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Researchers Michael Young (left), Hazal Kirimli (center) and Dan Graf (right) in front of a solar array at the J.J. Pickle Research Campus. Photo: Jackson School.

The Actual Cost of

Electricity

When you look at each electricity option from cradle to grave, there are hidden environmental impacts and economic costs to them all. Scientists with the Jackson School of Geosciences are working hard to understand them.

By Anton Caputo

The goal of the energy transition is simple: Lower emissions and still provide enough energy for society to grow and prosper.

“It’s really a matter of energy addition plus emissions reduction,” said Bureau of Economic Geology Director Scott W. Tinker, who is considered one of the world’s leading experts on energy issues.

“The world needs more affordable, reliable energy — not less — to lift struggling regions from poverty. And we need to lower the emissions from all forms of energy. It’s not an easy goal, but it’s achievable.”

Among the issues that make the goal so complicated is that no energy source comes without downside or environmental impact.

For instance, ramping up wind and solar power, and backing up these sources with batteries, are highly touted strategies because, once installed, they offer carbon- free energy production.

Here’s the rub though: Developing wind, solar and batteries on a large scale and replacing these facilities when they break down and degrade is going to take massive amounts of copper, nickel, cobalt, lithium and other rare earth minerals. In fact, the International Energy Agency (IEA) projects demand for these minerals will skyrocket from seven to 40 times the current rate by 2040.

And although finding and extracting these resources is possible, mining, refining and shipping them can create a lot of carbon dioxide (CO_2) depending on where and how this occurs. There are also other significant environmental impacts on water quality, land use, biodiversity and other issues that can significantly impact local environments and communities. And all these can vary tremendously depending on a series of choices made during the process.

With this give and take in mind, Tinker and Michael Young, a senior researcher at the bureau and the associate dean for research at the Jackson School of Geosciences, have put together an interdisciplinary team of scientists, engineers and economists from the Jackson School to unravel the impact and costs — both economic and environmental — of potential energy options. The team is doing that by first conducting cradle-to-grave life cycle assessments for different electricity generation options and then working to understand how the mix of these options affects the reliability of the electric grid and the cost to consumers. These analyses cover everything from mining, processing and shipping the metals needed, to building and siting the plants, and finally to operating the facilities for 30 years.

The goal isn’t to argue for any specific energy mix, but to understand the strengths and weaknesses of each, so that the overall system is made stronger, said Young, who is leading the project.

“Where I’m focused is to identify and understand the weak links in the supply chain, and by weak links, I mean from the standpoint of environmental load or environmental impact,” Young said. “And if we can identify those links, we can suggest ways to reduce impacts.”

Comparing Electricity Options

The program Tinker and Young created is called Comparing Electricity Options (CEO). Its goal is to move beyond a simple comparison of the options and investigate the actual impacts and costs of all forms of electricity generation.

The project is being done in stages. In Phase I, scientists are analyzing the environmental and economic impacts of five power generation options: combined cycle natural gas plants, wind with and without battery backup and solar with and without battery backup. Other power generation options, like hydrogen and geothermal, will probably be added in the future.

CEO takes a global perspective when analyzing the environmental impacts of raw materials for energy production, which can be sourced from many different areas around the world, including from Texas. But when it comes to electricity production and transmission, researchers are focusing on West Texas as the location of the potential plants in the study and the Texas grid for distributing the electricity.


(https://www.jsg.utexas.edu/news/files/Tinker-1-scaled.jpeg)

Scott W. Tinker

Narrowing the focus of this phase of research to a well-studied portion of the state and the state’s self-contained electrical grid will help researchers to get their arms around the issue, Young said. But he’s confident the findings will be relevant for communities and decision makers around the world.

In Phase II, the energy sources will be tested using a grid dispatch model. These models simulate the supply and demand of electricity over 15- to 60-minute increments and highlight where and when the electricity supply could run short. The reliability of the electrical grid is an important metric of success for the energy transition, and will potentially require investments in new transmission and distribution systems and other infrastructure, Young said. The model will show how different mixes of electricity sources behave over time, and the value of batteries or other forms of energy storage, which are considered critical given the intermittent nature of wind and solar.

The final phase of CEO will involve estimating the consumer cost of electricity produced by the five different options, considering environmental impact, power system costs, and the capital and operating expenses of power plants. Gurcan Gulen, a senior economist at the bureau, is leading this aspect of the study.

The idea, said Tinker, is to find a metric relevant to the consumer to replace the current cost metric used by policy makers and others to compare various forms of electricity generation, which is called Levelized Cost of Electricity (LCOE).

“It [LCOE] is misleading because it compares the cost at the plant gate — the panel, turbine or power plant — not the actual cost to the consumer,” Tinker said. “The actual cost requires that we consider the cost of making electricity reliable, and reliability can be expensive.”

Broad Impact

The list of environmental impacts CEO scientists are looking at is pretty inclusive. CO_2 emissions are certainly important, but so is air and water pollution, land and water use, and impacts on biodiversity and the larger ecosystem.

Consider land use, for instance. It takes about 2,500 solar panels for 1-megawatt capacity of solar power. Scale that up to 200 megawatts — about the output of a small natural gas plant — and you are looking at a footprint on the order of 750 football fields, according to researchers on the CEO team.

This scenario is the proverbial drop in the bucket when you consider the huge growth in the number of projected solar installations around the globe in the next few years. In 2022, the IEA projected that solar power capacity could grow by almost 1,500 gigawatts (1 gigawatt is 1,000 megawatts) in five years, surpassing coal by 2027.

For the CEO project, land use is one of about 17 different environmental parameters, including particulate matter formation, ecotoxicity, acidification and others. These other impacts have local effects and occur during the mining and manufacturing stages of wind, solar and battery technologies.

The team is nearly finished with the first phase of the CEO project, which includes life cycle assessment of combined cycle natural gas, wind and solar, and nickel, lithium and cobalt, which are essential minerals for wind, solar and batteries. They plan to publish their results in a series of peer-reviewed publications in the near future. Results will be posted on the projects webpage at ceo.beg.utexas.edu (https://ceo.beg.utexas.edu/).

The Global Nickel Supply Chain

The Nitty Gritty

Master's students are a very important part of CEO's research. Most come from the Jackson School's Energy and Earth Resources (EER) program.

Hazal Kirimli and Dan Graf are two of the seven graduate students to help with the project so far. Now an energy consultant with Rystad Energy in Houston, Kirimli tackled the life cycle assessment of nickel while she was earning her degree, with her analyses tracking the mining, processing, shipping and refining of nickel around the world.

Graf came to the EER program after working as a hydrogeologist for the state of Wisconsin and then as a water consultant in Santiago, Chile. His work in CEO is exploring the environmental impact of siting and building different kinds of power facilities, especially how different power generation choices affect local and regional ecosystems. He is focusing on a 33-county region in West Texas about the size of Kentucky that is home to five distinct ecoregions: The Chihuahuan Desert, High Plains, Southwestern Tablelands, Central Great Plains and the Edwards Plateau.

Each power generation facility in Graf's study is modeled using life cycle assessment methods and biodiversity and ecosystem services models. The latter help determine how developing power facilities will impact the environment's natural ecosystem services.

Ecosystem services, Graf said, are "basically the benefits we derive for free from nature." They include things like food, recreational benefits, climate regulation, pollination, water and air quality benefits, nutrient cycling and more.

Both Kirimli's and Graf's results showcase the staggering array of outcomes that can result at different parts of the energy production process.

For nickel alone, Kirimli came up with almost 700 different scenarios, which vary by the type of ore body being mined, ore grade, refining method and other factors. Environmental impact and CO_2 emissions were found to differ significantly from scenario to scenario.

The large number of scenarios is partly a function of nickel's diverse global footprint. Unlike some commodities, the nickel trade spans the planet. Indonesia, Australia and Canada all have rich deposits, but there are mines, processing and refining facilities spread throughout the world.

And dynamics can change with the development of new refining methods, price swings or even geopolitics.

Untangling the details of the global trade involved a tremendous amount of data, which Kirimli compiled by using the Ecoinvent Life Cycle Inventory Database and combing through the literature and reports from dozens of companies. She processed the data using OpenLCA software.

Further complicating the analyses, most nickel comes from two different ore types: nickel sulfide, which has historically provided most of the world’s nickel; and laterite, which has become more common in recent years as the ore grade of sulfide deposits has diminished. Laterite is closer to ground surface and tends to contain more water, which makes it more difficult to process after mining.

In addition to ore type and mining and processing locations, she tracked refinery locations and the numerous technologies used to process the ore. These varied greatly and depended on the end product desired, which can be nickel metal or ferronickel (an alloy of nickel and iron), both of which are used in stainless steel production, or nickel sulfate, which is used to make lithium-ion batteries.

“It’s really hard to generalize the process for nickel production, and I realized after months that when we saw a nickel number in the literature, it doesn’t tell the exact picture, because there are so many variables,” she said.

For each one of those 700 scenarios, Kirimli worked to uncover the details of environmental impacts. This translates to a lot of findings, with layers to each.

Left: Chemetall Foot Lithium Operation, Esmeralda County, Nevada. Photo: Doc Searls/Flickr. Right: Kennecott Copper Mine, Salt Lake County, Utah. Photo: Jean Weller/Flickr.

For instance, when simply comparing ore types, sulfides vs. laterites, she found that the average CO_2 output is three time higher for laterites than sulfides. She also calculated averages for 14 other environmental impacts, ranging from fine particulate matter pollution to marine ecotoxicity, a measure of the chemicals and other pollutants added to the marine environment.

But those are just averages by ore type. From there, she calculated the impact of all combinations of ore types, mining, processing and refining throughout the world.

This went beyond nickel itself, and took into account the generation mix of the electrical grid where the facilities were located. Her findings, not surprisingly, are encapsulated in a massive spreadsheet and will be published in a peer reviewed journal soon. (**You can find a preliminary list of key findings in the box below.**)

After two years of crunching the numbers, one take-home message Kirimli came away with was how important the ore grade is to limiting climate and overall environmental impact. This poses a fundamental challenge, she said, because the unavoidable trend in mining operations is toward lower grade ore over time.

“If we don’t find ways to make our operations more efficient or look for other ways to reduce our emissions, we are going to go the wrong way," she said.

Graf's results paint a similarly complex picture of the tradeoffs that come with different modes of energy development. For example, generating electricity with solar and wind can offer significant reductions in air pollution impacts and as much as 97% reduction in CO_2 emissions over the lifetime of a project. But the processing of metals needed to build these renewable sources of energy may create up to 67 times more water pollution than those used for combined cycle natural gas turbine plants. At the same time, the amount of water needed to operate a combined cycle natural gas plant can be nearly 100 times more than wind and solar. Findings like these are intended to help engineers and policy makers focus on how to minimize the impact of each energy source by, for example, finding cleaner ways of manufacturing metals or finding ways to minimize their impact on water.

The area Graf studied, which includes the Permian Basin, already contains significant energy development on the order of about 180,000 oil and gas wells and 105 utility-scale combined cycle gas, wind, and solar facilities. Combining wind and solar with batteries for backup yields the five different types of power generation facilities that were examined by the CEO project, with each generation technology producing an average of 3 terawatt hours per year over a 30-year lifespan. In each case, Graf is examining the intersection of the facility with the different ecoregions and assessing the local impacts to those ecosystems.

"We have done 500 simulations and we will probably do over 1,000 by the time we are done," he said. "We're finding that location matters. Particularly when looking at ecosystem services we're finding that small changes in location can have a big impact on the environment."

For example, installing energy infrastructure on previously disturbed lands has less impact on ecosystems than installing on pristine lands. Overlaying land use layers (from GIS data) onto energy infrastructure is allowing Graf to quickly see where impacts could be higher.

Looking Ahead

The CEO project is still working on crunching the numbers. Findings will be released as stand-alone studies and posted on the project site over the next few years. The goal is to offer decision makers the tools to make global energy and emissions decisions with as little impact to the environment and surrounding communities as possible. Young emphasized that this could be especially important to communities in developing countries who frequently bear the brunt of global energy and resource development, often without directly benefitting themselves.

“There is a growing movement to make sure that the energy transition and all of these processes are not going to create really huge environmental damage and health impacts on the communities that the rest of the Western world, for the most part, are relying on,” he said.

When it comes to climate change, CO_2 is among the most critical parameters. The study is showing complexity here, too. The projected development of solar and wind is going to initially spike CO_2 emissions, Young said. Eventually, once the facilities are running, the carbon-free energy produced will reduce the carbon intensity of the electricity sector and result in lower CO_2 emissions to the atmosphere. But exactly when this occurs will depend on the choices made about how and where the raw materials are mined, processed, shipped and refined.

“We expect a crossover point on carbon emissions at some point in time, but how long does that take?” Young said. “Is it 10 years, 20 years? That depends on a lot of different assumptions. We are being very open with these so that other people can understand the context of the study and replicate what we’re doing.”

All this is important to keep in mind as the energy transition progresses. It’s a necessary transition, but it's not straightforward.

"The scale of the resources needed is enormous and unprecedented," said Jackson School Dean Claudia Mora. "That's why this project is so important. When you look at the complete life cycle of all energy options, there is no free lunch. It is critical that we understand the options and the impact of each choice."

Environmental Impacts of the Global Nickel Industry

Hazal Kirimli, who recently earned her master's degree from the Jackson School of Geosciences Energy and Earth Resources program, spent two years looking at the environmental impact of the worldwide nickel industry. Her cradle-to-grave analysis examined nearly 700 global combinations of mining, processing, refining and shipping nickel.

Her complete findings will be published in a peer-reviewed journal in the near future. Preliminary results include these key points:

- The environmental impacts of nickel production from laterite ore, which accounts for two-thirds of global primary production, are 1 to 13 times higher than sulfides in 11 out of 16 impact categories.
- As ore grade decreases, emissions of all types increase non-linearly. For example, the energy requirement of traditional mining, processing and refining equipment (which are mostly diesel-powered) increase by up to 18-fold.
- Similarly, land use increases almost 25-fold as ore grade quality decreases from excellent to poor.
- Using pyrometallurgy (melting ore) to process nickel ore is the most emission-intensive method in most scenarios. Hydrometallurgy (leaching ore), requires more land, but produces fewer emissions.