainly during construction)	Habitat loss; edge and barrier effects; fragmentation; human and exotic species invasions; avian/bat mortality	[87,88]
Hydropower	Heavy usage of energy-intensive concrete, usually produced from coal-fired plants; greenhouse gas emissions from decomposing biomass in reservoir	Alteration of river flow and sediment transport	Higher water table affects soil, can cause landslides and soil erosion	Hydrological changes affect aquatic ecosystem; submersion of vast swathes of forest	[89,90]

Table 2. *Cont.*

Infrastructure Type	**Impact on Earth Systems**				**e.g., Ref**
	Atmosphere	**Hydrosphere**	**Geosphere**	**Biosphere**	
Coal plants	Toxic air pollution; acid rain; greenhouse gases	Heavy metal contamination; high water usage; thermal pollution	Subsidence from lowering of water table	Physical habitat destruction; air and water pollutants	[91,92]
Wind farms	Significantly lower impact than fossil fuel power plants, but will still have life-cycle impacts			Avian/bat mortality	[93]
Solar farms	Thermal pollution and microclimatic changes; glare effect	Reduced infiltration capacity due to shading of soil, potentially increasing runoff	Soil sealing, shading and degradation	Landscape alteration and habitat fragmentation	[94]
Economic					
Special Economic Zone	Air pollution; noise	Impede drainage–flooding risks; pollution and sediments in runoff	Soil erosion and pollution	Habitat loss and fragmentation driven by land cover change and urbanisation	[95,96]

Multiple direct and/or indirect impacts can aggregate and interact to produce cumulative impacts [21]. The cumulative impact dimension of BRI (Figure 1) is particularly significant because BRI will concentrate infrastructure and other economic activities along its routes, while also dispersing human activities to new or previously less accessible locations. While each direct impact can often be reductively studied within the confines of one discipline, human actors and actions play a key role in the cumulative dimension of impacts. Consequently, interdisciplinary cumulative impact modelling is fraught with challenges and has yet to be widely done even at a local scale, let alone continental-scale transformations like BRI [97].

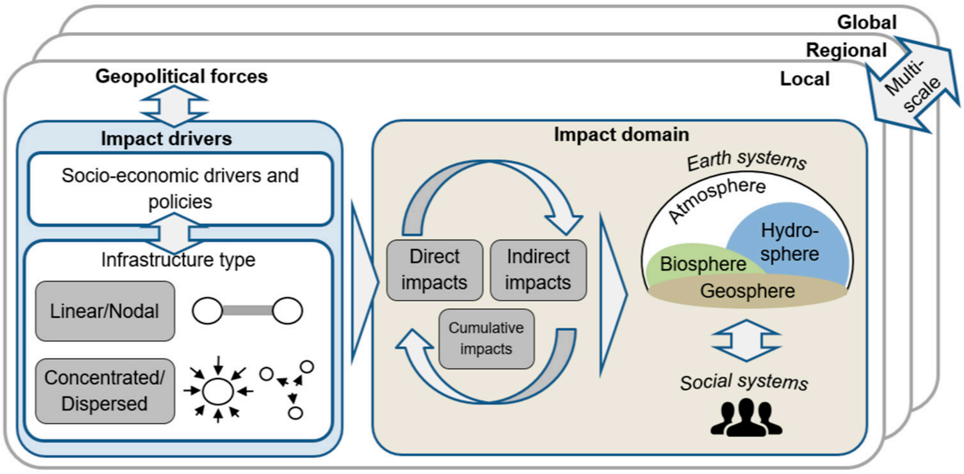

Figure 1. Multi-scale, socio-economic-political and environmental framework for planning and addressing the impacts of BRI.

Cumulative impacts occur at multiple temporal and spatial scales. For example, air pollution and anthropogenic climate forcing effects are determined by a confluence of factors, such as climate and topology, and have effects ranging from microclimatic changes to regional phenomena like smog when human activities are compounded. Substantial changes in the nature and spatial extent of human activity brought about by BRI will have regional climatic effects and teleconnections on a global scale. For example, Central Asian rangelands are carbon sinks of global importance [98], and there are concerns that increasing BRI-facilitated industrial activity will affect regional climate [99], but these are still poorly quantified.

Similarly, soil and hydrological conditions in BRI corridors interact with other Earth systems in response to human activity. These risks may sometimes be unavoidable. For example, the Karakoram Highway connecting Xinjiang, China to Gwadar Port, Pakistan passes through Himalayan regions known for “very high geodynamic activity” such as earthquakes, landslides, glacial erosion and unpredictable monsoons [73], but alternative routes are even more challenging. In the Aral Sea, Central Asia, cumulative impacts from the socio-environmental interactions between mis-management, over-irrigation and serious pollution causing water scarcity are magnified by “seriously dysfunctional” transboundary management which has the potential to result in armed conflicts [70].

4. Typology of BRI Environmental Impact Drivers

Characterising the drivers of environmental impacts requires an understanding of multi-scale, temporal and spatial characteristics of infrastructure development. Here, we attempt to provide a typology of BRI infrastructure according to function, causality, and spatiotemporal scale and intensity, in order to understand the features of BRI infrastructure which define and interact with the impact drivers and impact domain, especially through the context of the receiving environment. A key requirement for evidence-based strategic planning approaches and any form or modelling which attempts to project impacts into the future is a shared understanding of the dimensions of these impacts.

4.1. Function

The function of BRI infrastructure determines its features, particularly its spatial footprint on the landscape and interactions with other impact drivers. The sub-discipline of transport geography sees infrastructure as mediating flows of people, goods, information and energy [100]; infrastructure imposes a structure on space across spatial scales spanning from local to global, determined by economic links and relations [35]. Economic systems structure space, which impacts the environment through the characteristics of the spatial footprint of infrastructure. Linear physical infrastructure, as frequently mentioned in environmental impact literature (e.g., Reference [75]), extends long distances across space to connect two places, while nodal infrastructure occupies a more focused area. Economic infrastructure such as free trade zones serve to concentrate economic activity, while certain development initiatives may serve to disperse economic activity [101,102]. The type and function of BRI infrastructure is shown in Table 3. It is important to note that certain kinds of infrastructure may occupy more than one category—for instance, a Liquefied Natural Gas (LNG) terminal might be considered as both a transport and energy infrastructure.

Table 3. Typology of BRI infrastructure according to type and function.

Category	Type	Examples	Primarily Physical	Function
Transport	Linear	Road, rail	Y	Movement of people and goods between settlements separated by space
	Nodal	Airports, seaports, rail terminal	Y	Serve as land-sea, land-air, and land-land interface
Energy	Linear	Pipelines, power lines	Y	Energy transmission across space
	Nodal	Dams, coal, wind, solar, mines	Y	Energy generation-convert energy source into form suitable for human use
Communication	Linear	Fibre-optic cables	Y*	Movement of information between settlements separated by space
	Nodal	Receiving stations	Y*	Serve as network-network or network-user interface
Economic	Concentrated	Special Economic Zones (SEZs)	N	Concentrate economic activity in a geographically-limited area
	Dispersed	Development incentives, financial mechanisms	N	Facilitate economic activity across a wider region

* Communication infrastructure is physical, but physical distance and location have a less pronounced effect on the network. Additionally, it has a smaller physical footprint and landscape impacts.

4.2. Causality

The wide-ranging scope of BRI projects, especially when spatially concentrated along corridors, bring about complex causal relationships and interactions between different infrastructure types. A simplified model of this is presented in Figure 2. Economic activities are dependent on physical infrastructures (especially transport and energy), and increase demand for them [103,104]. Communications infrastructure often plays an "invisible" supporting role but can also stimulate certain types of economic activity [105]. Other infrastructure which promotes economic activity, such as Special Economic Zones (SEZs; [105]), can also be very influential in shaping economic activities and interactions [106–108]. These interactions and causal relationships can be used to model possible BRI activities and thus their cumulative impacts.

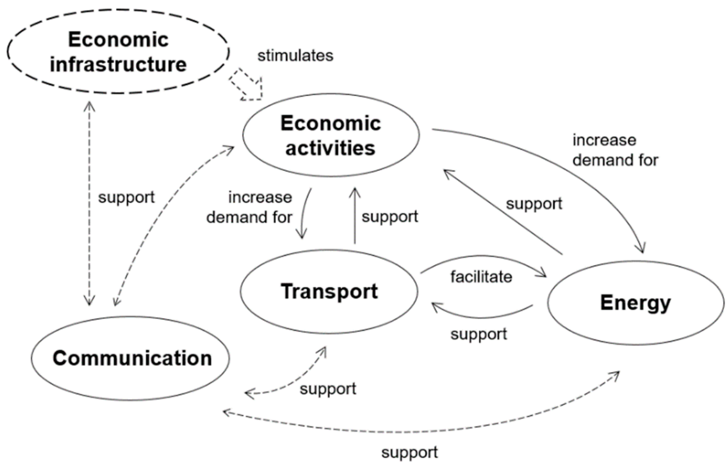

Figure 2. Relationships between different BRI infrastructure types. Plain arrows indicate causal relationships and dotted arrows indicate interactions.

4.3. Scale and Intensity of BRI Impacts

Infrastructure types differ in the manner in which they modify the landscape and thus create direct impacts. They also differ in how they create cumulative impacts by facilitating successive development and modifying the behaviour of other actors interacting with the landscape. Impacts can be considered as a function of immediate onsite footprint on the environment, which is the product of its total impact area and total impact intensity [109,110], demonstrated in Figure 3 as a generalisation for each "typical" project type. Nodal infrastructure (such as airports and seaports, see Section 4.1) tends to be more spatially compact than linear infrastructure (such as roads) and tends to have a smaller total impact area. However, long-distance road and rail projects may still have a higher total impact intensity (i.e., disruption of Earth systems). Although there may not always be a choice between different infrastructure types, limited by contextually-specific constraints, an awareness of how different infrastructure types affect the environment differently can aid planning and mitigation efforts. Taking a risk-based approach, the temporal and probabilistic characteristics could also be considered. For example, oil spills from pipelines and tankers are infrequent but potentially very damaging events to their receiving environments as well as having severe economic impacts.

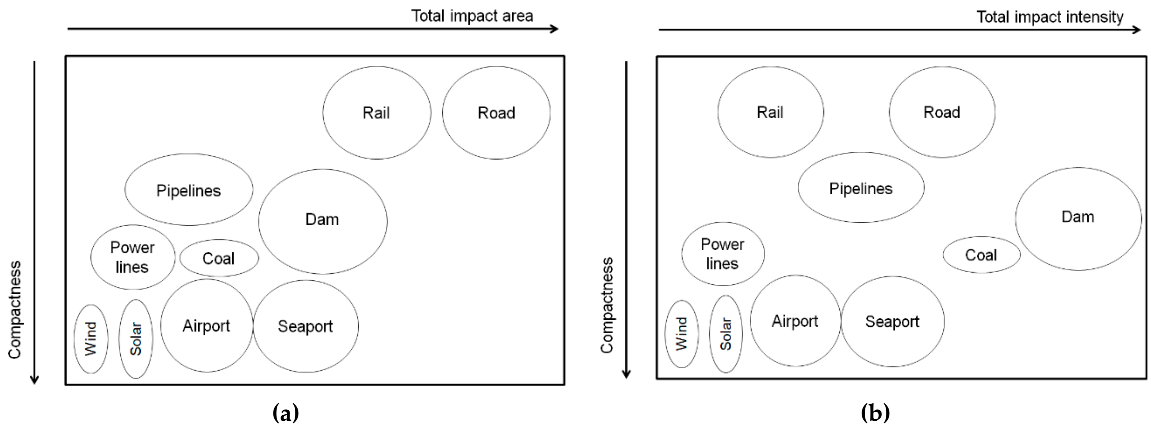

Figure 3. A simplified schematic describing (**a**) total impact area and (**b**) total impact intensity versus compactness of BRI infrastructure types.

A major infrastructure project often facilitates other development (Figure 4) and understanding the dynamics of this temporally sequential process can shed light on how different developments aggregate and interact over time to influence consequential impacts on the landscape. A large nodal project, such as a dam, requires a series of supporting developments such as concrete factories, settlements and road networks, and thus spurs the construction of more linear infrastructures across the landscape [76]. Alternatively, linear infrastructure may serve as a catalyst for nodal projects and more linear infrastructure to form networks. On a smaller scale this may take the form of transit-oriented developments [111]. For example, improved road and rail links between China and Kazakhstan, especially through the Khorgos border area, laid the groundwork for the China-Kazakhstan Khorgos SEZ [112]. Additionally, the Chinese-funded Karakoram Highway and Gwadar Port provide access to the Indian Ocean from Xinjiang. This improved transport connectivity has accelerated industrial development along the route [113,114].

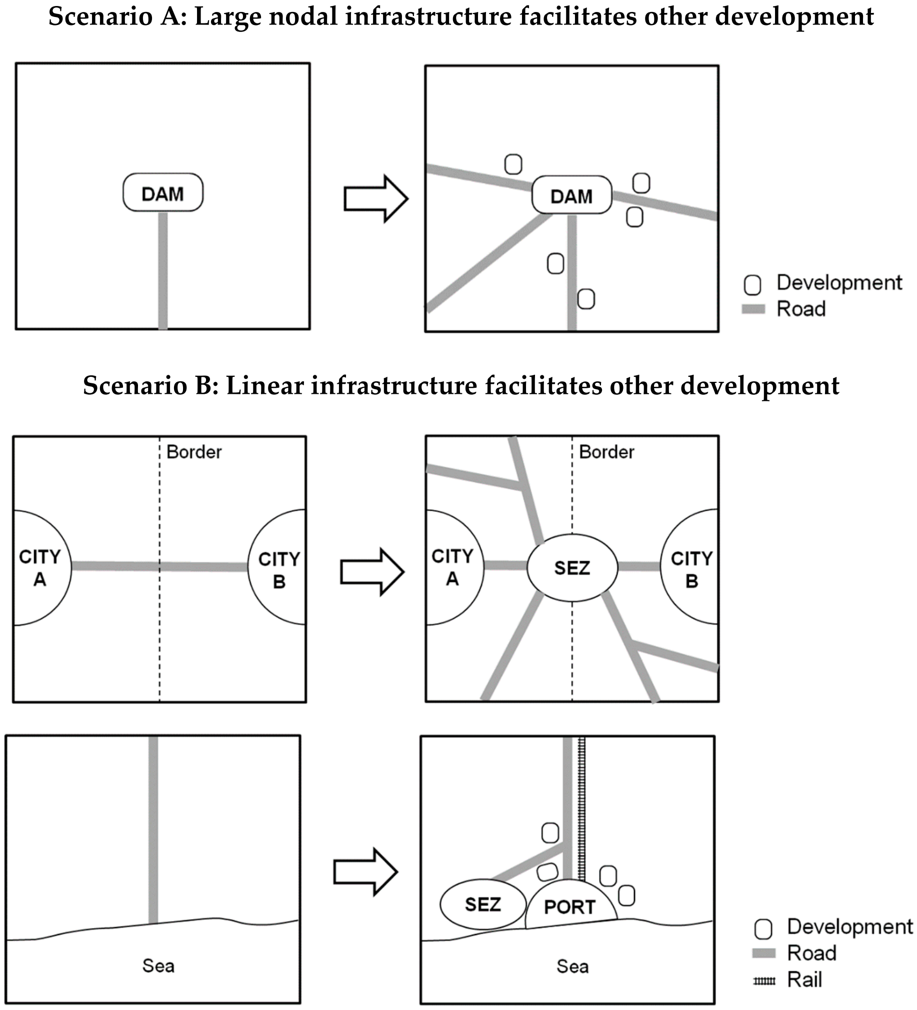

Figure 4. Examples of temporal sequentiality of BRI infrastructure development.

5. Economic Drivers and Environmental Impacts

Having already discussed direct and indirect impacts and drivers (i.e., what is happening on the ground), in this section we examine economic drivers and benefits and relationship with environmental impacts. The economic benefits of BRI infrastructure are driven primarily by increased trade in goods, services and resources, facilitated by reduced transportation costs and other trade barriers. BRI is projected to increase total exports of 46 BRI countries by \$5 billion to \$135 billion and GDP by 0.3 to 1.4 percent [2]. However, reduced trade barriers can cause jurisdictions with lax environmental regulations to gain a comparative advantage, redistributing environmental impacts [115]. There are fears that as trade barriers are lowered, China's tightening environmental regulations may make many BRI countries more attractive as pollution havens, a process which BRI may accelerate [116]. Heavily-polluting Chinese cement plants relocating to Tajikistan has been cited as one example of this [117]. Additionally, a logging moratorium in China's Heilongjiang province caused spill-over effects for forests abroad [12]. The extent to which this may be a problem has been questioned by empirical evidence from the economic literature which suggests that only marginal firms relocate, while most remain and comply with stricter laws [118]. In addition, trade-related changes in industrial composition may facilitate production at lower relative emission intensities [119,120]. Suggesting an interplay of these factors, an econometric study found evidence for the pollution haven effect in BRI countries from non-Chinese investment but found that Chinese investment reduced emissions [121].

Trade also transforms techniques of production and consumption, changing income and thus pollution levels [122]. According to the environmental Kuznets curve, pollution increases initially as income grows, but above a turning point, pollution falls as higher incomes bring technological improvements and increasing demand for environmental amenities. Although the evidence and theory behind the environmental Kuznets curve is highly contentious [123–126], evidence suggests that environmental policies, clean technology and economic liberalisation can help to flatten the Kuznets curve [127,128].

Production techniques can improve through mechanisms such as technology transfer and trade-induced innovation. Although China is the world's largest CO_2 emitter [129], increases in research activity, technological advancement and the assimilation of foreign technology have played a role in abating Chinese CO_2 emissions [130]. Additionally, China is also the world's largest investor in renewables, and high levels of Chinese investment and production have reduced the costs of renewable energy infrastructure [131]. By 2020, all Chinese coal plants will be more efficient and less pollutive than every US coal plant [132]. BRI can facilitate overseas transfer of Chinese technology, with concomitant environmental benefits [133]. China has upgraded Tajikistani and Kyrgyzstani coal plants with newer technology [53,134], and signed deals to upgrade Bangladeshi coal mines, power grids and factories [135].

Economic growth may increase the industrial pollution base, known as scale effects [136]. Negative scale effects and positive technique effects on the environment are difficult to isolate empirically, and quantitative studies disagree on whether the scale or technique effect is larger [137,138]. Different pollutants also react differently to trade-related changes. For example, a Chinese study combining scale and technique effects suggested that trade increased SO_2 and dust fall but reduced chemical oxygen demand, arsenic and cadmium [139]. This underscores the need for interdisciplinary studies combining the macroeconomic perspective with the spatial and contextual nuance of environmental science.

6. Socio-Political Drivers and Environmental Policies

As outlined above, BRI may cause foreseeable environmental impacts at a range of scales and intensities. Actors associated with multiple social, administrative and political scales (from the local to the global) will play a key role in moderating these environmental impacts [140]. While not the focus of this paper, the social impacts of development considered through social impact assessments alongside environmental impact assessments can have long-term negative effects on local communities [141]. Social drivers identify factors that contribute to and mediate environmental impacts, such as community structures and institutions, people's preferences, behaviour and capacity to influence change [142]. Chinese companies' past record of alleged forced evictions and environmental degradation [143,144] suggest that without local accountability the BRI is likely to face local resistance. Concerns about environments, communities and livelihoods can galvanise civil society into action. In Kyrgyzstan, for example, locals burnt down a BRI-supported Chinese gold-processing plant after their fears of pollution were not sufficiently addressed [145]. Fears of local backlash and Chinese political pressure can motivate Chinese corporations to take corporate social responsibility (CSR) more seriously with recognition of community concerns. For example, China Road and Bridge Corporation (CRBC) opened its procurement process for the Mombasa–Nairobi standard gauge railway to local contractors instead of using only Chinese contractors, and consulted with wildlife experts to enable animals to cross the railway line safely [146]. However, social drivers of BRI environmental impacts are not limited only to China and host countries. US and EU consumers are responsible for 30% of the carbon emissions in BRI countries through embodied carbon flows [147].

The dominant role of the state in China means that its intents and actions are central to any socio-political discussions and policies, and directly affect social drivers [148]. Crucially, Chinese political will to think long-term on strategic issues recognises environmental problems as a threat. Since the 'ecological civilisation' concept was added to the constitution in 2012, it has featured prominently in Chinese discourse regarding the environment and formulation of environmental policies [149]. Widespread dissatisfaction about environmental degradation has led policy makers to strengthen environmental regulations [149,150]. China has also sought to improve environmental governance frameworks and to engage stakeholders in resolving environmental conflicts and disputes. For example, Quanzhou municipality set up an ecological compensation scheme for the Jin River catchment in Fujian province. Downstream areas compensated upstream villages and local governments for taking measures to conserve the catchment [151]. Encouragingly, local and state governments in China are working to coordinate environmental policies at larger scales to resolve inter-jurisdictional environmental issues [152]. There have been similar calls to develop ecological compensation frameworks for BRI [153]. China's newfound concern for the environment is notable but benefits in BRI host countries remain to be seen.

Although intended primarily for economic development, BRI mechanisms can provide a platform for China and partner countries to promote cross-boundary environmental conservation and environmental management [10]. This is urgently needed as BRI countries are already responsible for 95% of global net embodied carbon exports [147]. Partly in response to foreign pressure, China has outlined its policies to promote green development and environmental protection for BRI [154]. This builds on the idea of a Green BRI described previously in a document co-issued by government officials describing the promotion of green energy, sustainable agriculture, aquaculture and forestry [155].

Guidelines also exist for specific areas that are relevant to BRI, some of which were developed prior to BRI. Two documents on forestry provide guidance on environmental protection (e.g., avoiding soil erosion, minimising noise and air pollution), and biodiversity conservation (e.g., conserving habitats, protecting threatened species, enhancing sustainable forestry, etc.) for the Chinese enterprises to integrate with environmental legislation and operations in host countries [156,157]. Other Chinese and international documents provide more detailed country-specific recommendations [158]. These guidelines suggest China's attempts to promote sustainable trade and green economy at the international level [154]. These include calls for expanding cooperation with international agencies, governments and non-governmental organisations around the environmental impacts of BRI [159].

However, some scholars and commentators are concerned that these policies will fail to translate into practice. Potential problems include serious concerns about enforcing China's environmental regulations across multiple jurisdictions and scales as many environmental policies directed towards China's overseas investment are already non-binding [160]. Mechanisms rely upon host countries laws to evaluate Chinese companies' conduct yet enforcement is often weak [160]. Moreover, local regulations and standards may be lower than those found in China (see also [9,161]) or have different agendas [162]. Often, limited information sharing between China and host countries hampers transnational enforcement efforts [160]. For Tracy et al. [12] the disjuncture between Chinese policy and host countries' poor environmental records means the BRI is an environmental 'race to the bottom'.

Secondly, there are gaps in the application of China's environmental policy. Most guidelines for environmental protection in foreign investment and cooperation target China's large state-owned enterprises (SOEs). This overlooks the impact of private companies, particularly small and medium enterprises (SMEs) [163]. SOEs will lead BRI initiatives over SMEs [40] yet private sector organisations from China and elsewhere still play a key role [164,165]. It is these firms that are often responsible for serious environmental degradation because SMEs are not as strictly regulated [161]. There remain questions about how China's environmental policies compare to international standards. A coalition of organisations led by the Green Finance Initiative [166] argues that projects deemed to be 'green' by Chinese Catalogue standards may not be considered green by international guidelines.

In summary, while China has been developing environmental policies around the BRI, questions remain as to how effective they will be. China stresses the improved economic value and global infrastructure associated with the BRI, yet unequal power relationships between Chinese and host nations along the road can cause contestation between sides. Too often misunderstanding in local communities that shoulder the burden of debt, degradation, corruption and displacement accompany BRI projects [167–169]. The challenge for China is to construct an integrative rather than exploitative BRI—one that is inclusive of host nations, provides beneficial infrastructure and outcomes, protects the environment, and is done in such a way that China's intent and reputation remains intact.

7. Conclusions: Planning for the BRI

Planning and addressing environmental issues associated with the BRI is immensely complex and multi-scaled. This paper defined BRI and the dimensions of its impacts and drivers. We did this by proposing a typology of BRI infrastructure, describing the range of impacts on different components of the Earth system and the economic and socio-political drivers which influence BRI development and impacts. In addition, we provided a multi-scale, socio-economic-political and environmental framework for planning and addressing the impacts of BRI.

Understanding the characteristics of impacts of BRI infrastructure on the environment is the first step for devising policy and plans for addressing its impacts to ensure sustainable development. The scale of its impacts may appear overwhelming and, given this, there is a tendency to address BRI in a piecemeal fashion at the project scale or with broad brushstrokes by examining the initiative in its entirety. However, the cumulative impacts that occur both regionally and globally mean we cannot take such an approach, particularly if standardised and not context-specific. A multi-scale approach is required ensuring that BRI is considered at the project scale through an environmental impact assessment, at the regional scale through strategic environmental assessments, then at the ecoregion scale (e.g., Central Asia; South East Asia coral reef triangle) and finally at the global scale. Recent guidelines on the BRI (see References [154,159]) have emphasised the importance of multi-scaled approaches to implementing the BRI, but have provided little detail about what this means in practice. Policy makers in China and recipient countries should find the interdisciplinary multi-scale analysis presented in this paper useful in debates about how the ecological and social impacts of BRI might be understood and managed.

The implications of BRI go even further, by spurring on other major powers to develop their own global schemes. For example, India's alternative is an economic corridor to Russia through Iran and Central Asia [170], while Russia is integrating Central Asian economies with the Eurasian Economic Union [171]. Meanwhile, Japanese influence is still strong, with Japan outspending China on road and railway projects in six Southeast Asian countries [172]. It is important that BRI provides a role model for dealing with environmental impacts in order to raise the bar for future global infrastructure development programs and ensure that leading practice environmental standards form an integral part of any global infrastructure scheme.

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