2016/60

WORLD BANK GROUP

livewire

A KNOWLEDGE NOTE SERIES FOR THE ENERGY & EXTRACTIVES GLOBAL PRACTICE

THE BOTTOM LINE

The Decision Tree offers a cost-effective, scientifically sound, replicable, and transparent method for demonstrating the robustness of a development project in the face of the risks posed by climate change, natural hazards, and other factors. The framework is most effective when a wide range of risks must be considered, as is typically the case with high-value hydropower investments. In order to gain maximum benefit from the framework, it should be conducted at both project and basin scale, first to answer questions immediately relevant to investors and then to provide perspective on alternative investment portfolios that may yield greater returns.

Toward Climate-Resilient Hydropower in South Asia

Why study the impacts of climate change on hydropower projects?

Planning for climate change is critical to protect—and increase—returns on the significant investment being made in hydropower

More than 80 percent of South Asia's hydropower potential remains untapped, and the countries of the region are depending on its development as a source of affordable renewable energy. Yet climate change threatens that development. Practical means of gauging the possible effects of climate change on hydropower projects would improve the Bank's investment decisions while also furthering its clients' understanding of and resilience to climate change and climate-related disasters through intelligent design and careful planning.

In December 2015, the United Nations Climate Change Conference (COP 21) in Paris placed high priority on building and strengthening the resilience of infrastructure projects. In response to this, the Office of the Chief Economist at the World Bank is launching an initiative called "Enhancing Climate and Disaster Resilience of World Bank Sustainable Development Operations." The work described here is part of that initiative.

Since its seventeenth replenishment in 2013, the International Development Association has required that all country partnership frameworks include an analysis of climate and disaster risks. Once the country agrees to the framework, climate considerations must be incorporated into the content of programs and results frameworks. All new IDA operations must be screened for short- and long-term climate change and disaster risks and, where risks exist, must integrate appropriate resilience measures.

In light of the foregoing imperatives (and in response to internal suggestions) the World Bank's Energy and Extractives Global Practice, with support from the Asia Sustainable and Alternative Energy Program (ASTAE) and the South Asia Water Initiative (SAWI, a partnership between the World Bank and Governments of United, Kingdom, Australia and Norway), launched an effort in 2013 to better understand the impacts of climate change on hydropower and to take stock of various ways to measure and boost the resilience of relevant projects.

The Practice began by analyzing several hydropower projects and observing how climate change had been addressed in the past. The team leader then formed a multidisciplinary team across global practices and initiated a Bank-wide consultation process.

The Energy and Extractives team quickly discovered that Bank units had various ways of screening for climate and disaster risk; there was no standard method for assessing the significance of climate risk or of forecasting climate conditions that might affect hydropower development. In an effort to fill this gap, Diego Rodriguez and his team in the Bank's Water Global Practice, supported by the Water Partnership Program, developed a conceptual framework known as the Decision Tree to guide project planners in applying


Pravin Karki is a senior hydropower engineer in the Energy and Extractives Global Practice and a member of the Global Solutions Group on Hydropower and Dams. He leads work on the resilience of hydropower at the Bank.


Haru Ohtsuka is an investment officer at IFC. He is using the methodology developed in this study to source $30 million in concessional financing for an IFC-led hydropower project.


Laura Bonzanigo is a young professional in the Climate Change Policy Office. She is an expert in modeling "decision making under uncertainty."


Sanjay Pahuja is a lead water resources specialist in the Water Global Practice and a member of the Complex Water Systems group.

the techniques of "decision making under uncertainty" (DMU) to the assessment and management of climate change risk.

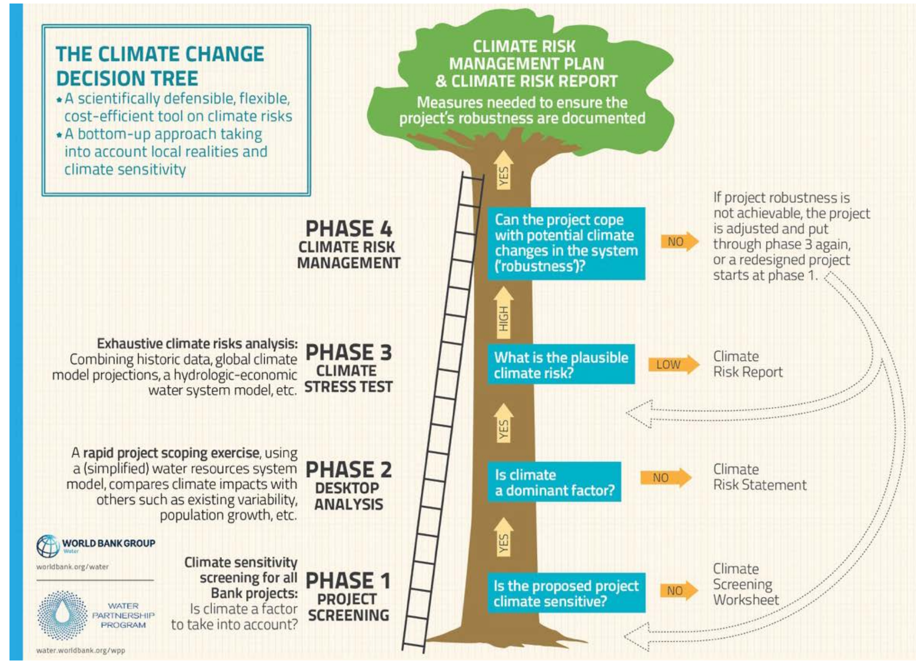
> "The Decision Tree helps decision makers to assess climate change threats without first having to predict the future, understand the strengths and limitations of projects under a wide range of conditions, and identify adaptation strategies for long-term success.

Why are DMU and the Decision Tree useful?

They allow for the analysis of variables that cannot be forecasted

DMU applies multidisciplinary tools and data to plan hydropower projects at the project, basin, or national scale so as to ensure strong physical and economic performance. The logic of DMU techniques is straightforward: After identifying future conditions that might be problematic for the design under consideration, one then evaluates to the extent possible the likelihood of their occurrence and determines whether and how their effects can be mitigated. The techniques can be applied to uncertainties beyond climate change as well, such as those surrounding sediment loads, electricity prices, the prices of various types of fuel, the magnitude of co-benefits (such as environmental flow support or flood control), construction costs, and projected energy demand.

Figure 1. The Decision Tree, an approach to decision making under uncertainty



Source: Ray and Brown 2015.

DMU facilitates the resolution of conflict surrounding hydropower development by providing (i) a transparent and accessible analysis that invites the testing of multiple project designs and portfolios; (ii) rigorous treatment of stakeholder views on how the future will unfold (requiring stakeholder input to the development of the analysis and continuing participation as new information arises); and (iii) an opportunity to consider multiple metrics of performance that facilitate discussion and agreement.

The Decision Tree, which is a framework for the staged application of DMU to managing risk in general and climate change in particular, helps decision makers to (i) assess climate change threats without first having to predict the future; (ii) understand the strengths and limitations of projects under a wide range of conditions; and (iii) identify adaptation strategies for long-term success.

In contrast to other project-level assessments, the Decision Tree focuses first on identifying a project's vulnerabilities. If warranted, climate projections are conducted in the final stages of analysis. Finally, the Decision Tree offers a systematic, step-by-step way for a project manager to decide what level of analysis is appropriate to the project's attributes.

The Decision Tree consists of four phases (figure 1). A project leader moves through only as many phases as are appropriate to the project. The overall procedure includes a feedback loop that addresses monitoring and evaluation, both of which are essential in the midst of a changing climate. For more details on each phase, see Ray and Brown (2015).

“By applying the Decision Tree to the Upper Arun project and a closely aligned approach to the Koshi basin, the usefulness of DMU approaches was ascertained.”

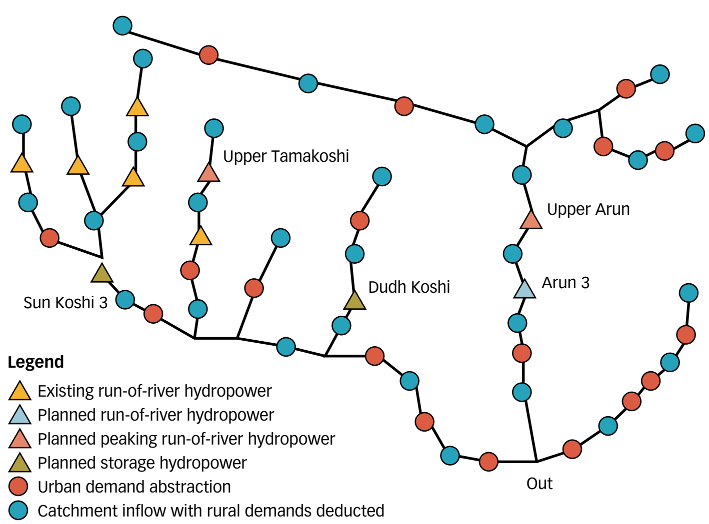
Has the Decision Tree been applied?

It has been applied at the project and basin scale—but it can be applied even more broadly

Rodriguez’s team saw an opportunity to apply the Decision Tree approach to the proposed Upper Arun Hydropower Project (UAHP) in eastern Nepal (an application on the project scale) and to the overall hydropower portfolio in the Koshi Basin (an application on the basin scale). By applying the Decision Tree to the Upper Arun project and a closely aligned approach to the Koshi basin, the usefulness of DMU approaches was ascertained.

In support of the applications, the team hired external modelers to conduct a project-level analysis of how climate change and other variables (such as the price of hydropower supply) might affect the project’s optimal design capacity (World Bank 2015; Ray and Brown 2015). A parallel study examined how glacial volume and the flow of water from glaciers and snow would be influenced by changes in temperature and rainfall (Pahuja and others 2015). A complementary analysis of the Koshi Basin, where the UAHP is located (figure 2), tested efficient and robust mixes of planned hydropower capacity

Figure 2. Planned hydropower projects in the Koshi Basin examined in the basin-level study



Source: Harou and Hurford 2015; World Bank 2015.

within the context of a complex physical system, laying the groundwork for future river basin and energy sector planning in Nepal (Harou and Hurford 2015). Sediment effects were also included in the analysis. A technical note on sediment management and a software program called RESCON2 are being developed by Fichtner (Germany) and will be released in early 2016.

Applying the Decision Tree at the project scale. What risks might be faced by the UAHP, considering a prefeasibility design of 335 megawatts (MW)? The team’s analysis considered climate change and other factors identified in discussions with stakeholders. Such factors include performance metrics for project evaluation: namely, the economic value of the project (net present value) and the total and dry season hydropower production.

Application of the Decision Tree to the UAHP demonstrated that the project is robust to climate change and other risks. This was indicated by a stress test on a multistage ensemble of models that included a weather generator, an advanced hydrologic model with a glacier component, and a water system model that translated water availability into hydropower production.

The general hydrologic response of the Upper Arun River to changes in climate was as follows. The stream flow was projected to increase as temperatures warmed by about +3C, after which the flow decreased moderately because of declining contributions from glacial melt. The stream flow during the low-flow season was found to decline slightly with warmer temperatures; however, the effect was small. The effects of a rise in temperature were far less significant than those regularly expected from changes in precipitation. Projections for the region, of unknown credibility, indicate warmer temperatures and no clear signal regarding precipitation.

The assessment also considered alternative (larger capacity) designs for the UAHP. The original prefeasibility design of 335 MW was found to be robust to the range of uncertainties considered; few scenarios posed significant problems. But the design was not able to exploit much of the increase in flows during the wet season. A design capacity of 1,000 MW emerged as an attractive alternative, providing the best combination of robustness and efficiency, including during the dry season; however, it was also more sensitive to increases in capital costs and electricity prices. These issues need to be carefully addressed if this design is to remain competitive.

The ranges of the input variables selected for this analysis exceed what is deemed plausible. This is to ensure that no vulnerabilities are overlooked. Once vulnerabilities are identified, it can then be decided whether the values of the variables causing them are plausible or not. Thus, the initial ranges used do not influence the results of the analysis. To ensure that the initial ranges exceed any plausible values, they were developed in consultation with the Nepal Electricity Authority and relevant literature, and included a discount rate and cost estimates. The input variables for climate change (temperature and precipitation) were developed based on an analysis of historical records and with the specified intention of going far beyond the ranges covered by the climate change projections of the Intergovernmental Panel on Climate Change.

Not all hydropower projects need be subjected to the degree of analysis applied to the UAHP. According to current World Bank policy, as noted at the outset, projects must be subjected to an appropriate level of analysis to demonstrate that they are resilient to future climate change. The Upper Arun analysis went on to the later phases of the Decision Tree, even after climate risks were shown in Phase 2 to be low, only because the investors and stakeholders wanted to know if a larger design size might capitalize on the opportunities for hydropower generation presented by more favorable conditions (climate and nonclimate). Other projects may not require such extensive analysis, and in general the Decision Tree can be applied flexibly to meet stakeholders' needs.

“Basin-scale analyses that consider climate change are not required by World Bank policy, and not all basins need this type of analysis. However, when basins have complex interdependencies and when the various possible interventions are contested, system-level trade-off analysis can help bring clarity and consensus.”

Applying DMU approaches at the basin scale. Applying a DMU analysis to the entire Koshi River basin demonstrates how DMU approaches can be used to select efficient and robust combinations (portfolios) of hydropower investments in complex interdependent systems. Because the performance of hydropower assets depends on factors such as river flows, water management rules, and upstream and downstream water use, the basin-scale analysis aims for integrated water resource management. A stakeholder-trusted model is used to simulate the basin system over a 30-year period, given various options for infrastructure development and operating rules. The simulation tracks flows and storage throughout the basin over time, as well as various engineering, economic, and environmental metrics that quantify salient aspects of the system's performance. Examples of performance metrics include hydropower generation, irrigation deliveries, and the reliability and resilience of the public water supply and ecological flows.

In this DMU application the river-basin impact model was linked to a multi-criteria search algorithm that filters possible combinations of investments and their operating modes to identify a small set of the highest-performing portfolios (the most efficient and robust combinations of options), given a range of uncertainties, including climate change. This high-performing group of proposed assets and the trade-offs between their benefits can be assessed visually and interactively. Stakeholder-preferred investment bundles are then stress-tested in detail to identify any vulnerabilities, including to institutional and financial variables. Ultimately, this approach aims to help decision makers identify which investments can achieve robust outcomes and appropriately balance the system's benefits.

Should every river basin be subjected to the analysis applied to the Koshi Basin? Basin-scale analyses that consider climate change are not required by World Bank policy, and not all basins need this type of analysis. However, when basins have complex interdependencies and when the various possible interventions are contested, such system-level trade-off analysis (Geressu and Harou 2015) can help bring clarity and consensus. Most river-basin organizations conduct basin-system simulation to aid in operations and capital project planning (for example, in the development of water master plans); the application of DMU methods is a natural extension building on existing tools. The sort of planning applied to the Koshi Basin promises to be particularly useful under the following conditions:

- When substantial new investment involving multiple sites and infrastructure options is being considered.
- When water and water infrastructure are being used in many ways (hydroelectric generation, municipal and agriculture supply, flood control, and others), and when complex trade-offs between these uses are either already apparent or could crop up (and be challenging to manage).
- When decisions about new investments and how to make them are sensitive to one or more uncertain factors, such as climate change, future demand for electric power, and the price of electricity or alternative forms of energy.

> "Climate-related impacts have caused significant increases in the operational complexity and costs of hydropower projects, but most private investors are unwilling to pay for the additional costs of climate proofing, even though the same analysis that makes a project or set of projects more resilient also makes it more bankable. The answer lies in using blended finance to ensure that resiliency issues are given the attention they deserve."

Because almost any part of a system can affect the performance of many or all other parts, basin-scale analysis can reveal insights that are surprising and would not emerge from simpler, independent analyses with a smaller scope.

What next?

Toward a programmatic approach to climate change and hydropower projects in South Asia

The use of DMU to screen operations for short- and long-term climate change and disaster risks at the project and basin level is part of the World Bank's broader, systematic approach to climate change and hydropower projects in South Asia (figure 3). Our next step will be to develop detailed guidelines on building the resilience of the sector.

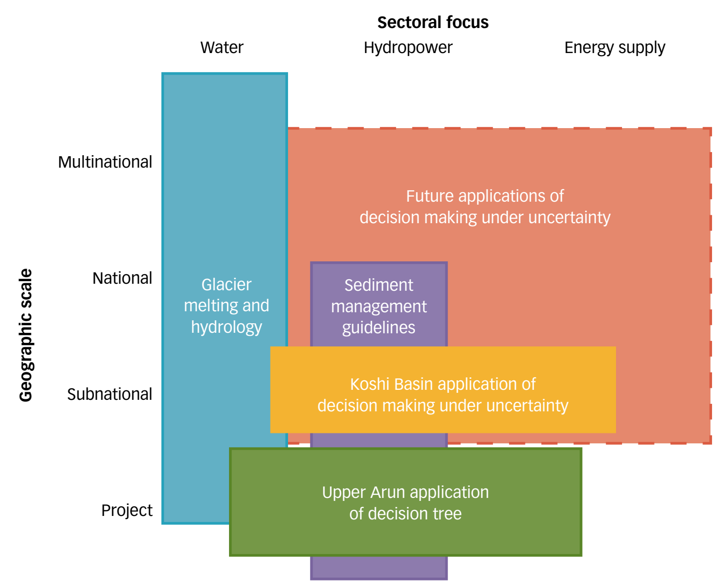
By 2035, an additional 750 gigawatts (GW) of hydropower capacity is expected to be added around the world, requiring over $1.2 trillion in new investment in countries outside the industrialized countries of the Organisation for Economic Co-operation and Development. Many of the new facilities in question will be located in climate-vulnerable areas. Yet, even in the face of high demand, no product on the market adequately supports the "climate proofing" of new and existing hydropower facilities. Climate-related impacts have caused significant increases in the operational complexity and costs of hydropower projects, but most private investors are unwilling to pay for the additional costs of climate proofing, even though the same analysis that makes a project or set of projects more resilient also makes it more bankable (by reducing risk).

The answer lies in using so-called blended finance to ensure that resiliency issues are given the attention they deserve.

The methods applied to the Upper Arun case study have been replicated by Haru Ohtsuka, an investment officer at the International Finance Corporation (IFC), in a privately financed 218 MW hydropower project called Upper Trishuli A in Nepal. In that project, the Pilot Program for Climate Resilience (PPCR, a climate investment fund) and the IFC (as an implementing entity for the PPCR) committed to an initial equity investment that incorporated an assessment of climate change adaptation. The assessment included the identification of design changes needed to make the hydropower plant resilient to future climate change. A further PPCR coinvestment linked to the additional cost of adaptation measures is being considered.

By providing long-term financing and investing in local currency, blended finance investments such as the PPCR seek to mitigate the financial risks of project developers—risks that are known to hinder the development of climate-resilient infrastructure for hydroelectric facilities. It is expected that these blended finance investments will help establish a track record for the development of climate-resilient hydropower capacities, sending a positive signal to investors and financiers looking to enter the hydropower sector. By demonstrating the bankability of climate-resilient hydropower, these investments can catalyze significant further investment in the sector on a commercial basis.

Figure 3. Elements of a systematic approach to climate change and hydropower projects in South Asia



Source: Neumann and Black 2015.

MAKE FURTHER CONNECTIONS

Live Wire 2014/36. "Supporting Hydropower in the Developing World: An Overview of World Bank Group Engagement," by William Rex, Julia Bucknall, Vivien Foster, Rikard Liden, and Kimberly Lyon.

Live Wire 2015/38. "Integrating Variable Renewable Energy into Power System Operations," by Thomas Nikolakakis and Debabrata Chattopadhyay.

References

Geressu, R. T., and J. J. Harou. 2015. "Screening Multi-Reservoir System Designs via Efficient Tradeoffs: Informing Infrastructure Investment Decisions on the Blue Nile." *Environmental Research Letters* 10(12). DOI:10.1088/1748-9326/10/12/125008.

Harou, J. J., and A. P. Hurford. 2015. "South Asia, Investment Decision Making in Hydropower: Decision Tree Case Study of the Upper Arun Hydropower Project and Koshi Basin Hydropower Development in Nepal." Unpublished consultants' report. June.

IEG (Independent Evaluation Group). 2012. "Adapting to Climate Change: Assessing the World Bank Group Experience." World Bank, Washington, DC. http://ieg.worldbankgroup.org/Data/reports/cc3_full_eval_0.pdf.

Neumann, J., and M. Black. 2015. "Programmatic Approach to Impacts of Climate Risks on Water, Hydropower and Dams: Synthesis Document." Unpublished consultants' report. June 29, 2015

Pahuja, S., D. Alford, U. Kamp, C. Pan, and E. Yin-Chen Yang. Forthcoming. "Glaciers and Stream Flow in the Arun Basin, Nepal." Unpublished consultants' report.

Ray, P., and C. Brown. 2015. *Confronting Climate Uncertainty in Water Resources Planning and Project Design: The Decision Tree Framework*. Washington, DC: World Bank. https://openknowledge.worldbank.org/handle/10986/22544

World Bank. 2015. "South Asia Investment Decision Making in Hydropower: Decision Tree Case Study of the Upper Arun Hydropower Project and Koshi Basin Hydropower Development in Nepal." World Bank Report AUS11077, World Bank, Washington, DC. June.

The study was led by Pravin Karki and a World Bank Group team consisting of Laura Bonzanigo, Haru Ohtsuka, Sanjay Pahuja, and Diego Rodriguez. Pravin Karki leads work on the resilience of hydropower at the World Bank. Laura Bonzanigo is an expert in modeling decision making under uncertainty. Haru Ohtsuka is using the methodology developed in this study to source $30 million in concessional financing for an IFC-led hydropower project. Sanjay Pahuja is a member of the Complex Water Systems group at the World Bank.

Research related to the Decision Tree and UAHP analysis was conducted by Casey Brown, Patrick Ray, Sungwook Wi, and Ethan Yin-Chen Yang of the University of Massachusetts, Amherst. Julien Harou and Anthony Hurford of the University of Manchester undertook the analysis of the Koshi Basin with the help of Laura Bonzanigo and using hydrological information from Luna Bharati and Pennan Chinnasamy (IWMI) and Patrick Ray (UMASS). George Annandale of Golder Associates and Gregory Morris of GLM Engineering produced a guidance note on sediment management for dams and run-of-river hydropower. James Neumann and Margaret Black of Industrial Economics, Inc., provided overall support and guidance. Special thanks are due to Rohit Khanna and William Young for helping secure funding for the studies through ASTAE and SAWI, respectively.

The authors also thank Divas Basnet, Julia Bucknall, Rafaello Cervigni, Nathan Engle, Marianne Fay, Luis Garcia, Johan Grijsen, Rikard Liden, Peter Meier, Jie Tang, Michael Toman, and David Viner. Additionally, the authors thank the government of Nepal, especially the Nepal Electricity Authority, Luna Bharati and her team at the International Water Management Institute (IWMI), Radhesh Pant and his team at the Investment Board Nepal, and the Nepalese Ministry of Energy.

Get Connected to Live Wire

"*Live Wire* is designed for practitioners inside and outside the Bank. It is a resource to share with clients and counterparts."

The *Live Wire* series of online knowledge notes is an initiative of the World Bank Group's Energy and Extractives Global Practice, reflecting the emphasis on knowledge management and solutions-oriented knowledge that is emerging from the ongoing change process within the Bank Group.

Each *Live Wire* delivers, in 3–6 attractive, highly readable pages, knowledge that is immediately relevant to front-line practitioners.

Live Wires take a variety of forms:

- **Topic briefs** offer technical knowledge on key issues in energy and extractives
- **Case studies** highlight lessons from experiences in implementation
- **Global trends** provide analytical overviews of key energy and extractives data
- **Bank views** portray the Bank Group's activities in the energy and extractives sectors
- **Private eyes** present a private sector perspective on topical issues in the field

Each *Live Wire* will be peer-reviewed by seasoned practitioners in the Bank. Once a year, the Energy and Extractives Global Practice takes stock of all notes that appeared, reviewing their quality and identifying priority areas to be covered in the following year's pipeline.

Live Wires are designed for easy reading on the screen and for downloading and self-printing in color or black and white.

For World Bank employees: Professional printing can also be undertaken on a customized basis for specific events or occasions by contacting GSDPM Customer Service Center at (202) 458-7479, or sending a written request to cgsdpm@worldbank.org.

Printing & Multimedia Services
General Services

Please visit our Live Wire web page for updates: http://www.worldbank.org/energy/livewire

OKR OPEN KNOWLEDGE REPOSITORY

Contribute to livewire

Do you have something to say? Say it in *Live Wire!*

Those working on the front lines of energy and extractives development in emerging economies have a wealth of technical knowledge and case experience to share with their colleagues but seldom have the time to write for publication.

Live Wire offers prospective authors a support system to make sharing your knowledge as easy as possible:

- Trained writers among our staff will be assigned upon request to draft *Live Wire* stories with staff active in operations.
- A professional series editor ensures that the writing is punchy and accessible.
- A professional graphic designer assures that the final product looks great—a feather in your cap!

Live Wire aims to raise the profile of operational staff wherever they are based; those with hands-on knowledge to share. That's your payoff! It's a chance to model good "knowledge citizenship" and participate in the ongoing change process at the Bank, where knowledge management is becoming everybody's business.

If you can't spare the time to contribute to *Live Wire*, but have an idea for a topic, or case we should cover, let us know!

We welcome your ideas through any of the following channels:

Via the Communities of Practice in which you are active

By participating in the Energy and Extractives Global Practice's annual *Live Wire* series review meeting

By communicating directly with the team (contact Morgan Bazilian, mbazilian@worldbank.org)