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POLICY PERSPECTIVE

Growth-inducing infrastructure represents transformative yet ignored keystone environmental decisions

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Abstract
As the defining force of the Anthropocene, human enterprise is reshaping Earth's surface and climate. As part of that process, growth-inducing infrastructure, such as electrical transmission lines, export facilities, and roads, presents nonincremental changes in where and how natural resources are exploited. These projects open intact areas, induce or intensify industrial development, and accelerate carbon emissions. The direct impacts of large-scale infrastructure are widely acknowledged and policy and legislation exists to account for them in environmental decisions. Yet, decision makers often ignore the secondary, growth-induced effects, even though they can outweigh the impacts of the initial development. Given the extensive area and magnitude of such impacts, we argue that regulatory or funding approvals for growth-inducing infrastructure represent keystone decisions. Credible approval processes require the consideration of the full range of impacts resulting from the ensuing growth. This will necessitate a shift in assessment thinking, from the traditional focus on the immediate project footprint to one that recognizes the sustainability implications of approving infrastructure that will transform the trajectory of development at regional and national scales. We identify the characteristics of growth-inducing infrastructure and provide an overview of methods and policy that can facilitate a deliberate assessment of these keystone decisions.

KEYWORDS
climate change, conservation decision-making, cumulative impacts, environmental assessment, growth-inducing infrastructure, keystone decision, resource access

1 | INTRODUCTION

Many nations couple their aspirations for economic growth to large infrastructure that can access, transport, or commodify untapped resources (Ascensão et al., 2018; Laurance, Sloan, Weng, & Sayer, 2015). The direct, site-level impacts of large infrastructure such as highways, mines, and hydroelectric facilities are usually obvious (Laurance, & Arrea, 2017), and the primary focus of the environmental assessment process. In contrast, we rarely consider the indirect or secondary impacts of induced human activity or development during preproject planning, approval, and mitigation (Arlidge et al., 2018). This lack of accounting is of greatest consequence when considering projects designed to trigger or facilitate resource development (Laurance & Arrea, 2017; Figure 1). The review and approval of such "growth-inducing infrastructure" represents

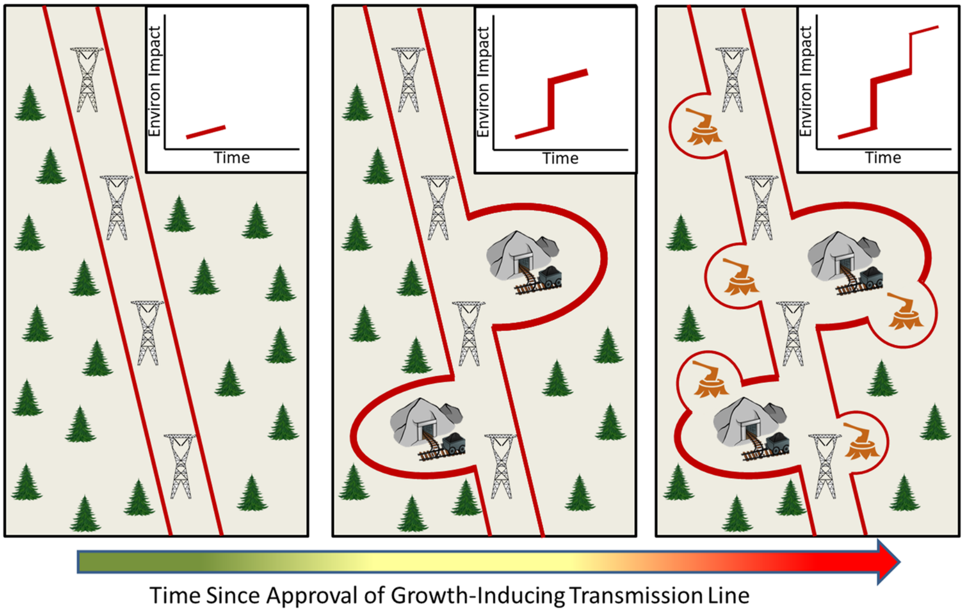


FIGURE 1 Cumulative environmental impacts resulting from the keystone decision to approve growth-inducing infrastructure. In this example, an electrical transmission line provides inexpensive energy, inducing the development of mining and the resulting mines provide new road access for forestry. Width of red line indicates development's zone of influence and the magnitude of impact

keystone decisions for regional or even national strategies to plan and manage land use, achieve sustainability goals, and meet international targets for biodiversity conservation and carbon emissions.

2 | IDENTIFYING KEYSTONE DECISIONS

We define a "keystone decision" as a project approval or land-use decision that results in nonincremental and transformative change to the receiving environment. These "first cut" decisions can accelerate the development of natural resources or initiate new human activities that are indirectly related to the project under consideration (Laurance, 2018). The secondary developments that follow keystone decisions have a much greater magnitude or extent than is represented by the initiating growth-inducing infrastructure on its own. The compounding projects and resulting cumulative impacts often are cross-sectoral, spanning different resource sectors and development types. Collectively, these projects are difficult to monitor and mitigate, especially across large regional areas (Gillingham, Halseth, Johnson, & Parkes, 2016). Thus, the approval of the growth-inducing infrastructure will set in motion a set of cascading, irreversible developments with the potential to fundamentally degrade ecological integrity and the corresponding ecosystem services. There has been some discussion of keystone decisions in the tropics, especially in the context of road construction, but these have been limited (Alamagir et al., 2017; Laurance, 2018). As we illustrate, the types of keystone decisions are diverse and international, being as likely in high- or low-governance countries (Timoney & Lee, 2001).

The measure of success of growth-inducing infrastructure is often the "growth" of spin-off developments, including secondary access through rail or roads, areas of settled or agricultural lands, or new mines or hydrocarbon extraction. Indeed, such infrastructure investments tend to be marketed to communities, governments, and investors as opportunities to exploit previously unexploitable resources or develop the economy across inaccessible regions. Although the economic benefits of the secondary development serve as grounds for approving growth-inducing infrastructure, the future environmental and social costs of the resulting indirect activities often are marginalized by project proponents and rarely considered by decision makers (Alamagir et al., 2017).

3 | TYPOLOGY OF GROWTH-INDUCING INFRASTRUCTURE

The full temporal and spatial scope of growth-inducing projects is underrepresented during environmental assessment processes. In many cases, the much hoped for spin-off developments are considered too uncertain to be counted as a component of the environmental or social impacts resulting from the reviewed project even if those future developments are the impetus for the proposed infrastructure. This is despite the formal recognition by many national and state-level regulatory agencies of past, present, and future cumulative effects when making assessment decisions. Although not common, some legislation even demands an accounting of the impacts associated with growth-inducing infrastructure. For example, the USA National Environmental Policy Act identifies indirect project effects that "may include growth-inducing effects and other effects related to induced changes in the pattern of land-use, population density, or growth rate, and related effects on air, water, and other natural systems, including ecosystems" (Council on Environmental Quality, 2005). Yet, for both cumulative and growth-inducing effects, the resulting future developments must be qualified as "reasonably foreseeable." This assessment loophole allows proponents or regulators to underrepresent the future environmental and social costs of growth-inducing infrastructure. Given the consequences of such keystone decisions, there is a clear need to formally identify and acknowledge the compounding impacts of growth-inducing infrastructure within decision-making processes designed to account for future developments (Whitehead, Kujala, & Wintle, 2017).

Infrastructure can facilitate or induce resource development and growth through three mechanisms: (a) increase access to resources, (b) reduce production constraints, and (c) facilitate market development. Formal recognition of these mechanisms is the first step in the identification and full assessment of the direct and indirect impacts of growth-inducing projects.

3.1 | Access

Growth-inducing infrastructure can provide access to intact, roadless areas, and untapped resources (Table 1). These projects often are designed with the specific intention of opening up new watersheds for exploitation. Alternatively, a road or rail corridor may be intended to connect population centers or geographic regions, while in the process bisecting and providing primary access to an intact area.

The Trans-Amazonian Highway is a striking example of access-related growth-inducing infrastructure. Opened in 1972, the ~4,000 km highway linked much of the northern part of Brazil to the Atlantic coast and was intended to provide access to Colombia, Ecuador, and Peru. The direct impacts of the construction, traffic, and footprint of the highway were significant, but predictable (Freitas, Gonçalves, Kindel, & Teixeira, 2017; Table 1). More importantly, the highway provided access to the Amazon basin for forestry, agriculture, and settlement. During the 1990s and early 2000s, the highway spurred innumerable secondary roads and resulted in an estimated 25,000 km^2 of deforestation per year (Fraser, 2014). The unofficial, secondary road network continues to be a major cause of deforestation, with 95% of all forest clearing occurring within 5.5 km of a road (Barber, Chochrane, Souza, & Laurence, 2014).

Such road-induced impacts are ubiquitous at a global scale (Torres, Jaeger, & Alonso, 2015). As demonstrated for the Congo Basin, reductions in biodiversity and ecosystem services, including carbon storage, follow closely behind resource and general road development (Kleinschroth, Laporte, Laurence, Goetz, & Ghazoul, 2019). In that case, old roads had a legacy effect, resulting in a greater rate of annual deforestation within 1 km of that road type, when compared to new or abandoned roads.

3.2 | Production constraints

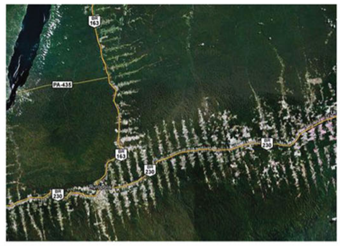
Growth-inducing infrastructure can stimulate industrial development by addressing a constraint in the capacity to extract natural resources. For these projects, the downstream industrial growth is intentional and predictable. For instance, the 340 km high-voltage Northwest Transmission Line was completed in 2014, spanning an area of mostly undeveloped montane forest in northwestern Canada. Proponents argued that inexpensive electricity was necessary to support the development of rich mineral reserves, and that the proposed infrastructure would result in investments that exceeded $2 billion, far outweighing the $570 million required to construct the line (British Columbia Transmission Corporation, 2007). This was a keystone decision, where the environmental impacts of future mines, hydroelectric facilities, and roads dwarfed those associated with the immediate area of the transmission line.

Oil and gas pipelines are associated with a range of environmental and social impacts. This infrastructure becomes growth inducing when oil and gas reserves are isolated from refining facilities or markets and the pipeline increases levels of production or makes such reserves economically viable. In the oil sands region of western Canada, for example, the sale of bitumen-derived heavy oil is dependent on access to refineries on the Gulf Coast of the United States or tidewater shipping to Asia. Being the third largest source of oil in the world, with proven reserves of 165.4 billion barrels, the climate and resulting environmental implications of facilitating the shipment of this product are immense. Typically, these considerations are not part of the regulatory process that governs the approval and development of new pipelines. Pipelines are assessed relative to the immediate impacts to waters and lands associated with clearing a right-of-way and potential oil spills, not the indirect carbon emissions generated during the consumption of the processed petroleum products.

3.3 | Market development

Infrastructure can provide postextraction processing that adds value or creates markets for products and natural resources. Increased market access or competiveness can spur further land use or resource extraction with corresponding

TABLE 1 Typology of growth-inducing infrastructure and associated direct and indirect impacts

Mechanism	Infrastructure	Direct impacts	Growth-induced impacts
Facilitate access to land and natural resources	Road and rail corridors	Highway construction and use: forest loss on right-of-way, barrier for wildlife, habitat fragmentation, pollution, altered microclimate and hydrology, invasive species, vehicle collisions	Facilitate range of new developments (e.g., roads, agriculture, forestry) with proliferation of direct impacts (e.g., habitat loss, fragmentation)
			
Support or lower cost of resource extraction	Electric power; pipeline	Electrical transmission line: forest loss on right-of-way, barrier for wildlife, habitat fragmentation, alter forest microclimate, invasive species	Facilitate cost-effective development (e.g., mines) and associated infrastructure (e.g., roads) with proliferation of direct impacts (e.g., habitat loss, fragmentation).
			
Increase market access through value added processing	Liquefied Natural Gas facility	LNG terminal: loss of nearshore and coastal habitat, impacts of shipping on marine life, emissions from compression facility	Exploration, drilling and extraction of gas (e.g., habitat fragmentation, water use and pollution); pipelines to transport gas to LNG facility (e.g., habitat fragmentation, barrier, invasive species)
			

environmental and social impacts. This is important even in places where the capacity to extract, process, and ship natural resources already exists. Typically, the site of the market-developing infrastructure will receive much regulatory attention and postconstruction monitoring and mitigation. However, it is the upstream supply of resources—often over very large areas or at a considerable distance from the growth-inducing project—that is the greatest source of impacts.

Currently, there are 28 Liquefied Natural Gas (LNG) plants under development in the United States, Australia, Russia, Indonesia, Malaysia, and Cameroon, each with a construction cost of roughly $30–50 billion (International Gas Union, 2017). Although these plants typically only occupy a few square kilometers of land, combined they will process 111 million tons per annum of LNG, significantly increasing global carbon emissions. Based on average yields from natural gas fields, ~2,900,000 hectares of land will be converted to well pads, roads, pipelines, and other infrastructure to supply these facilities with the methane necessary to generate LNG (McDonald, Fargione, Kiesecker, Miller, & Powell, 2009).

4 | ACCOUNTING FOR KEYSTONE DECISIONS

Although growth-inducing infrastructure is globally common and the secondary, induced impacts are significant (Table 1), the assessment of the full range of future impacts of such projects is rare. This is despite the inclusion of cumulative effects and, in rare cases, the formal recognition of growth-inducing projects in some national and state-level environmental assessment legislation (Mandelker, 2010). Unfortunately, assessment processes tend to be constrained by a limited geographic and temporal scope that restricts the consideration of impacts to those that are "reasonably foreseeable" (Duinker, Burbidge, Boardley, & Greig, 2013) relative to future growth. This constrains environmental assessment, as it is possible to argue that most growth-inducing impacts are not reasonably foreseeable, even when the rationale for such projects is future economic growth. In the case of the Northwest Transmission Line, the anticipated economic benefits were clearly stated by the government regulator, yet only the footprint of the right-of-way and a handful of existing projects or projects under review were considered during the environmental assessment process (Table 1).

The full assessment of growth-inducing projects should not be constrained by a lack of data, technical capacity, or regulatory tools. Analytical methods are available for forecasting rates of industrial growth and corresponding impacts. Regulatory and policy frameworks in many jurisdictions already contemplate cumulative effects, albeit in a limited fashion. However, meaningful analyses and corresponding decision-making will require a shift in mindset, moving away from approaches that simply consider the individual project footprint to ones that evaluate the sustainability, management, or conservation of broader regional areas over decadal time periods. In one sign of movement in that policy direction, the Canadian government recently required that the environmental assessment of a 4,500 km heavy-oil pipeline consider both the upstream and downstream CO^2 emissions of the project (National Energy Board, 2017). Unfortunately, Canada's new Impact Assessment Act (2019) does not require the identification of growth-inducing infrastructure. This is a missed opportunity for formalizing the assessment of indirect development effects.

More broadly, growth-inducing development projects must be recognized as having the potential to initiate rapid, extensive, and potentially irreversible development trajectories. Globally, there are numerous examples of where these longer-term impacts are purposefully ignored. In the Ring of Fire region of northern Canada, for example, regulators are evaluating road and electrical access in piecemeal segments with no consideration of the downstream effects of completing the network never mind the resulting mines that are the reason for the infrastructure. Similarly, the Carmichael coal mine in northeastern Australia will result in a $16.5 billion (Australian dollars) investment, which includes a 189-km rail link and port facility that will facilitate the development of other coal resources (Queensland Government, 2019). Those mining projects threaten the habitat of at-risk species and will result in downstream coal emissions that greatly dwarf those associated with the production activities of the reviewed mine.

Once identified (Table 1), growth-inducing projects should trigger regional review and approval processes, such as Strategic Environmental and Social Assessments (Ascensão et al., 2018; Whitehead et al., 2017). These decision-making processes are especially important for areas that are globally significant when considering high levels of endemism, ecological intactness, and broad-scale ecosystem services, including carbon storehouses. Large areas of Canada, Brazil, and Australia meet those criteria (Watson et al., 2018).

Some have argued for a more fundamental change in how we consider and assess development projects, including growth-inducing infrastructure. Sustainability assessment will address many of the technical and philosophical limitations of traditional environmental assessment. Although there are few empirical examples of true sustainability assessment, the process is more holistic, considering the short- and long-term, direct and indirect economic, and social and environmental impacts of human development (Gibson, 2017). Clearly, keystone decisions would be recognized and carefully evaluated during such processes, as the resulting decisions will set the development and sustainability trajectory for a region or in the case of national climate policy, a country.

When reviewing growth-inducing projects, we should expect negative impacts for human and ecological communities. Rapid economic development can have long- and short-term health effects, and stress or break the critical infrastructure that supports human populations (Hansen, Vanclay, Croal, & Skjervedal, 2016; Werner, Vink, Watt, & Jagals, 2015). This includes not only the physical systems that transport people, energy, and their waste, but also the social systems that support communities. For example, rapid influx of temporary workers or even growth of the resident population can exceed the capacity of schools and the health care system (Kinnear, Kabir, Mann, & Bricknell, 2013).

Although governments and project proponents highlight the positives of economic growth, there are considerable risks when investing hard-earned public and private capital in growth-inducing infrastructure (Laurance, 2018). Roads, for example, may lead to nowhere when the secondary development projects suffer from the vagaries of international export markets. Given expected reductions in the demand for hydrocarbons, there is a strong possibility of stranding oil and gas infrastructure, such as pipelines and LNG export facilities.

Rapid growth associated with infrastructure construction can stimulate local economies, but often over a short period of time and largely to the benefit of outside workers and businesses. Furthermore, communities dependent on newly developed resources can suffer through boom and bust cycles that are the result of fluctuations in the global demand for the resulting commodities (Barth, 2013). As stressed by Gillingham et al. (2016), we must consider and integrate the health of environments, local economies, and societies when addressing the cumulative impacts that follow the development of growth-inducing infrastructure. This includes the socioeconomic resilience and self-determination of Indigenous peoples (Parlee, Geertsma, & Willier, 2012).

The magnitude and the forms of growth-induced impacts will never be certain, as much depends on the future rate and types of secondary development. Yet uncertainty is no reason to avoid or ignore the impacts of future land use and community change when making the initial development decision. Scenario-based approaches conducted at regional scales allow for a bounding of growth forecasts and consideration of a range of environmental and social impacts. Indeed, such methods have been in wide use for decades (Schneider, Stelfox, Boutin, & Wasel, 2003). Unfortunately, the results are often of academic interest only, rarely being used to inform strategic or even project-based decision-making (Duinker et al., 2013).

More fundamentally, decision makers and the public must realize that the review of a growth-inducing project represents a keystone decision. The approval of even one road of modest length into a resource-rich but ecologically intact watershed can have profound impacts for a range of environmental, cultural, and social values found across that area. A credible assessment process requires a shift in orientation from the immediate project footprint that will occur in the present to one that confronts the induced growth that will inevitably take place in the future. Increasingly, that growth will compromise conservation objectives or climate targets. And as history has taught us, it is very difficult to reverse those approval decisions once "growth" begins (Timoney & Lee, 2001). The time to act on growth-inducing infrastructure is now not later.

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