

# INSIGHTS

## PERSPECTIVES

### BRIDGE – CONSERVATION AND DEVELOPMENT

## Roads to riches or ruin?

Global infrastructure expansion must balance social benefits and environmental hazards

By William F. Laurance<sup>1</sup> and Irene Burgués Arrea<sup>2</sup>

We are living in the most explosive era of infrastructure expansion in human history (1, 2). In the next 3 years, paved roads are projected to double in length in Asia's developing nations (3); in the next three decades, the total length of additional paved roads could approach 25 million kilometers worldwide—enough to encircle the planet more than 600 times (1). Nine-tenths of all new infrastructure is being built in developing nations (1), mainly in tropical and subtropical regions that contain Earth's most diverse ecosystems. In a world that is projected to have 2 billion vehicles by 2030 (4), we need a better understanding of the impacts of roads and other infrastructure on our planet, societies, and economies (1–3, 5)—and more effective planning to en-

sure that the benefits of infrastructure outstrip its costs.

### ROADS FOR BETTER OR WORSE

Government planners have often seen road expansion as a cost-effective means to accelerate economic growth and social integration. However, the magnitude and nature of such benefits vary widely and depend on local context. New or improved roads are particularly beneficial when they link rural farming populations efficiently to urban markets, allowing farmers to gain high crop prices and improved agricultural technologies while meeting growing urban food demand (1). In other settings, however, the benefits of new roads, and their potential risks, are far less certain. For example, road building in floodplains or steep terrain can indirectly cost governments and investors billions of dollars in lost revenue because of cascading impacts on downstream fisheries,

agriculture, recreation, aesthetics, and the costs of ecological restoration. Through its impacts on water quality and fish-breeding sites, planned road expansion in the Lower Mekong Basin could negatively affect fisheries worth an estimated U.S.\$2 billion per year; similarly, deforestation from forest road-building in Aceh province, Indonesia, is costing about U.S.\$15 million per year in flood-prevention measures (6).

Waves of new roads cutting into intact or critical habitats can unleash a Pandora's box of environmental ills, such as land encroachment, wildlife poaching, forest fragmentation, exotic-species invasions, and illegal mining (1, 2). Even carefully managed projects can provoke societal hazards such as land speculation, corruption, cost overruns, and political conflict (5, 6). In worst-case scenarios, projects can collapse, stranding large financial investments and natural assets. Unpaved tropical roads can quickly become unusable because of deep rutting from vehicle use in the wet season (3, 6). For such reasons, road-expansion schemes have inconsistent, and sometimes

<sup>1</sup>Centre for Tropical Environmental and Sustainability Science, and College of Science and Engineering, James Cook University, Cairns, Queensland, Australia. <sup>2</sup>Alliance of Leading Environmental Researchers and Thinkers (ALERT), 663-2300 Curridabat, San José, Costa Rica. Email: bill.laurance@jcu.edu.au



Access roads enable rapid ecosystem destruction in tropical regions, including the lowland rainforest in Sarawak, Borneo, Malaysia.

The unprecedented pace of infrastructure expansion is generating intense global interest. A meeting of more than 160 leading financiers, decision-makers, ecologists, and social-development specialists in Hanoi, Vietnam, in May 2017 (3) showcased state-of-the-art thinking about strategies to limit the environmental impacts of roads, but also revealed their limitations. Some experts asked participants to map out a new road between two rural towns while minimizing both construction costs and environmental damage—a surprisingly challenging exercise in real-world planning. Strategies such as clever landscaping or vegetation planting to help vulnerable wildlife species, such as forest elephants, traverse a highway are expensive and may do little to increase animal movements. Furthermore, they do not address the major impacts of infrastructure expansion on carbon emissions, water quality, and other environmental services.

The Hanoi forum also revealed deep rifts among those who are planning, funding, and evaluating infrastructure. The gulf between many ongoing road schemes and economic reality is striking. For example, trillions of dollars are being invested in road construction in high-rainfall tropical environments. Here, rapid slumping, pot-holing, and flooding can render expensive paved roads virtually impassable in just a few years, precluding access to the forest lands, minerals, or timber for which they were initially constructed (6). Typically, too much funding is being earmarked for the initial construction of ambitious new road networks and too little for their ongoing maintenance (6). Few roads are adequately engineered for challenging local conditions, and many suffer from shoddy construction, because road contractors cut corners on materials such as road bases and cement while siphoning off construction funds (10). World Bank studies suggest that typically 15 to 30% (and in some cases, up to 60%) of road funding in developing nations is lost to cartels and corruption (6).

An urgent concern is that new roads and the dramatic land-use changes they catalyze are penetrating rapidly into many of the world's last wild places. From 1993 to 2009, the extent of global wilderness declined by about 10% (11); 70% of the world's forests now occur within 1 km of a forest edge (12), reflecting a widespread decline of intact core habitats. Too often, the specific routes and siting of infrastructure projects are determined by factors such as political patronage, corruption, or a desire to consolidate

national claims to remote frontier territories (6). Cost-benefit analyses frequently ignore or underestimate key challenges—such as the effects of inflation, the expense of servicing project debt, and long-term environmental and social costs—on the financial viability of infrastructure projects. This creates strong biases in favor of project approval, even for marginal or high-risk ventures (5, 13).

### NEW MONEY, NEW DANGERS

Such challenges are exacerbated by profound changes in the world of major multilateral banks (14). New institutions such as the Asian Infrastructure Investment Bank (AIIB) and Chinese Import-Export Bank are heavily funded, and their strategic approaches focus partly on cutting through lengthy environmental and social checklists to push big infrastructure projects ahead quickly. This contrasts with the approaches of multilateral lenders such as the World Bank, which after years of criticism have gradually improved their safeguards and project-management procedures. Yet last year, the World Bank announced that it was streamlining its own environmental and social rules, in a move that was partly provoked by its desire to remain competitive with the lithe new lenders (14). Will decades of important safeguards survive or be left partially in tatters, replaced by meaningless greenwashing?

In addition to multilateral banks, private capital—from mutual funds, insurance groups, and other large institutional investors—is a growing driver of global infrastructure expansion (15). It is far from certain whether private financiers will support projects that strive to balance environmental and social criteria with profitability. Most investors remain strongly profit-oriented, although there is growing interest in creating projects that can compete financially with traditional infrastructure schemes by proactively reducing their long-term environmental and social risks (15). Other innovators, meanwhile, are trying to devise novel mechanisms to attract private funds for more-sustainable projects, such as by emphasizing the many advantages of protecting natural capital (16).

### PROACTIVE PLANNING

Traditional environmental impact assessments (EIAs, see the table) are widely seen as too myopic and transient to rein in the negative consequences of new infrastructure projects. But that is about where the harmony ends. Some planners believe that broader assessments such as strategic EIAs (SEAs) and social cost-benefit analyses—which embrace geographically wider perspectives while considering both the indirect and direct impacts of projects (17)—can forge a better balance.

clashing, impacts on human needs, as illustrated by their widely varying effects on the UN Sustainable Development Goals (2).

Strategies for driving economic growth via road expansion can thus be plagued by a range of financial, social, and environmental hazards (7). The World Bank has characterized large infrastructure projects such as major roads as a blunt instrument for aiding the poor (8). Yet, few governments consider the diversity and depth of challenges wrought by large road and infrastructure projects.

### DRAMATIC CHANGE AMID URGENT CONCERN

Earlier this year, an international forum in Beijing officially launched China's long-planned One Belt, One Road and 21st Century Silk Road initiatives. These enormous networks of road, rail, port, energy, and water projects will stretch from China across Europe, Africa, and the Asia-Pacific region. Collectively, the projects will link China to 70 nations and around two-thirds of the world's energy resources. Beyond this, Chinese investments for big infrastructure and extractive industries are surging dramatically in Latin America (9). Even putting geopolitics aside, there is plenty to be anxious about from environmental, economic, and social perspectives.

Others, such as ourselves, look favorably on these broader approaches but see them as inadequate unless urgently married to proactive land-use and infrastructure planning (1). The latter approach—as embodied in the global road-mapping scheme (1)—seeks to zone regions or nations to maximize the socioeconomic benefits and minimize the environmental costs of all new developments. We and other researchers are currently using it to compare the relative desirability of massive development corridors in sub-Saharan Africa (18), and of roads and other infrastructure projects across Indochina (19) and the Asia-Pacific region.

A critical reason for pushing proactive planning is that many infrastructure projects instigate large-scale land-use change. In the Brazilian Amazon, roads are over-

ture projects as inevitable—a kind of cure-all for sluggish economic growth, food security issues, and other human development challenges. The only realistic solution, they opine, is to use local tactics such as biodiversity corridors or wildlife overpasses to help preserve nature and its benefits, while accepting that a nearly ubiquitous human footprint is unavoidable (3). The second group, among which we count ourselves, says this is dangerously simplistic, not least because the imperiled species and natural services that we most urgently need to maintain can be easily destroyed or severely damaged by human activities.

The recognition that many important financial, environmental, and social costs are not adequately captured in cost-benefit analyses for infrastructure projects may

term, they will only persist if we can keep them at least partially separate. The most effective way to achieve this is by proactively zoning Earth's land regions and subregions such that development is concentrated in agriculturally suitable areas, especially where most native vegetation has already been cleared. Such areas are prime locales for new or improved roads, which increase transport efficiency and access to growing urban markets for farmers, while attracting investments (such as for improved farming technologies and medical and educational services) that enhance rural livelihoods (1, 19). The vital mirror side of this type of proactive infrastructure zoning (1) is to maximize road-free areas where habitats are intact and well-connected and where maintaining high environmental values is paramount. With such proactive planning, it is clearly possible to devise cost-effective scenarios that vigorously benefit humanity while lessening impacts on our natural environment. ■

## Assessing infrastructure

Some advantages and disadvantages of environmental impact assessments (EIAs), strategic environmental assessments (SEAs), and strategic land-use planning [as typified by the “global road-mapping” strategy (1): [www.global-roadmap.org](http://www.global-roadmap.org)]. For further details see the supplementary table.

NAME	ADVANTAGES	DISADVANTAGES
EIAs	Generally fast (less than a year) and relatively inexpensive Well-known and established protocols Mandatory for major projects in most nations	Typically narrow geographic focus and short-term impact time frame Often based on grossly inadequate data Rarely implemented and monitored rigorously
SEAs	Broader spatial and temporal focus than EIAs More emphasis on indirect or longer-term impacts May account for other existing or planned developments	Much more expensive and time consuming than EIAs Costs are borne by governments, not project proponents Not legally required in most nations
Strategic land-use planning	Complementary to EIAs and SEAs Analyses can often be based on publicly available data sets Considers cumulative impacts of multiple development projects on rural livelihoods and habitat integrity	Requires access to moderate to high-resolution data for relevant environmental and infrastructure variables Requires some expertise in modeling spatial data Not widely applied or required by legislation in most nations

whelmingly the strongest correlate of forest loss, with 95% of all deforestation occurring within 5.5 km of a legal or illegal road (20). In the Amazon, as elsewhere, deforestation first spreads along an initial road and then proliferates to an expanding spider web of illegal secondary and tertiary roads. The only real solution is to avoid the first cut: to not build new roads in intact forests in the first place. If one must build forest roads, such as for a logging or mining operation, then close the roads as quickly as possible when the project is completed (1).

This hard-won perspective can create a sharp divide between those promoting new roads and those attempting to limit their impacts. The first group sees many infrastruc-

ture projects as inevitable—a kind of cure-all for sluggish economic growth, food security issues, and other human development challenges. The only realistic solution, they opine, is to use local tactics such as biodiversity corridors or wildlife overpasses to help preserve nature and its benefits, while accepting that a nearly ubiquitous human footprint is unavoidable (3). The second group, among which we count ourselves, says this is dangerously simplistic, not least because the imperiled species and natural services that we most urgently need to maintain can be easily destroyed or severely damaged by human activities.

help to overcome these divisions. If nations build fewer new roads overall, but concentrate them in strategic locations, then they can provide better socioeconomic advantages and considerably less environmental damage. Factoring in the high maintenance costs for road networks in high-rainfall tropical environments in infrastructure decisions will also promote a more pragmatic attitude to road building: one that recognizes that it is better to build fewer roads overall and to ensure that those that are built provide strong returns on investments with fewer social, financial, and environmental risks.

Nature's vulnerable elements and modern humanity do not mix easily. In the longer

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## SUPPLEMENTARY MATERIALS

[www.sciencemag.org/content/358/6362/442/suppl/DC1](http://www.sciencemag.org/content/358/6362/442/suppl/DC1)

10.1126/science.aao0312