WORLD BANK GROUP

2017/81

livewire

A KNOWLEDGE NOTE SERIES FOR THE ENERGY & EXTRACTIVES GLOBAL PRACTICE

THE BOTTOM LINE

Integrated planning analysis can provide evidence to support decision making and consensus building about sensitive issues in the energy sector. To support analysis, an optimization model imputes costs to a range of pertinent activities (capital and operating costs of power plants, operating and closing costs for mines, emission control costs), thereby defining a set of functions that can be solved simultaneously to determine the lowest system cost.

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The Effects of Carbon Limits on Electricity Generation and Coal Production: An Integrated Planning Approach Applied to Poland

Why is this issue important?

Essential efforts to reduce carbon emissions have local consequences

When 175 states signed on to the Paris Agreement on Climate Change in 2016, they set in motion a process that, for most, affects the way electricity is produced.[1] For countries that purchase coal, oil, or other fuels for power generation, the effect may simply be a decrease in import volumes. But for countries that export fossil fuels or use their own fossil-fuel resources for generation, reducing production may mean shutting down coal mines or oil wells. The natural question then becomes which facilities to shut down. The question may be complex even when the power sector alone is considered; it becomes even more so when the extended effects of closures are taken into account.

Mines and wells provide a livelihood for families; in some cases, whole communities are built around them. Haney and Shkaratan (2003) describe the social impact of mine closures in Romania, Russia, and Ukraine; the effects include reduced employment, migration of labor, cuts in municipal and social services, and frayed community ties.

Because of these social effects, the question of mine closures is often politically charged. In such contexts, where policy choices must be explained to citizens, evidenced-based decision making is extremely important. Although not all of the implications of a closure can be quantified or modeled, systemwide estimates that show the relative effects of closing different facilities make it easier for policy makers to explain their decisions to citizens.

The necessary analysis must simultaneously consider wider options in the electricity and mines sectors—including increased shares of gas and renewables, profitability, staffing, transportation of fuel from mines and wells to power plants, imports of power and coal from neighboring countries, and the installation of abatement equipment to meet emission standards. Such systems-level analyses are complex and data intensive, but they provide invaluable insights on the impact of decisions.

Among the tools available for systemwide or multi-sectoral analysis are Times/Markal, Primes, Message, and Leap, but none produces results that are sufficiently granular to provide a full understanding of specific choices.

What is the key challenge?

The lowest system cost must be determined and presented in a transparent manner

Perhaps the most effective way to illustrate the challenge, even at the technical level, is to break down the problem statement. Consider the illustrative system in figure 1, where mines supply coal to power plants, which, together with other plants fueled by gas or renewables, must meet growing demand within specified emission targets. Several related factors must be considered:

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1 http://newsroom.unfccc.int/paris-agreement/175-states-sign-paris-agreement/.

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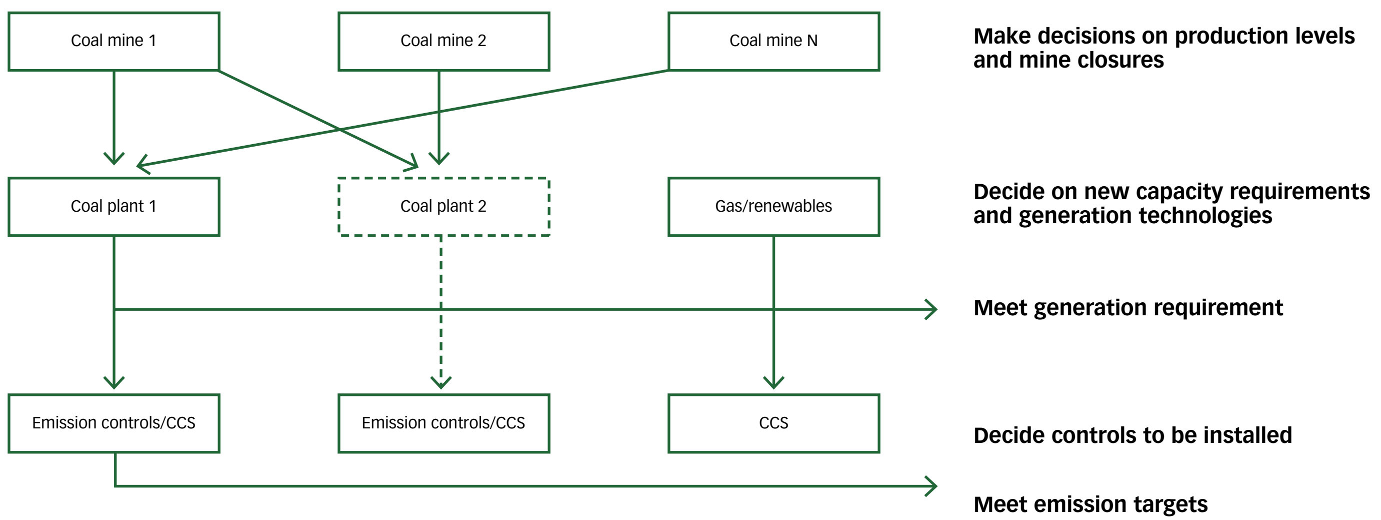
- Which mines currently supply fuel to the most efficient fleet of plants? With the cost of transportation taken into account, are these necessarily the cheapest mines to operate?
- Does the equation change when the number of employees at each mine is taken into account? Does the fact that some mines supply fuel to plants that must be kept in service (often these are plants that provide heat as well as electricity) change the equation?
- What is the best way to meet emission targets? Is it more cost-effective to install emission-control systems on existing coal-fired plants or to replace coal with less-polluting but more-expensive technologies (such as gas and renewable energy)? What is the optimal mix of the two approaches?
- How does the imposition of emission targets change the ranking of mines?

This optimization problem can be formulated as a cost-reduction function. By imputing costs to all activities (capital and operating costs of plants, operating and closing costs for mines, emission control costs, and so on), it is possible to define a set of functions that can be solved simultaneously to determine the lowest system cost. The analysis of mining costs may even be extended to include the cost of various options—for example, acquiring new technology or combining operations of adjacent mines.

And this brings us to the second challenge: data requirements.

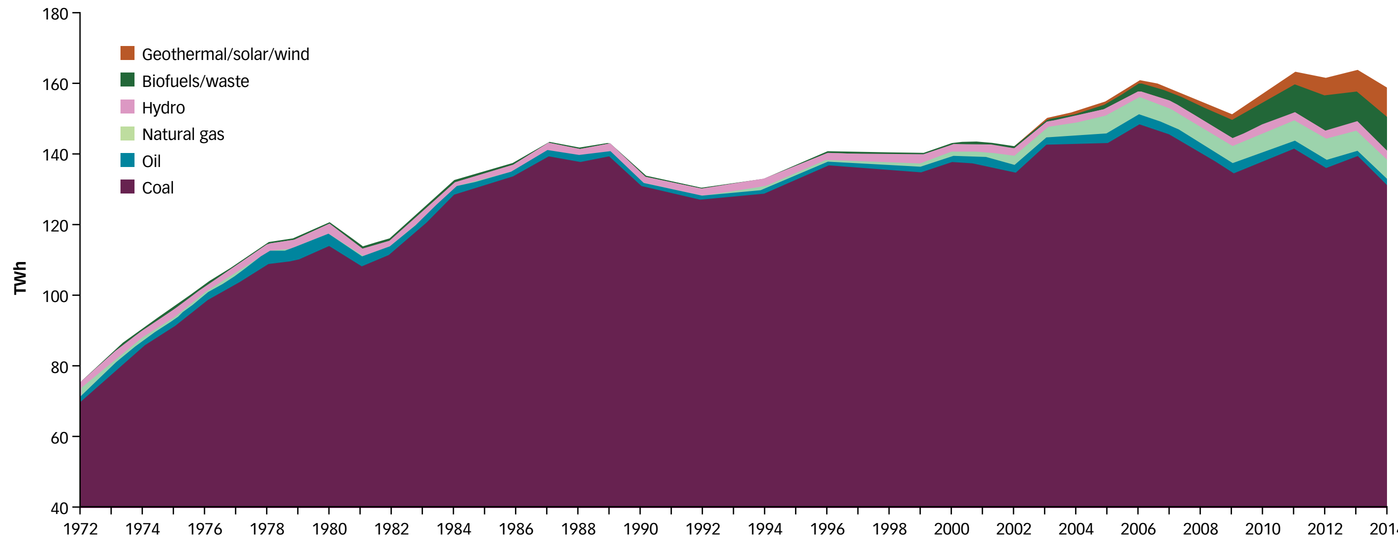
Data requirements for the optimization problem just posed can be extensive, especially since both the power and mining sectors are implicated. In countries with good data-management systems, this type of information is routinely aggregated and readily available. But in other countries, a great deal of effort may be required to collect and collate it. The challenge is often not with the existence of the data per se but rather with the format (hard copy versus electronic, or incompatible electronic files) in which data are available and, on occasion, their quality. Even—or especially!—in such cases, systems-level analysis can advance the cause of building databases that can be beneficial to the sector.

Figure 1. Framework for analysis of a coal-supplied generating system in the presence of emission limits



CCS = carbon capture and storage

Figure 2. Poland's generation mix, 1972–2014



Source: IEA.

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How has the World Bank addressed the challenge of integrated planning analysis?

Poland provides an illustration

Poland produces electricity and heat from aging plants (half are more than 30 years old). Although coal production has been on the decline over the past 20 years, Poland's 31 active mines still produce more than 100 million metric tons of coal each year to generate electricity and heat (IEA 2011). These mines employ more than 80,000 people, and coal accounts for more than 80 percent of generation.

Although this state of affairs would seem to present an opportunity to introduce newer, cleaner technologies, serious issues of investment requirements, energy security, and mine employment must be dealt with (IEA 2011). These problems have long been recognized, but to date only limited steps have been taken to modernize and decarbonize the sector through increases in wind, biomass, and gas generation (figure 2).

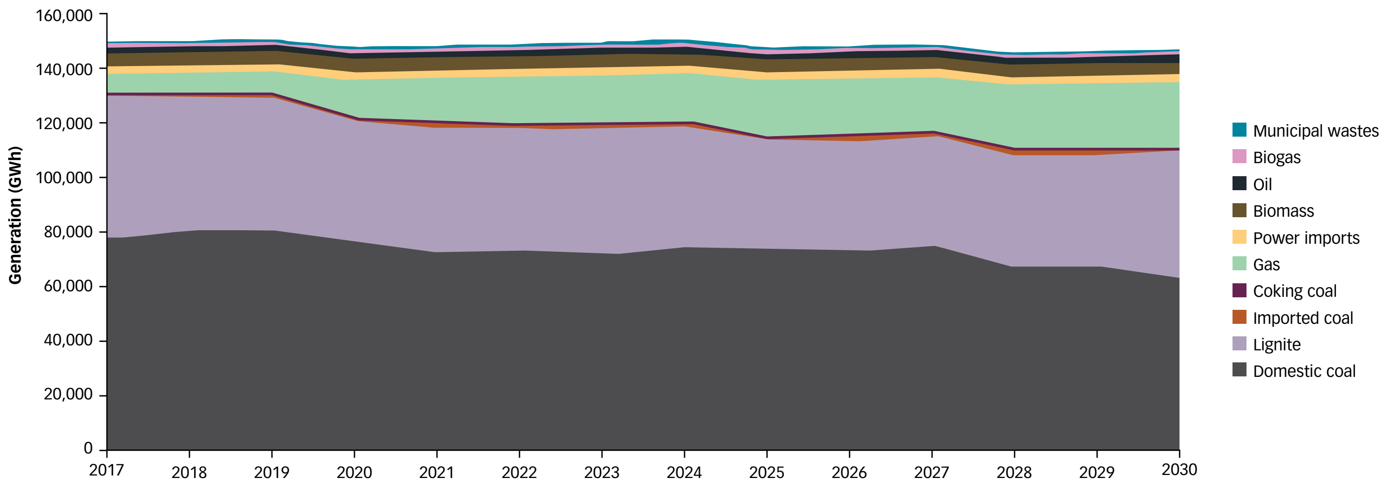
The country's production of electricity and heat emits 166 million tons of CO_2 each year, 97 percent of which comes from coal-based generation. Gas generation, which has been on the rise, accounts for 2 percent of emissions. Emissions of local pollutants are also significant; they include 3.28 million tons of particulate matter and more than a million tons of SO_2.

Reducing these emissions will entail cutting down on coal production (closing the most unproductive mines), developing alternative sources of generation (gas and renewables), grappling with the unemployment caused by mine closures, and investing in equipment to control pollution and, potentially, to capture and store carbon.

Asked to help the government of Poland analyze options for reducing emissions, a World Bank team developed an integrated planning model to address the following questions related to coal, heat, and mines through 2030:

- What are the present generation mix and associated coal requirements for electricity and heat production (referred to below as "business as usual")?
- How would a carbon constraint affect the cost of supplying electricity and heat, the generation mix, coal production, and mine employment?
- What would be the best ways to meet the imposed carbon limit?

Figure 3. Generation mix through 2030 under business as usual



The country's production of electricity and heat emits 166 million tons of CO_2 each year.... Reducing these emissions will entail cutting down on coal production, developing alternative sources of generation, grappling with the unemployment caused by mine closures, and investing in equipment to control pollution.

An optimization model was custom-built for this purpose by the Bank Power System Planning Group. It draws on an integrated coal-power model that one of the authors developed for the Indian power sector in the 1990s.[2] The integrated coal-power model developed for Poland determines (i) the dispatch of individual power stations over the period, (ii) the optimal selection of new projects to meet demand and emissions constraints, and (iii) upstream production and closure decisions for individual mines. The upstream linkage from power plants to mines is very useful in deciding how emissions of carbon and other pollutants can be effectively mitigated through a mix of fuel switching (e.g., coal to gas or coal to renewables) and through associated decisions on mines. The model can optimize coal production by capturing the productivity of individual mines (expressed as the number of employees per ton of coal produced), the minimum technical production level that must be maintained to supply coal-fired plants, and the mine's costs. It performs the optimization by taking into consideration the lowest economically feasible employment and production levels and determining how, in light of the resulting production level, the generation level of the downstream power station should be adjusted.

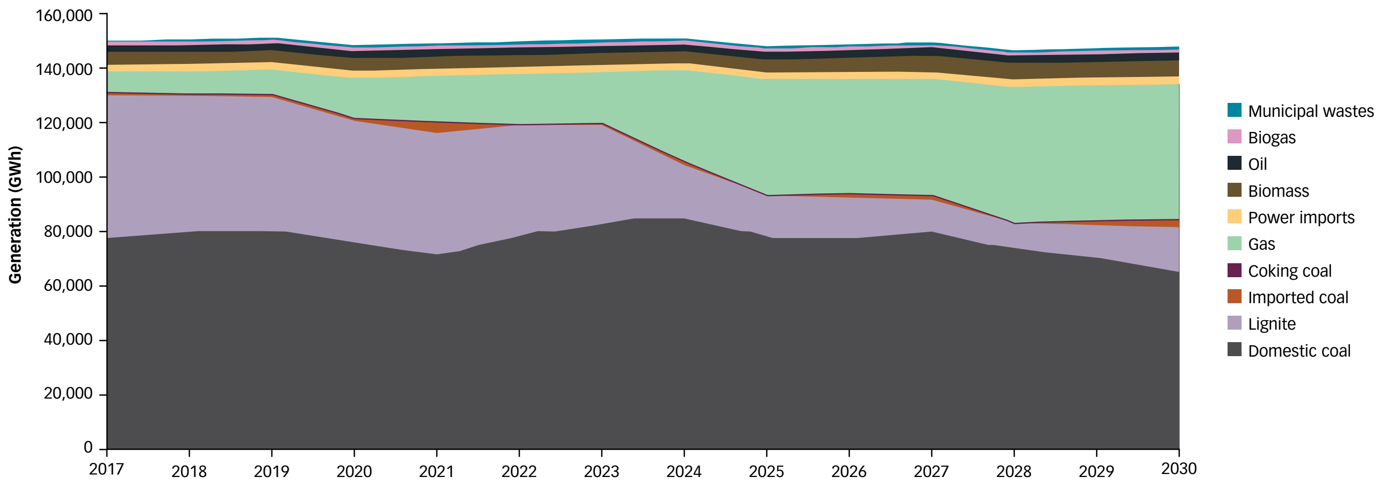
Under business as usual, with demand stable, Poland's generation mix changes only gradually through 2030. The most notable change is an increase in gas generation, as coal plants are retired under the least-cost plan and replaced by gas (figure 3). CO_2 emissions decrease slightly, from 166 million tons in 2017 to 144 million tons in 2030.

Lowering annual emissions to 107 million metric tons annually by 2030—a 26 percent reduction from business as usual and a 40 percent reduction from the 2005 emission level (as per the Poland's declared target[3])—would increase the cost of the system by \$2.4 billion, a 2.1 percent annual increase over 2016–30. For the years 2017–20, the reduction is based on a Polish government report (KASHUE-KOBIZE 2010), and, for the rest of the period, on the linear trend needed to reach a level of emissions that is 40 percent lower than the 2005 level.

2 See Parikh and Chattopadhyay (1996). A variant of this model including emissions control decisions was deployed for China Light and Power in Hong Kong in 2001/02 to decide on type and timing of installation of controls. CLP continues to use the model for fuel budgeting and dispatch analysis.

3 "Intended nationally determined contributions" for reductions in greenhouse gas emissions were declared in advance of the 2015 United Nations Climate Change Conference in Paris in December 2015.

Figure 4. Generation mix if CO_2 limits are observed over 2017–30



Although generation from lignite is presently the cheapest way for Poland to produce power, there is no way to avoid reducing it if near-term CO_2 emission limits are to be met.

Because the agreed CO_2 limit is not binding until 2022, Polish decision makers may recoil from the cost of meeting it ahead of time.

In any event, if existing carbon commitments are scrupulously observed, gas-fired units will have to play a much greater role in the generation mix after 2023, replacing old lignite power plants (figure 4). Although generation from lignite is presently the cheapest way for Poland to produce power, there is no way to avoid reducing it if near-term CO_2 emission limits are to be met. Under the carbon-constrained scenario, gas generation increases in the model to almost 50 TWh in 2030 compared with 24 TWh under business as usual. Generation from renewables is unaffected, because the economic case is the same in both scenarios, although biomass generation increases slightly over the period from 4.5 TWh in the business-as-usual case to 6.3 TWh with the carbon constraint.

Respecting carbon limits has a significant effect on coal mines. Under business as usual, annual coal production drops from 100 million tons currently to 90 million tons by 2030 (figure 5a). Under the carbon-constrained scenario, however, the binding CO_2 limit after 2022 drives down lignite production sharply, and overall coal production falls to 48 million tons in 2030 (figure 5b). While some mines continue their production at full capacity, five close down by 2030.

Mine employment stood at about 80,000 in 2016. With business as usual, that level declines slowly to about 67,000 by 2030. Under the carbon-constrained scenario, however, it drops to 54,000—a drop of 20 percent of the workforce.

In summary, the model applied to Poland reveals that under a business-as-usual scenario, with no emissions constraint, coal's share in generation and heating would likely fall from about 80 percent in 2017 to 63 percent in 2030. Gas and renewables would play a growing role, coming to account for about 30 percent of the generation mix in 2030.

The cost of meeting the specified carbon-reduction target by 2030 is relatively small: a 2.1 percent annual increase in overall system costs. Under this scenario, coal's share in generation would drop to 48 percent by 2030 and that of gas and renewables would rise to 43 percent. Lignite's share would fall steeply from 28 percent under business as usual case to below 10 percent. But these gains would mean closing five coal mines and laying off about 20 percent of Poland's remaining coal miners.

MAKE FURTHER CONNECTIONS

Live Wire 2014/5. "Understanding CO_2 Emissions from the Global Energy Sector," by Vivien Foster and Daron Bedrosyan.

Live Wire 2014/18. "Exploiting Market-Based Mechanisms to Meet Utilities' Energy Efficiency Obligations," by Jonathan Sinton and Joeri de Wit.

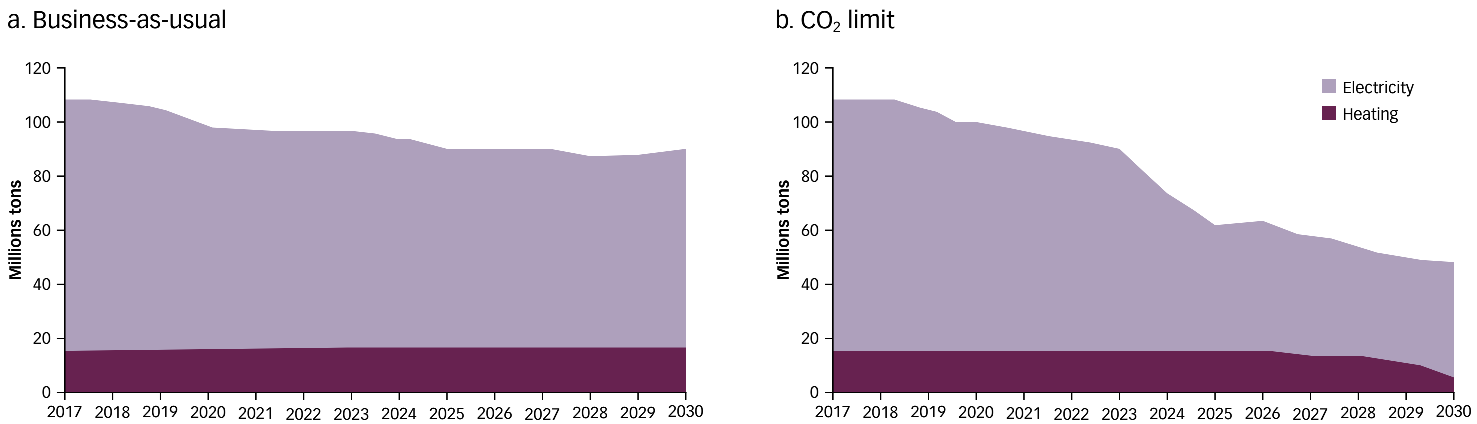
Live Wire 2014/24. "Capturing and Storing Carbon: The World Bank's Role," by Nataliya Kulichenko, Richard H. Zechter, and Asad Ali Ahmed.

Live Wire 2015/43. "Integrating Climate Model Data into Power System Planning," by Debabrata Chattopadhyay and Rhonda L. Jordan.

Live Wire 2016/55. "Designing Effective National Programs to Improve Industrial Energy Efficiency Programs," by Feng Lieu and Robert Tromop.

Live Wire 2017/78. "Minerals and Metals to Meet the Needs of a Low Carbon Economy," by Kirsten Lori Hund, Daniele La Porta, and John Drexhage.

Figure 5. Coal production under two scenarios



What is the message for our clients?

Integrated planning analysis supports good decisions—*and* vital intersectoral coordination

Applying integrated planning analysis to a real case reveals its ability to support evidence-based decision making, which can be useful in dialogues with stakeholders. Yet the analysis is just that: a tool for decision making; and it must be complemented by programs to spread awareness and to cope with the dislocations caused by the decisions it underpins.

While the data requirements of this type of analysis can be heavy, the process of assembling those data fosters discussion among sectors that should focus their efforts in pursuit of common national goals. Collaboration in data gathering also improves the chances that the results of the ultimate analysis will be embraced by a wide range of stakeholders.

References

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We gratefully acknowledge the contributions to this work of Leszek Pawel Kasek and Ryszard Malarski in the World Bank's office in Poland.