

Examples of coupled human and environmental systems from the extractive industry and hydropower sector interfaces

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Large-scale corporate projects, particularly those in extractive industries or hydropower development, have a history from early in the twentieth century of creating negative environmental, social, and health impacts on communities proximal to their operations. In many instances, especially for hydropower projects, the forced resettlement of entire communities was a feature in which local cultures and core human rights were severely impacted. These projects triggered an activist opposition that progressively expanded and became influential at both the host community level and with multilateral financial institutions. In parallel to, and spurred by, this activism, a shift occurred in 1969 with the passage of the National Environmental Policy Act in the United States, which required Environmental Impact Assessment (EIA) for certain types of industrial and infrastructure projects. Over the last four decades, there has been a global movement to develop a formal legal/regulatory EIA process for large industrial and infrastructure projects. In addition, social, health, and human rights impact assessments, with associated mitigation plans, were sequentially initiated and have increasingly influenced project design and relations among companies, host governments, and locally impacted communities. Often, beneficial community-level social, economic, and health programs have voluntarily been put in place by companies. These flagship programs can serve as benchmarks for community–corporate–government partnerships in the future. Here, we present examples of such positive phenomena and also focus attention on a myriad of challenges that still lie ahead.

impact assessment | community health | corporate social responsibility

In the ideal world of Adam Smith, companies do well by society just by making profits. But the eighteenth century and the Enlightenment are behind us, and the world in which we live is a world of external costs and of disputes about what is a fair distribution of the benefits from economic activity. In this world, the invisible hand needs some help to reach an efficient outcome. Here, corporate interests are not automatically aligned with the social interest. Society gains from realigning corporate interests with social interests, and corporations also gain from this realignment as it reduces conflicts between them and society. Conflicts between social and corporate interests in general hurt both parties. So if corporations behave as if they have obligations on the social and environmental fronts as well as in the area of profits, then both sides can gain. Ultimately, this is a matter of self-interest.

Geoffrey Heal, *When Principles Pay*, p. 18

In the first half of the 20th century, a variety of industrial accidents (1–3) and forced resettlement of entire communities as part of corporate and government-sponsored economic projects (4, 5) were associated with major negative consequences for more disadvantaged segments of societies around the world. Destructive ecosystem transformation, social disruption at the community level, and human health consequences—including deaths—were linked to such projects.

What these and many other projects lacked was a planning process in which the maximization of profit subject to the constraint of minimal harm to the surrounding ecosystem was operational. Here, the term “ecosystem” includes physical, biological, and social surroundings. For the early twentieth century projects, there was essentially no analysis of where externalized costs were going and who was bearing them. Modern notions of a priori impact assessment and alignment of corporate and societal interests (6) were not factored into project development and essentially did not exist. It is important to note, at the outset, that the constrained optimization problem of maximizing profit subject to minimizing negative impact to the surrounding ecosystem carries cost considerations with it. Indeed, if taken seriously, this problem can lead to cancellation of what might otherwise have been a highly profitable venture. A well-known example from the pre-1969 era is the proposed Hells Canyon high dam (7).

Over the past 60 y, there has been a groundswell of activist groups strongly supporting regulation of the process of corporate development, particularly in the extractive industries (oil and gas and mining). In the United States, the National Environmental Policy Act (NEPA) of 1969 and the establishment of the Environmental Protection Agency (8) in 1970 were early manifestations of such societal pressure, which rapidly spread outside of the United States. The NEPA requirement of environmental impact assessment (EIA) for projects a priori thought to have potential negative impacts represents a first step in the process of constraining ecosystem destruction and of forcing consideration of the rights of individuals and communities to maintain living standards that existed before a project.

In Brazil, for example, the government has also had environmental regulation and requirements of environmental impact assessment for large infrastructure (e.g., dams) and extractive industry projects in place since the 1981 Environment National Policy (9). However, the positive intentions of such requirements have frequently not proven to be effective in practice, as carefully

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documented in a collection of papers by Fearnside (10–16). More recently, there has been a politically driven effort to roll back extant requirements regarding impact assessments before authorization of projects in Brazil (17).

With the intent of alleviating some of the project-driven societal–corporate conflict, Citigroup organized a consortium of 10 private sector international development banks to sign onto the Equator Principles (18) in 2003, as part of which environmental, social, and health impact assessments (ESHAs) and associated environmental, social, and health (ESH) risk management/mitigation plans (ESHMPs) would be a requirement for corporate loans to finance large development projects where there was a priori perceived risk of negative environmental and/or social and/or health impacts. The environmental and social expectations and requirements of the Equator Principles are based on the International Finance Corporation's (IFC's) Performance Standards (19). Currently, over 80 financial institutions around the world have voluntarily agreed to abide by the Equator Principles (20).

Over the past 20 y, there has been a progressive attempt to integrate social impact assessment (SIA), health impact assessment (HIA), and human rights impact assessment (HRIA) with the ESHA process for corporate projects, with accompanying risk management/mitigation strategies. Beyond individual projects per se, the oil and gas industry, through its coordinating trade organization, the International Petroleum Industry Environmental Conservation Association (IPIECA), has put forth both general and detailed discipline-specific impact assessment guidelines that are targeted to upstream and downstream projects industry-wide (21). Analogously, the International Council of Mining and Metals (ICMM) (22) was launched in 2001 by a consortium of the major international mining companies at that time with a focus on fostering sustainable development in concert with their sector's projects. ICMM has also created a similar set of impact assessment technical guidelines. These initiatives reflect a growing awareness and commitment by extractive industry corporations to positive engagement and outcomes with communities where they operate. There is no shortage of international practice guidelines, policies, procedures, and requirements that have been promulgated. However, the actual impact of the “impact assessment industry” is more complex.

Currently, a vexing aspect of impact assessments and their role in decision making regarding the implementation of projects is the reality that companies themselves are largely responsible for carrying out the assessments and putting forth ESH risk management/mitigation plans. This perceived imbalance between societal and corporate roles in the specification of conditions for projects to move forward, or not, is a potential source of tension and conflict between project proponents, host governments, international multilateral development/poverty alleviation institutions, potentially impacted communities, and other stakeholders, including local and international nongovernmental organizations (NGOs). Our emphasis herein is on projects in low and middle income countries (LMICs).

A new and potentially powerful entrant into the impact assessment arena is the Roman Catholic Church. A balanced statement of principles under which EIA could take place appears in sections 183–188 of the encyclical letter (23) *Laudato Si*, issued by Pope Francis on June 18, 2015 (see *SI Appendix* for the full statement). In many low and middle income country (LMIC) settings, the Roman Catholic Church has enormous salience, particularly regarding the provision and delivery of social and health services. The holistic perspective presented in the encyclical letter may create a place from which one can begin to rethink the details of the implementation of impact assessments and under whose auspices they should be carried out. Moving ahead in this particular direction is a challenge of considerable magnitude.

Impact assessments to date have mostly been forecasting exercises carried out before or during the construction phase of a project. Mitigation plans have been based on these forecasts. However, this perspective is a limited one relative to thinking about current impact assessments as simply the first stage in an ongoing longitudinal data collection process that is also operative during the operation phase of a project. The World Bank Group has

recognized the problem of the lack of longitudinal monitoring in a retrospective survey of environmental impact assessments (24). The World Bank Group's review clearly noted the lack of consistent longitudinal monitoring programs once a project transitioned from construction to operation. Nevertheless, within the EIA community, there is a move toward an “eco-systems” approach (25). However, this effort is relatively nascent although spreading via the 2012 revision of the IFC Performance Standards. For example, the 2016 oil/gas industry trade association HIA guidelines did include a technical appendix on how to integrate ecosystems strategies within an HIA. A more holistic and integrated impact assessment methodology will likely develop and hopefully evolve in a manner consistent with the high-level perspective embodied in the Papal encyclical letter.

The sense of corporate social responsibility accompanying the impact assessment and ESH risk management/mitigation plan process to date has led to company-driven installation and support for many environmental, health, education, and socioeconomic programs in local communities impacted by projects.

The purposes of this paper are to (i) present several case examples of extractive industry projects in LMICs, summarizing particularly disease control and community health initiatives that were voluntarily initiated by the involved corporations; (ii) describe monitoring and surveillance systems, including a longitudinal program that is a partnership between a corporation and a national government-affiliated research institute that can benefit both the company and larger society, potentially for many years into the future; and (iii) describe some extant organizational structures that are responsible for impact assessments and mitigation plans with emphasis on strategies for improving transparency of key documents and both corporate and societal accountability for agreements.

Extractive Industry and Hydropower Sector Projects: Examples of Impact Assessments and Company-Driven Installation of Positive Community Initiatives

Chad Export Project. Oil exploration was launched in Chad more than 40 y ago, and significant oil reserves were discovered in the Doba basin in southern Chad in 1975 (26). The high costs associated with oilfield developments and transportation, paired with political instability, hindered its early extraction. A consortium of private sponsors consisting of ExxonMobil (operator; 40% private equity), Chevron (25%), and Petronas of Malaysia (35%) committed direct investments of more than approximately \$3 billion and obtained \$600 million from export credit agencies and commercial banks. The World Bank Group granted total loans of \$193 million. In 1988, a convention agreement between the government of Chad and the consortium was signed that put in effect the legal foundation for the project. An exploration permit was granted with validity until 2004, together with a 30-y concession for oil field development and crude oil transportation to international markets (27). Planning for the project began in 1993, construction commenced in October 2000, limited oil production was realized in July 2003, and full production started in July 2004. With expansion to nearby “satellite” oilfields, the project currently produces ~117,000 barrels of oil per day. A detailed picture of the expansion process post-2004 can be seen in the annual Chad Export Project updates (28).

The environmental assessment (EA) for the project, which also incorporated social and health topics, was initiated by the consortium in 1993. During the assessment synthesis period (1993–1997), the World Bank Group appointed an independent panel of experts (IAG) to advise the project proponents regarding noteworthy ESH issues/challenges. Complementary to this group, an external compliance monitoring group (ECMG) reporting directly to the lender group was also put in place, which was an innovative aspect of the project and represented an important feature of a more elaborate environmental management and monitoring process discussed in detail in Moynihan et al. (29). As noted by the World Bank Group (30), “Broad consultations with the public on the draft EA led to significant changes in project design. In particular, the pipeline route was modified to avoid crossing the Mbéré Rift Valley and the Deng Deng Forest in Cameroon. Crossing the Atlantic

Littoral forest could not be avoided, but the pipeline route (roughly paralleling an existing road) was optimized to limit damage to areas of high biodiversity value.”

In addition, the consortium agreed to provide funds to help Cameroon create two protected areas to offset any residual biodiversity impacts, including pipeline rerouting in Chad, and the establishment of forest reserves for preservation of biodiversity in Cameroon. Scientific and technical studies focused on a diversity of environmental issues continued for several years post-1993. A draft EA was released for public comment in 1997. The full environmental impact statement (EIS) was also released in 1997 in the form of a 20-volume treatise. The HIA, which had also been developing since 1992/1993 was folded into the EIS as an additional volume. In 1999, the consortium submitted an environmental management plan (EMP) in six volumes, which was placed in the Bank’s Public Information Center to solicit additional public comments. After careful review, this plan was approved by the Bank Group. (31). Similar parallel lender-commissioned expert panels have been created for other large extractive industry and water resources projects [e.g., the Papua New Guinea Liquid Natural Gas Project (PNG LNG) and the Nam Theun 2 hydroelectric project in the Lao People’s Democratic Republic (PDR), both of which are discussed in subsequent sections of this paper].

Whether the lender-driven system of external review for development projects is sufficient and equitable is the subject of substantial debate and controversy, particularly from international NGOs (e.g., International Rivers Network, Greenpeace International, and Amnesty International). An ESHIA, although typically performed by a contracted consulting firm, is essentially a self-assessment, no matter how well it is carried out. In the United States, the NEPA rules stipulate that a designated lead federal agency is the entity responsible for directing the ESHIA process, not a project proponent. It could be argued that lender-appointed ESH expert panels play an equivalent role for externally financed projects.

The Chad Export Project’s ESH documentation was developed as a collaboration involving the consortium, the governments of Chad and Cameroon, and the World Bank Group. It is worthy to note that this effort featured a high degree of transparency and stakeholder engagement and involvement. The EA documents for the project were published in late 1997, and an initial multivolume EMP (which, like the EA documents also incorporated social and health topics) was placed in the public domain for review and comment in later 1997/early 1998. Taking into account comments received during the protracted public review period, the final 20-volume EMP (about 5,200 pages in length) was published in mid-1999 (31). Impact assessments of this magnitude have been generic across large infrastructure projects regardless of setting (i.e., LMIC context versus Western Europe and North America), which raises the question of who can actually read and understand these highly technical assessments and whether they are of any use for host communities and other stakeholders. To be useful, an impact assessment needs to be more than a “check the box” exercise that fulfills lender requirements for loans and licensing agreements with host governments. We conjecture that, in general, these reports are hardly read by local communities, let alone fully appreciated, thereby leading to much less long-term follow-up and mitigation than might otherwise be the case. The previously mentioned World Bank retrospective review largely confirms this perspective (24).

This problem has motivated the International Finance Corporation to explore video reports (32) as the output to be placed in front of all parties to a development project. The current paper products would then serve as appendixes to provide much greater detail to peers who might be implementing mitigation strategies mandated by upper-level management who can readily react to video output but who have, heretofore, been only minimally engaged with the full set of impact assessments. However, we are unaware that broad-scale adoption of this proposal has occurred, despite a clear and rapid evolution of the public at large toward visual media sources, such as YouTube, Facebook, and Snapchat, to name a few.

The Chad Export Project is a notable exception and innovator in this seemingly discouraging situation. Indeed, an EMP agreed to before the start of the construction period has been the basis for a fully transparent and adaptive management of relationships with local communities that has involved land transfers with compensation, health initiatives and interventions, the proactive and reactive management of environmental issues/challenges, and the provision of community services not explicitly foreseen at the start of the project. The project’s EMP is available online (33).

With the World Bank Group involved in the project via the provision of some financing, it was determined that involuntary resettlement was to be avoided to the maximum extent practicable (34, 35). In fact, only a small number of households needed to be resettled in the oilfield development area of southern Chad, with no resettlement occurring along the 1,100-km path of the export pipeline through southern Chad and neighboring Cameroon (36). The initial resettlement plan has been adaptively tuned to the present time as part of ongoing community engagement and in view of incremental post-start-up land use requirements (33).

Community Health and Corporate Responsibility: An Unavoidable Tension.

In 2000, ExxonMobil initiated a community health outreach program (CHOP). This program, directly funded by ExxonMobil, operated successfully during the construction phase (37). CHOP primarily focused on public health outreach and education [particularly related to HIV/AIDS/sexually transmitted infection (STI) prevention and malaria], the distribution of tens of thousands of treated bed nets, the provision of some medical supplies to oilfield development area clinics, and providing logistics support to immunization programs in outbreak locations coincident with the oilfield development area (see *SI Appendix* for details on CHOP and its accomplishments). However, consistent with the notion that ExxonMobil is in the oil and gas business versus the health services provision business, CHOP transitioned to a longer term HIV/AIDS, tuberculosis, and malaria control program after the construction period; this effort is operated by NGOs and health-specific corporate partners (33) with support from the ExxonMobil Foundation. During the 11 y this program has been operating—as described in the project’s annual EMP reports—it has been an exemplary case of what can be done in an economically limited and politically difficult environment that is, nevertheless, proximal to a large corporate project. The EMP is an outgrowth of the EIA conducted during the construction phase of the project and represents commitments made by ExxonMobil for managing ESH risks. As indicated previously, health-related considerations were integrated into the synthesis and implementation of the project’s EMP, and on-going community health needs and downstream risks have been taken into account in the evolution of the undertaken initiatives and programs (33).

On a broader front, the project-derived revenue streams realized by the governments of Chad and Cameroon, which have the potential to transform public health on a national scale in both countries, have not resulted in sustainable and larger scale improvements, which is but one instance of an ongoing challenge of substantial magnitude for the future of coupled human–environmental systems more generally.

Batu Hijau Mine at Sumbawa, Indonesia. Batu Hijau (www.newmont.com/about-us/default.aspx) is a large surface mine operation, primarily producing copper and small amounts of gold and silver. It is one of the largest copper mines in the world. The operator is Perseroan Terbatas Newmont Nusa Tenggara (PTNNT), a subsidiary company of Newmont Mining. The mine is located in the southwest region of the island of Sumbawa, in the district of Sekongkang, West Nusa Tenggara province, Indonesia. PTNNT operations are based on a Contract of Work (COW) signed with the Government of Indonesia in December 1986 and were preceded by exploration activities until a commercially viable deposit of copper-gold (Cu-Au) porphyry was discovered in the area of Batu Hijau in 1990. Construction was initiated in 1997, and production began in September 1999. In 1996, after completion of a

prefeasibility analysis, feasibility study, and environmental impact study (AMDAL), the Government of Indonesia granted a permit for the exploitation of the mine.

Total mineral reserves in the PTNNT Batu Hijau location, to the end of 2008, amounted to 1,046 million tons of ore classified as measured, indicated, and inferred mineral resources. Total reported reserves fluctuate based on mineral sale prices for copper, gold, and silver, as well as geotechnical and geological aspects (38). All ore extraction activities in the Batu Hijau pit are scheduled for completion in 2022; however, stockpiled ore processing will continue until 2027. The production schedule and mining ore tonnage are based on the 2008 final version of the mining plan, which is constantly reviewed and periodically updated based on mining operations and on conforming to geological and geotechnical conditions, precipitations, economic conditions, and applications of the latest technology.

Looking into the future, PTNNT developed a mine closure plan (39) that relates to long-term environmental management and protection. It also reflects PTNNT policies on social responsibility, policies that include the legal norms and regulatory requirements applicable in Indonesia, as well as significant risk management that has examined technical, environmental, and economic aspects and that places a premium on cooperation and partnership with the local community, NGOs, and the government to jointly produce a sustainable development paradigm.

Since the start of production in 2000 and through 2008, PTNNT has expended roughly \$32 million on community development programs. These programs have been aimed at improving the quality of life for communities proximal to the mine. Ongoing human resource and economic development activities have been in place to reduce the potential negative impacts of mining. PTNNT is committed to the communities around the mine and believes they must accrue financial benefits from the mine operations through direct employment or other ancillary beneficial activities associated with the mine. PTNNT also believes the communities should obtain these benefits even after mine closure.

The PTNNT community development program has four strategic objectives: (i) Infrastructure development: Since 1997, PTNNT, in partnership with the government of Indonesia, has been involved in a comprehensive community development program focused on improving infrastructure and public facilities in the 15 villages of the three subdistricts within its area of influence; descriptions of specific community investments are included in the community profiles in the SIA report (40); (ii) Agriculture and small business development: This strategic objective is intended to guarantee continuous household sources of income through the development of advanced, integrated, and value-added agricultural practices, and through competitive business skill training to reduce unemployment and stimulate investment; (iii) Public health: This activity aims to improve basic health standards through health education programs focused on reducing infectious diseases and improving nutrition of children and pregnant women through the activities of the posyandu (integrated services post) and local health clinics (puskesmas); and (iv) Education: The objective is to improve basic skills and primary formal education of the community in partnership with the government and active participation from the community.

PTNNT partnered and consulted with the government, NGOs, academic institutions, private sector, donor agencies, communities, and other parties to guarantee and promote a sense of ownership in development activities among the stakeholders. In this context, PTNNT supported the establishment of two foundations: *Yayasan Olat Parigi* (YOP) and *Yayasan Pengembangan Ekonomi Sumbawa Barat* (YPESB).

Most important in the strategic implementation of the above programs are the close partnerships with the local communities. Each local community is represented by a village delegate charged with putting forth transparent and interactive community development programs. The village delegates are a group of community leaders that bridge community interests with the PTNNT community development department.

Having described the overall PTNNT community development effort, we focus in more detail on the health program, giving

particular emphasis to a malaria control initiative that has lessons for the contemporary large-scale international malaria campaigns. Proximal to the mine (Fig. 1), there is a population of ~20,000 people, including 8,000 PTNNT employees who are at risk for contracting malaria, with any combination of *Plasmodium falciparum*, *Plasmodium vivax*, or *Plasmodium malariae* being present. Aside from the contemporary corporate social responsibility objective of engaging in disease prevention in such areas, there is an obvious economic motivation for having effective malaria control in the immediate vicinity: namely, that copper cannot be mined without a healthy workforce. Indeed, for British colonial copper mines in malaria-endemic areas in Africa—specifically, the former Northern Rhodesia (now Zambia)—the primary control program (41) output statistic of interest was “days of work lost due to malaria.”

Before PTNNT operations in 1997, public health infrastructure, including malaria control, in the villages near the mining site was essentially nonexistent. Thus, after initial vector and human population surveillance in 1997–1998, a multiintervention malaria control program was put in place under PTNNT auspices in 1999. It involved environmental management (heavily focused on managing the lagoons), larviciding, active and passive case detection and treatment of diagnosed cases, and adult mosquito control. In detail, the following monitoring and intervention steps were initiated in 1999 and have been maintained to the present time:

- i) Environmental management—There are around 20–30 lagoons in the project area, which increase in size during the rainy season and decrease during the dry season. The lagoons contain brackish water that enables the growth of algae, thereby providing viable breeding places for *Anopheles sundaicus* and *Anopheles subpictus*, the main malaria vectors in the area. Each day vector control teams manually remove algae from the lagoons. Some lagoon boundaries are also modified to reduce the likelihood of algae accumulation.
- ii) Larval control—Larval density is monitored using dippers and the manual counting of contents. Larval identification is done by microscope in a laboratory. *Bacillus thuringiensis israelensis* (Bti) is the larvicide of choice, dispersed via hand spraying except in the largest lagoons, where rubber boats go out with workers using mist blowers.
- iii) Adult mosquito monitoring and control—Vector density is assessed via human landing catches, with subsequent vector identification via microscopy. Adult vector control is carried out using indoor residual spraying (IRS) using pyrethroids, carbamate, and organophosphate.
- iv) Monitoring and treatment of the human population—Early diagnosis and prompt treatment for malaria has been routinized since 1999. Active case detection is carried out by community volunteers and a mobile team. Passive case detection is carried out in both government and private clinics, including the Newmont clinic. Examination of Giemsa-stained slides by microscopy is routinely carried out. From 1999 until 2013, antimalarial drug treatment was a combination of chloroquine and primaquine. Then there was a transition to artemisinin-based combination therapy (ACT) with primaquine, which has been in place to the present time.

With this overview of interventions at hand, Fig. 2 shows slide positivity rates from annual surveys of school-aged children in villages within the malaria control program zone, which provides a qualitative picture of malaria trends in these villages from 1997 through 2015. Active case detection rates from 2007 into 2016 are shown in Fig. 3.

Implications, Lessons, and Questions Beyond Batu Hijau. The higher malaria case detection counts in 2007 and 2008 and the gradual reduction thereafter in the vicinity of the Batu Hijau mine are qualitatively similar to the slow reductions in case rates in the colonial copper mine settings of Zambia (41). The central issue here is that the lagoons are prime *Anopheles* mosquito breeding sites that are difficult to control. Adaptively tuning the extent and

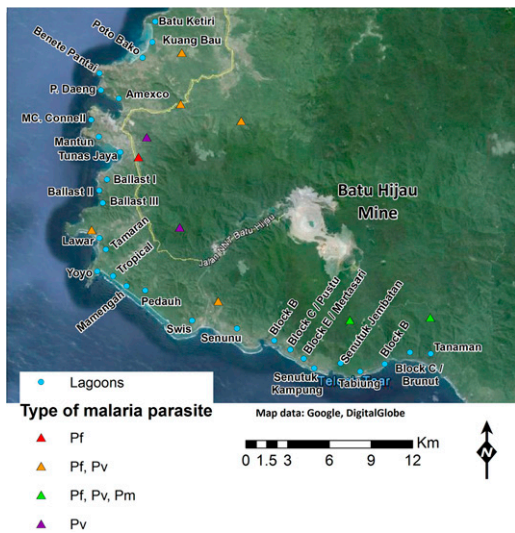


Fig. 1. Malaria control program area with emphasis on lagoons as prominent vector-breeding sites. Information for the map was obtained through personal communication with Nelson Chin, PTNNT Malaria Control Program, and overlaid in a DigitalGlobe image obtained from Google Maps.

intensity of larviciding, as well as modification of lagoon boundaries, is a critical feature of the Batu Hijau program. Indeed, it is our impression that this aspect of the control program has had the largest effect on the observed reduction in malaria cases of any of the interventions, which is again analogous to the environmental management component of the Zambian copperbelt programs.

The Batu Hijau and the Zambian programs have a generic feature that contrasts considerably with the philosophy and practical considerations of public sector malaria control, not only currently but over at least the past 50 y. In particular, there is no cost-effectiveness analysis emphasizing the relative contribution of individual interventions toward reduction in outcome measures, such as incidence rates or mortality rates (e.g., of infants and young children). The corporate programs are specified by asking: What is the package of interventions that might have some effect and that can be brought to bear in the ecosystem of interest? With answers in hand, a full package of interventions is simultaneously put into place and retained over multiple years.

Modifications of corporate programs generally consist of adaptive tuning, coordinated with monitoring and surveillance, of an initial package of interventions, together with new technological additions (e.g., DDT was an amendment to the malaria control programs after 1944). What was learned in the corporate programs is that the full packages that were put forth worked. However, we do not know how much antimalarial drugs, or bed nets, or vegetation/stream clearance, or any other particular intervention contributed to the declines shown in Figs. 2 and 3—and their counterparts at the Zambian mines.

From a design perspective, empirical determination of the contribution of specific interventions to improvement in outcome measures would require high dimensional factorial experiments run over many years, which is simply not practical. What would be of interest, but is rarely tried, is to start with a full package of interventions shown to work and then remove one or two interventions at a time that might serve to reduce cost without impairing progress on the outcome measure(s). Whether any corporate program would be willing to engage in this kind of experimentation seems doubtful, given the premium placed on maintaining a healthy workforce. Further, from a corporate perspective, the cost of running a relatively elaborate and intense malaria control program is a minor expenditure relative to the profits made on the sale of copper, oil, natural gas, or other extractive industry products.

The contrast between corporate and public sector programs in terms of economic resources expended per person covered by

the programs and the efficiency and organization of program operation and management raises the question of how to bridge these seemingly disparate worlds to provide for considerable improvement of public sector programs. Further, the scale of national public sector programs goes far beyond the quite local nature of corporate ventures.

Nevertheless, it is useful to consider that the largest and longest running national malaria control program, the Chinese national program, has operated since its inception in 1950 in a manner analogous to the corporate programs. Intervention packages were tuned to local ecosystem characteristics, guided by an elaborate network of supporting organizational structures running from the village through the district, regional, and national levels. It is worth studying this program to gain some understanding of how to make a national program, idiosyncratic to communities, actually function (42, 43). To our knowledge, there has been no rigorous comparative analysis dealing with the scope and limits of adapting this kind of program to public sector initiatives in other countries. In addition, the question of linking a public sector national program to corporate programs within the same country also needs to be addressed with a clear understanding that extractive industry companies are not in the health business, but at the same time they bring a great deal of expertise to health ventures. The challenge is to find new working symbiotic relationships.

Papua New Guinea Liquid Natural Gas Project. ExxonMobil and its precursor companies have been involved in exploration and production activities of oil and gas in PNG since the 1930s. The company holds an interest in ~2.1 million acres containing several oil and gas discoveries. In 2004, an affiliate of ExxonMobil initiated work on a plan to extract the natural gas in PNG's southern highlands and transport it via a 3,000-km pipeline to customers in Australia. It was subsequently decided, in 2007, that this gas project was not feasible, and planning and evaluation for the present PNG/LNG project was initiated.

In 2008, the initial project partners signed a joint operating agreement. At the same time, an independent economic impact study was commissioned. Analysis in the study showed that the LNG project should have a significant positive impact on employment, business opportunities, and the gross domestic product (GDP) of PNG. Then on May 22, 2008, the project venture participants—ExxonMobil (41.6%), Oil Search (34.1%), Santos (17.7%), AGL (originally founded as Australian Gas Light Co. in 1837; 3.6%), Nippon Oil (1.8%), and Landowners (1.2%)—and the PNG state formally signed the gas agreement. This agreement established the fiscal regime and legal framework by which the PNG/LNG project is to be regulated throughout its lifetime. It also

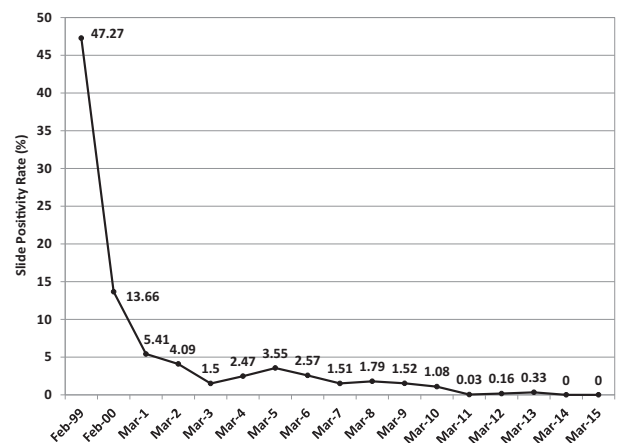


Fig. 2. Slide positivity rates. Calculated as the percentage of primary school children surveyed in mine-impacted community that tested positive for malaria parasites in the blood. Surveys were conducted in the wet season. Source: International SOS Batu Hijau Malaria Control Program.

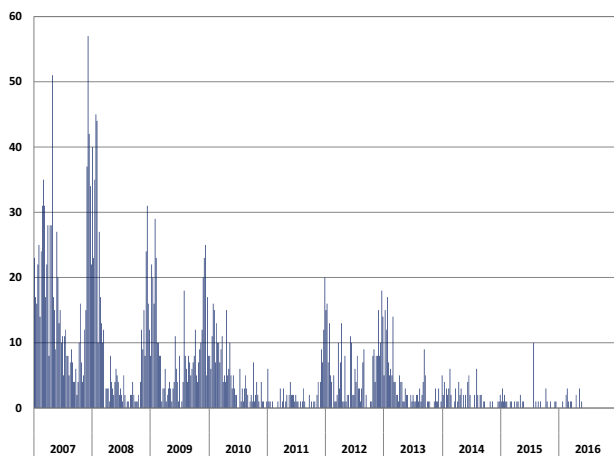


Fig. 3. Weekly number of malaria cases in the mining area. Numbers are based on active case detection during the years 2007–2016; each bar represent one week of the year.

set the terms and mechanism for state equity participation in the project. After the gas agreement, there was an announcement that the project would begin front end engineering and design (FEED).

In parallel with these activities, a major EIS (which also included social and health topics), comprising 6,000 pages and drawing on 26 supporting appendixes, was prepared over a 2-y period from 2007 to 2009 (44). In October 2009, the government of PNG approved the EIS, thereby initiating a process whereby the project would rigorously fulfill commitments and use appropriate measures to manage its environmental, social, and health risks.

During the period from December 2009 until March 2010, sales and marketing agreements for LNG were signed with four major customers: China Petroleum and Chemical Corporation (Sinopec), Osaka Gas Co., Ltd., Tokyo Electric Power Co., Inc., and Taiwan Chinese Petroleum (CPC) Corporation. The time frame for these agreements is 20 y. Construction work began on the project in early 2010, and production of liquefied natural gas started ahead of schedule in April 2014.

It should be observed that, in contrast to the Chad Export and PTNNT projects discussed above, assessment of social and health risks for the PNG/LNG project comes as close as anything we know to actually meeting the desideratum of impact assessments in advance of the project itself. However, as it stands, the previous two examples are clearly in opposition to the opening lines of section 183 of the encyclical letter of Pope Francis, *Laudato Si* (21), regarding fundamental principles for EIA: “Environmental impact assessment should not come after the drawing up of a business proposition or the proposal of a particular policy, plan or program. It should be part of the process from the beginning, and be carried out in a way which is interdisciplinary, transparent and free of all economic or political pressure” (see *SI Appendix* for full text). A large open question is the following: Can we get from where we are to the alternative standard in *Laudato Si* (23), and how do we practically do this?

PNG/LNG and Corporate–Government–Research Institute Partnerships. Historically and in current practice, HIAs have been forecasting exercises carried out in advance of a project and leading to action plans based on health risks as seen from this early vantage point. A decidedly superior set of assessments would be longitudinal health surveys carried out over the life of a project, where the results over time could be used to guide risk management/mitigation and disease prevention in communities impacted by the project, as well as on a broader scale around the country. A unique role model for this aspiration is the integrated health and demographic surveillance system (iHDSS) implemented alongside the PNG/LNG project with construction phase funding from ExxonMobil and the establishment of a partnership between the company and the

Papua New Guinea Institute for Medical Research (PNG IMR), a PNG government entity.

The iHDSS is established at two primary sites impacted by the project: four Hiri-area villages that are proximal to the LNG facility on the coast southwest of Port Moresby and Hides-area communities proximal to the gas conditioning plant in the Highlands. Two comparison sites, Asaro Valley near Goroka (to compare with Hides) and Karkar Island (to compare with Hiri), were also included in the iHDSS. Household demographic information, socio-economic conditions, morbidity indicators and mortality, and in- and out-migration are assessed twice each year, covering ~70,000 people (45). The core measures allow for documentation of changes in household economic conditions, particularly for people hired by the project, comparison with household economic conditions in communities not physically proximal to either the gas conditioning plant or the LNG facility, changing health circumstances, and, of course, births and deaths. Of particular importance is the fact that the iHDSS also served as a training ground for young scientists of diverse backgrounds, thereby expanding the horizon of the PNG IMR.

In the first years of the iHDSS, more specialized health studies were added to the core surveys, with emphasis on tuberculosis, febrile and diarrheal illnesses, sexually transmitted infections (including HIV and human papilloma virus), and noncommunicable diseases (21, 45). The tuberculosis (TB) study (46), which also included add-on data collection at Kikori, was motivated by the early recognition of the PNG/LNG medical team that tuberculosis was a growing and potentially dangerous public health issue in the country. The importance of Kikori stems from the fact that it is on a historic trade route connecting to the Hiri villages, which, in turn, are close to the LNG facility and a source of workers for the LNG plant. Early project experience led to questioning of whether or not extant published data were underestimating the extent of the local tuberculosis problem, especially at Kikori and in Hiri villages. Active and passive surveillance was carried out at Hiri, Hides, Asaro, Karkar Island, and Kikori hospital. The active case detection study revealed that the incidence rate at Hiri in 2013 was 458/100,000 people, in comparison with the nationally reported rate of 348/100,000, as of that time. The incidence rate at Kikori, one of the highest in the world, was 1,290/100,000. More than 10% of the tuberculosis cases at Kikori were multidrug-resistant. Interestingly, HIV coinfection is not a problem at Kikori, but it could become an issue in Port Moresby.

In parallel with the iHDSS study, the LNG project itself identified 13 active tuberculosis cases from Hiri and 7 active cases from Port Moresby among the workforce. All workforce cases received treatment, contact tracing was conducted, and no worksite transmission occurred. These details serve to illustrate the considerable value, for the company, the government health ministry, and the people in the villages of having an iHDSS platform from which to launch targeted investigations as needed (see *SI Appendix* for more details and outcome results of this program).

Lessons from the ExxonMobil–PNG IMR Partnership. First, regarding impact assessments per se, it would be desirable for the upfront activity of the entire process to be the installation of an iHDSS platform with project impact area communities and more distant comparison communities as the sites for immediate assessment and long-term longitudinal data collection. An iHDSS also serves as the backbone for a diversity of specialty studies, such as the tuberculosis project described above. This point is emphasized in the recently released HIA guidance (21) for the oil and gas industry, with the PNG/LNG project being treated at length as an example of a dynamic that could be adopted in the mining and other industries. Environmental, economic, health, and social dynamics consequential to a corporate project can be readily monitored over time. The acquired information would then be the basis for informed adaptive environmental, social, and health risk management strategies as needed, support for new local business opportunities, improvements in local health services and disease prevention, and the provision of a local societal database that can be linked to, and be a model for, improved national data systems.

Second, the iHDSS, and the PNG IMR as its implementer, has become a member of an international network of such systems: namely, the international network of field sites with continuous demographic evaluation of populations and their health in developing countries (INDEPTH) (www.indepth-network.org/). It is the only such system, out of the 53 field sites distributed over 20 countries, that is directly linked to a major corporate project with the capability of long-term monitoring, surveillance, and the provision of an important tool for decision making by both a government and corporate entity regarding the health and welfare of entire communities. It is important to note that, although Exxon-Mobil funded the initial few years of the iHDSS, it is now expected that PNG IMR will raise the funds internationally to continue the longitudinal data collection. This expectation is again principled on the point that ExxonMobil is not in the health survey data collection business, but it has paved the way for a health, demographic, and economic surveillance system that can be a major resource for the country in which it is operating. The project serves as a role model for what could be possible in many LMICs where extractive industries will operate in the future.

Nam Theun 2 Hydroelectric Project in Lao PDR. The potential of the Nam Theun River on the Nakai Plateau in Lao PDR to be exploited for hydroelectric power generation was identified as early as 1927, but it was not until the mid-1970s that detailed studies of the feasibility of a project began. In the late 1980s, the Lao government targeted Nam Theun 2 (NT2) as a key vehicle for the economic and social development of the nation and invited the World Bank Group to participate in the project. The government and various private investors set up a company and named it “Nam Theun 2 Electricity Consortium (NTEC)” to research and develop the scheme. In 1994, Electricité de France and the Italian-Thai Development Company of Thailand joined the project, and Nam Theun 2 moved from a conceptual to a development phase. The design and preparation of a complete set of economic, environmental, and social safeguards took more than 10 y, during which time NTEC became the Nam Theun 2 Power Company Limited (NTPC). Project financing was gradually put in place, and full construction activities commenced in June 2005.

Consistent with the oil, gas, and mining projects discussed above, impact assessments for NT2 began in the 1990s when the project was in the development phase. The HIA for this project, the last to be commissioned, was completed along with a public health action plan in March 2004. From the time development of NT2 was initiated, the project was sharply criticized by activist groups (47–49), particularly focused on potential inequities for communities to be resettled to facilitate the economically and geologically most viable dam construction site and the consequential water flow patterns. Considerable public debate about the perceived damaging effects of NT2 persisted for several years (50). Nevertheless, the power company (NTPC), the World Bank, and the government of Lao PDR solidified financing and moved ahead with the project (51).

Two positive and unique—among large scale corporate projects anywhere—features of NT2 deserve to be highlighted and put on the table for consideration in future projects: (i) the appointment of an independent panel of experts (POE)—analogous to the World Bank Group’s expert panel put in place during the planning period of the Chad Export Project to advise on the preparation of the environmental (and social and health impact) assessment and management plan—and (ii) the incorporation of major parts of the public health action plan—derived from the HIA—into the concession agreement between the power company and the government, the contents of which were made publicly available (see *SI Appendix* for details on the health program that was in place during the early years of the dam operation).

The POE issued its first report in 1997 and continued for 24 rounds through July 2011, which was just over 6 y beyond the start of construction of the dam and 1 y beyond commissioning. In its original charter, we find that the primary responsibility of the POE is “to provide independent review and guidance on the treatment of environmental and social issues associated with a project under

preparation. Although the POE’s findings and recommendations are to be submitted directly to the Ministry of Industry and Handicraft and the World Bank, it is free to make its own determination on which environmental and social issues it should focus. In the Nam Theun 2 case, the POE interprets its purview to include the entire Nam Theun River basin from the border of Vietnam to the Mekong River, interbasin transfers from the Nam Theun to Xe Bang Fai and Nam Hinboun rivers, the NT2 transmission line, and whatever enhancement and other projects are impacted by water release from the Nam Theun reservoir. The Panel is also obligated to assess the extent to which planning for the NT2 project meets World Bank environmental and indigenous people resettlement with development and other guidelines.”

The entire set of POE reports are available online (www.namtheun2.com/index.php/reports). They represent an unprecedented level of transparency about the impact over time of a large-scale project as seen through the eyes of independent critics. When apparent violations of World Bank guidelines are pointed out, the response of the NTPC is evaluated during the next POE assessment several months later. The longitudinal POE monitoring process should be viewed as complementary to an iHDSS, as implemented for the PNG/LNG project. Looking to the future, it seems that these two evaluative components can be an invaluable guide to decision making regarding provision of improvements in environmental and social well-being and human health by corporate management, local and national governments, and village leaders in impacted communities.

Regarding the incorporation of public health action items in the concession agreement for NT2 (52), this agreement represents signing on to a previously unheard of level of mutual commitment by the government and corporate entity to long-term health improvements in impacted communities. A challenge ahead for positive development of coupled human and environmental systems is to establish routine inclusion of health and social issues into concession agreements. In the case of NT2, we at least have a role model to get started.

Discussion

We have discussed four examples of strategies not only for reducing corporate–societal conflict in the face of large-scale extractive industry and power generation projects in LMICs, but also for the formation of partnerships that have the potential to improve local living standards on a long-term basis. Projects of the kind we have been discussing are usually operating over periods of at least 30 y, which is far beyond the time horizon of sponsorships/funding of environmental, social, and health programs by virtually all NGOs and private foundations. The corporate world offers something different. There is a window of opportunity, early in the life cycle of a project, to expand the always local corporate–community partnerships to regional and national scales, provided governments invest revenue realized from projects toward the elevation of living standards of their own people. There is no escaping the difficult politics of getting this frame of mind to be operative among government leaders. However, the potential is there. The challenge is, of course, implementation.

Although our focus has been corporate–community–government interrelationships, a missing element with regard to extractive industries in LMICs has been linkage to the academic community. We bring this matter up because of the near nonexistence of university training programs that include systematic research linkage to the extractive industry or large dam projects that involve environmental, social, and health-related mitigation. This lack was not always true. Indeed, a program titled “Industry and Tropical Health” was initiated in 1950 at the Harvard T. H. Chan School of Public Health (53) with the avowed purpose of establishing symbiotic links between essentially extractive industries and the academic research community in the hope of improving health and living standards of people in the tropics who were impacted by corporate ventures. This initiative held joint academic–industry–government conferences every 2 y until 1978, with published proceedings describing the interactions, many of which were focused on issues of the kind we have addressed herein. Regrettably, and we feel to the detriment of all parties concerned, the Industry and

Tropical Health initiative was abandoned in response to student protests against what were perceived by some as being too close a set of connections between corporations and the academic community. This kind of program could be reactivated today, with much the same template that was in place in 1950 (53). We feel that this action would be a concrete one welcomed by the corporate sector and would open up new opportunities for university students and faculty to work on important societal questions that are not being addressed in contemporary academic circles.

Regarding impact assessments per se, the principles enunciated in the encyclical of Pope Francis (23) represent a set of standards that not only could facilitate corporate profits in the future, but also could help to avoid corporate-societal conflict and establish far greater equity relative to impacted communities than has

historically occurred. Here again, the challenge is substantial, but *Laudato Si* and the extensive international consultations that went into its production provide a new framework for impact assessment (23) that, as the Pope has said, “is about all of us.” Can this new framework be implemented, or is there some perturbation of it that can get corporations and governments moving in a new direction on large projects? Answers lie in the future.

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