Epistemic Turbulence in Renewable Energy Engineering on the Chinese "Belt and Road"

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Abstract

Energy issues constitute a nexus of technological, political and economic challenges, particularly in light of the global climate crisis. Chinese banks and corporations, guided by a multi-trillion dollar infrastructure investment program called the "Belt and Road Initiative," now account for one-third of global investment in renewable energy. In this ethnographic study, we explore the professional knowledge and practices of Chinese, Israeli and European engineers working on a pumped-storage hydropower project in Israel with financial and technical backing from Chinese energy firms. We examine how these experts construct and maintain a set of epistemic cultural practices within transnational flows of capital, technology, materials and expertise. Situating our findings within Science and Technology Studies (STS), we use the hydrological engineering concept of "turbulence" as a metaphor for the rapid transnational movements of engineering concepts and personnel in the renewable energy sector.

Keywords

engineer; energy infrastructure; epistemic culture; standards; belt and road

Introduction

In a meeting room in central Tel Aviv during the summer of 2019, three Israeli and three Chinese engineers sat at a roundtable discussing a highway project to service a hydropower station that their companies were designing and constructing. A satellite map of the road was hanging on one wall. On another wall was a large whiteboard full of structural drawings, numbers and dates, some of which had been blotted out and rewritten in another font, indicating the intense discussion taking place regarding the project plan, cost and schedule. All of the engineers spoke English, though none of them spoke it as a native language. Communicating about technical subjects was one of many obstacles they commonly faced. One of the Israeli engineers, taking a sip of coffee,

To cite this article: Chen, Zhuo, Bryan Tilt, and Shaozeng Zhang. 2022. "Epistemic Turbulence in Renewable Energy Engineering on the Chinese 'Belt and Road.'" *Engaging Science, Technology, and Society* 8(2): 13–33. https://doi.org/10.17351/ests2022.1161.

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asked in a worried tone about how they would solve communication problems, particularly when they arose on the hydropower project's busy and hectic construction site, located about an hour outside the city. "You know," he said, "Not every engineer speaks English as well as we do. Remember the Tower of Babel?"

Before any of the Chinese engineers could respond, one of his Israeli colleagues turned to him and said, "How could they know about the Tower of Babel? They don't read the Bible!" After a moment of confusion, one of the Chinese engineers, with a look of enlightenment crossing his face, said, "The Tower of Babel? We know the story in the Bible." Then, turning to the whiteboard, he added, "Don't worry, my friend. Keep in mind what we discussed over the last several hours: money is our common language!"

Energy issues constitute a nexus of crucial technological, political and economic challenges, particularly in light of the global climate crisis. In many Asian, African, and Latin American countries, a variety of renewable energy projects—including wind, solar, hydropower and marine energy—are under development to meet the rapid growth of energy demand without continuing to overburden the natural environment of our planet (International Energy Agency 2019). Building on a long tradition of social studies on energy, researchers have recently called for adopting an ethnographic approach to shed light on energy infrastructures that often remain invisible to energy consumers and under theorized by scholars (Smith and High 2017; Goodman 2018). Energy ethnography thus helps to contextualize the ontological positions and subjectivities of people connected through new kinds of infrastructures; in the process, it can help elucidate the relations between technology, society and environment.

In this context, understanding the knowledge and practices of engineers and other professionals working on energy infrastructure is a crucial step toward understanding humanity's possible energy futures. Differences in language are a surface manifestation of deeper epistemological conflicts within the increasingly transnational renewable energy sector. Understanding the ways in which engineers implement professional standards and produce knowledge in an emerging industry within a novel geopolitical context may shed light on new energy futures, particularly in an era of climate crisis. Our ethnographic study explores the professional knowledge, practices and experiences of engineers working on a multinational energy production site—in this case, a pumped-storage hydropower (PSH) project in Israel constructed under the auspices of the country's National Infrastructure Committee.

PSH, which we describe in detail below, is a rapidly growing industry that complements other forms of renewable energy such as solar and wind by storing energy and allowing it to be distributed during times of peak demand. To meet the need for increased system flexibility and stability aligned with wind and solar capacity expansion, PSH projects are forecast to experience the highest decadal growth in history (International Energy Agency 2021), accounting for almost 30% (65GW) of global hydropower capacity expansion during 2021–2030.

In this article, we don't take a position on whether hydropower, or PSH in particular, *should* be considered renewable energy sources, which is a topic of some scholarly debate. Instead, in adopting an ethnographic approach, we aim to capture project engineers' native perspectives, in this case, including their view of this emerging energy technology as renewable. This methodological approach is essential to gaining an understanding of engineering knowledge and practice within the context of this project and within the broader context of the global energy transition.

This particular project has major financial and technical backing from Chinese energy firms and is linked to China's Belt and Road Initiative (BRI), a multi-trillion dollar infrastructure investment program designed to export Chinese technology and expertise around the globe through a network of transportation, logistics and energy infrastructure, thereby presumably bringing countries more firmly into China's sphere of geopolitical influence. While there is a rich literature on the BRI in terms of large-scale geopolitics, few ethnographic studies have analyzed how BRI institutions and personnel operate in specific local contexts (Sidaway et al. 2020). Scholars have pointed out that BRI is better understood as a bundle of intertwined policies and projects rather than a monolithic program, and that it must be examined empirically in specific places (Oliveira et al. 2020).

Sociologist Karin Knorr Cetina critically examined the processes of knowledge-making in two scientific fields, high-energy physics and molecular biology. In her analysis, "epistemic cultures" consist of "sets of practices, arrangements, and mechanisms bound together by necessity, affinity, and historical coincidence which, in a given area of professional expertise, make up how we know what we know" (1999, 363). In the present paper, we explore a series of questions about how renewable energy engineers from China, Israel and Europe construct and maintain a set of epistemic cultural practices, especially related to the implementation of professional standards, within transnational flows of capital, technology, materials and expertise. How do renewable energy engineers employ "objective" knowledge such as engineering standards and codes, while also drawing on their subjective experiences to solve day-to-day technical problems? How do they conceptualize safety and risk amid challenging and uncertain conditions? How do historic and contemporary geopolitical relations, including China's Belt and Road Initiative, shape knowledge hierarchies and practices on site? When epistemological differences arise, particularly along the fault lines of nationality or cultural background, how are these differences negotiated and managed?

We draw inspiration from the scientific and technical concepts these engineers work with on a daily basis—in particular, the idea of "turbulence." In fluid mechanics, a field that is foundational to hydrologic engineering, a turbulent flow is driven and characterized by chaotic changes in pressure and velocity. In contrast to "laminar flow," which occurs when a fluid flows in parallel layers with no disruption between those layers (Batchelor 2000), turbulent flows are inherently stochastic and unstable. Similarly, the engineers working on the pumped storage hydropower project—Israeli, European and Chinese nationals—dealt daily with turbulent conditions shaped by their divergent backgrounds and training, by differences in technical standards and codes, and by a rapid development paradigm driven by China's geopolitical rise and the imperative for renewable energy to mitigate the climate crisis. We argue that the concept of turbulence captures the unstable but creative qualities of the epistemic differences in such transnational engineering projects.

Developing renewable energy is one of the defining challenges of our time. Global investment in renewable energy is growing exponentially, with major backing from the Chinese government, banks and corporations. Understanding the emergent epistemic cultures of the engineers and experts within this sector is thus a crucial step toward understanding the present and future of this geopolitically vital field.

Methods And Research Site

Pumped storage hydropower is a type of renewable hydroelectric energy storage used by electric power systems for what is often termed "load balancing." The technology is essentially a hydrologic battery. It works by constructing two reservoirs at slightly different elevations, generating power at high-demand (and high-price) times by moving water downward through a turbine, then pumping the water back up at low-demand (low-price) times. In Israel, PSH is used as a backup power source, with the potential to generate 1.1 billion kilowatt-hours of electricity, constituting more than 50% of the country's emergency power. This project, and others like it, are thus of great strategic significance to Israel's national security and for maintaining the stability of the local power system.

Our research site is the largest pumped storage hydropower project in Israel, with an installed capacity of 344 megawatts. It is located in the Jordan Valley, near the Sea of Galilee (see figure 1). The first author, who was responsible for fieldwork, carried out several months of ethnographic research in 2019, both in Tel Aviv and at the construction site. It was the dry season, with average high temperatures reaching 44 degrees Celsius. The engineers came and went from a series of one-story temporary office buildings located near the hydropower station's lower reservoir in a dusty valley, their faces red and windblown beneath their hardhats. In one sense, time seemed to stand still amid the constant noise of clanging steel rebar, excavators, trucks, cutting machines, and other heavy equipment. In another sense, however, the passage of time was evident: with any delay threatening the project's financing, the engineers were under enormous pressure to bring their work to completion as quickly as possible.

The PSH project was initiated in 2017 and was scheduled for completion in late 2021, but has since been delayed to 2022. Approximately 160 engineers regularly work on site. These engineers come from different national and professional backgrounds, including local engineers from the Israeli government and project developer; German and British engineers from the banks financing the project; and Chinese, French, Italian, and local engineers from contracted construction companies.

China's economic and technological ties to Israel are part of the Belt and Road Initiative (BRI), a massive global infrastructure development program that began in 2013 (see figure 2). The Chinese government describes the Belt and Road Initiative as a strategy "to enhance regional connectivity and embrace a brighter future together" (Xinhua 2015a). The history of this policy initiative is significant, marking China as a major geopolitical player capable of shaping international relations through the exercise of soft power. During a visit to Kazakhstan in September 2013, Chinese President Xi Jinping called for the establishment of what he called the "Silk Road Economic Belt" (Xinhua 2015b). One month later, in Indonesia, Xi called for the creation of the Asian Infrastructure Development Bank (AIIB) and the construction of a "Twenty-First-Century Maritime Silk Road." These proposals collectively came to be called the "One Belt and One Road Initiative," later shorted to the "Belt and Road Initiative," or BRI (Huang 2016). In November 2013, the BRI was written into the comprehensive reform blueprint adopted by the Chinese Communist Party leadership as a key policy priority in the years leading up to 2020 (Central Committee of the Communist Party of China 2013), which would shape the priorities of key government agencies for years to come.

Figure 1. Map of Project Location. (Source: Google Maps. Accessed June 30, 2022).

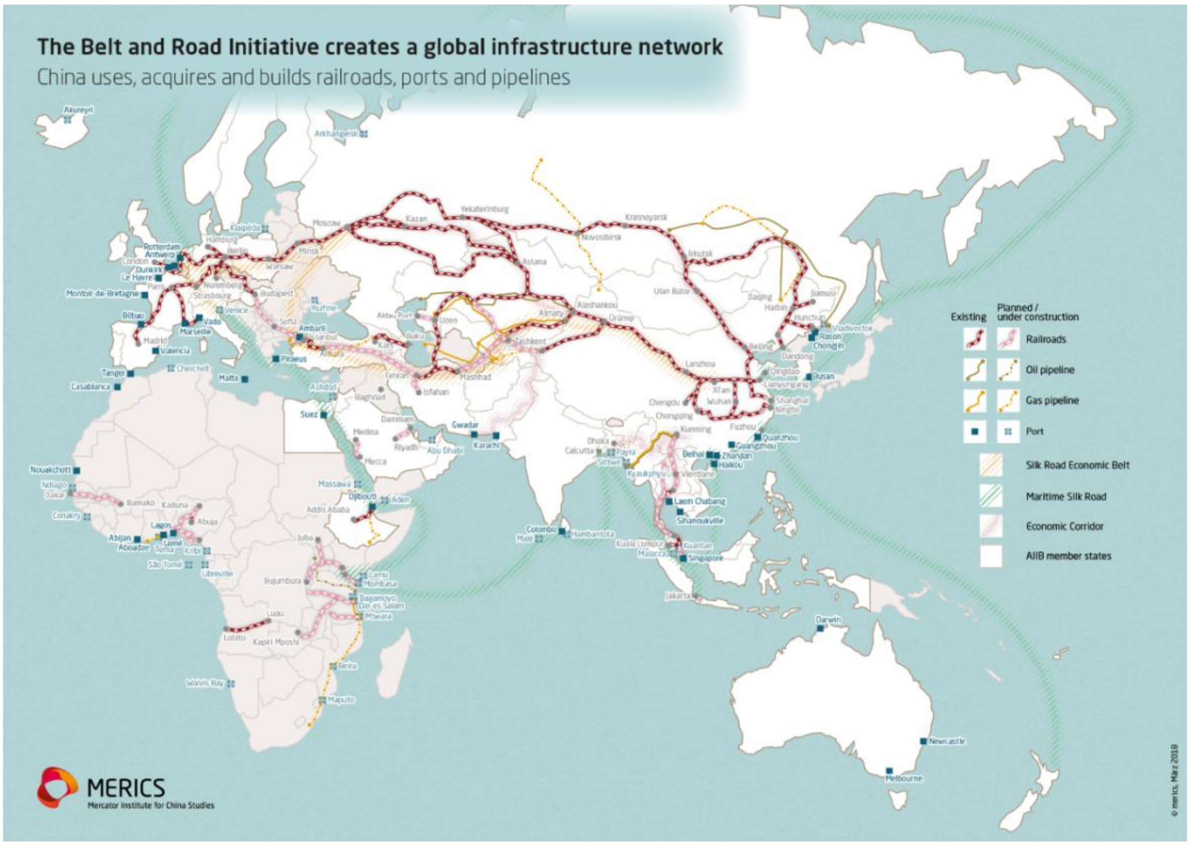

Figure 2. Map of key BRI projects. (Source: Reproduced with permission of the Mercator Institute for China Studies).

Table 1. Basic demographic characteristics of interview participants

Participant Pseudonym	Nationality	Age	Years of Experience	Professional Role
Ages	Israel	68	35	Construction site management
Gur	Israeli	39	12	Mechanical
Ashkenazi	Israeli	35	10	Geological
Allesio	Italian	61	25	Geological
Basquin	French	45	18	Electric
Li	Chinese	49	24	Mechanical / procurement
Shen	Chinese	49	24	Hoist
Wen	Chinese	44	24	Construction site management
Zhao	Chinese	42	20	Geological
Chang	Chinese	41	25	Construction site management
Chu	Chinese	40	12	Geological
Mao	Chinese	39	15	Contract management
Chen	Chinese	38	13	Structural / design
Wu	Chinese	38	12	Geological
Shen	Chinese	37	14	Mechanical / design
Yao	Chinese	37	15	Civil / design
Ao	Chinese	37	15	Construction site management
Liu	Chinese	37	14	Civil / design
Dai	Chinese	36	13	Construction site management
Chen	Chinese	35	12	Civil / design
Hou	Chinese	33	9	Civil / construction
Wang	Chinese	33	8	Construction site management
Luo	Chinese	32	6	Civil / design
Zhang	Chinese	32	10	Procurement management
Wu	Chinese	32	10	Construction site management
Xue	Chinese	31	7	Geological
Liu	Chinese	30	6	Mechanical / procurement
Xu	Chinese	30	3	Geological
Ding	Chinese	28	2	Contract management
Liu	Chinese	27	2	Structural / design

Initially focused on China's neighbors in Central Asia, the scope of the BRI has broadened to include new regions and a huge array of projects such as roads, seaports, oil and gas pipelines, railways, and logistics centers. Israel occupies an attractive strategic position within the BRI framework: at the crossroads of the Indian Ocean and the Mediterranean Sea, the country is a key geopolitical link between Asia, Africa, the Middle East and Europe (Harutyunyan 2020). Although Israel has not signed a formal memorandum of understanding acceding to the BRI, Prime Minister Benjamin Netanyahu, in bilateral meetings with President Xi Jinping, expressed Israel's support of the initiative. Israel is also among over 100 member states in the Chinese-led Asian Infrastructure Investment Bank.

The first author conducted participant observation and in-depth interviews with thirty engineers working on the project. We adopted a quota sampling method (Bernard 2017) such that the nationality of engineers in the sample roughly matched that of the overall population of 160 engineers working on the project: about 82% Chinese, 10% Israeli, and 8% European (see table 1). The study participants were all male, reflecting a gender imbalance common to most Belt and Road project sites. While there were a few women on the project site, they worked as cooks, secretaries, interpreters and cleaners—not as engineers or other technical professionals (Chen 2020). We coded and analyzed interview transcripts in the original language (Chinese or English), developing a codebook containing themes and subthemes on the topics of interest (Saldaña 2015; Bernard, Wutich, and Ryan 2017). Interviews ranged in length from 45 minutes to four hours, exploring engineers' personal and professional backgrounds; their use of both objective bodies of knowledge and subjective judgment in their work; their ways of managing cross-national and cross-cultural conflicts on-site; and their perceptions of how geopolitics influence renewable energy development. We also conducted participant observation, both in the project office and on the construction site, and attended work meetings and after-work activities. Additionally, we collected audiovisual materials related to their work processes and outcomes, including photos and videos of design drawings, rock samples, and construction procedures, along with technical reports and policy documents for archival research.

Theorizing Renewables: Energy, STS, and Epistemic Culture

Advances in energy development have arguably constituted the most crucial driver in improving humanity's material wellbeing. Yet energy is far more than a physical entity; it is a conduit through which social, political and economic relations are negotiated. Anthropologist Laura Nader, writing in the last four decades ago, presciently observed that scientific specialization could lead to insular thinking and conformity, with the potential to close off creative thinking about energy futures (Nader 1996, 2010). Driven in part by the climate crisis, the last few years have seen vigorous engagement in the social sciences and humanities pushing us toward "new ways of thinking about, valuing, and inhabiting energy systems" (Daggett 2019, 2). Scholars have identified the need for more human-centered explorations of energy development (Sovacool 2014), and many have noted the crucial goal of linking social science and natural science to elucidate the normative and cultural factors that underlie new energy technologies (Szeman and Boyer 2017; Jenkins et al. 2016). Ethnographers have recently made notable empirical contributions on particular energy sources in disparate places, from offshore oil production in Equatorial Guinea (Appel 2019) to wind power in Mexico (Boyer and Howe 2019), hydropower development on Latin America's transboundary rivers (Folch 2019), and marine energy development in Scotland (Watts 2018).

Some of the most productive ethnographic engagements with energy are situated in the interdisciplinary field of Science and Technology Studies (STS), exploring how social, political and cultural forces shape scientific and technological innovation, and vice versa (Jasanoff et al. 2001; Traweek 1993). These engagements owe an intellectual debt to researchers working from the 1970s onward, as two important trends converged: the energy crisis with its subsequent oil embargos, and economic shifts in the world's richest countries from manufacturing to the service sector. This provided a rich environment for researchers to begin thinking about how to understand the linkages between technology and society in new and productive ways, with energy at the center of analysis (Callon 1986; Law and Callon 1988; Wong 2016). Critical social scientists in STS and related fields even encourage researchers to consider the more-than-human relationships stemming from the choices humans make about energy and the environment (Haraway 2016; Ingold 2013).

Since Bowker (1995) developed the idea of infrastructure inversion, encouraging scholars to foreground infrastructure in their analyses, scholars in STS have followed this line of inquiry and examined the ways in which engineers in energy and related sectors intervene in the technological, sociological, and cultural connections between machines, biota, built environments, and human beings (Larkin 2013; Carse 2014; Anand 2017; Harvey and Knox 2015; Fisch 2013). A recent trend has been the investigation of mega-projects and other forms of infrastructure, with a focus on how professionals employ particular standards and materials in the knowledge production process (Lampland and Leigh Star 2009; Smith and High 2017; Goodman 2018).

In this way, we can consider the extent to which engineers working in the renewable energy sector generally, and on this particular project in Israel, construct and maintain an "epistemic culture" (Knorr Cetina 1999). Applying an epistemic culture framework allows us to examine how transnational networks of experts are bound together by common values, common understandings of material reality and knowledge production, and even common ways of acting and influencing policy (Haas 1990; Sovacool 2006). It allows us to see this particular renewable energy project in Israel, built with Chinese financial and technical input, not merely as a site of geopolitical contact or technological application, but as a mixing site of epistemic culture shaped by turbulent flows of knowledge and expertise.

Objective Standards, Subjective Interpretation

Wen, the chief engineer representing the Chinese contracting firm, occupied an office with a large bookcase full of white, blue and yellow binders. The bookcase also held the bowl and chopsticks Wen used for his meals, the only non-work-related items in evidence in the room. During an interview, Wen said that the binders were full of engineering standards, but that he had not read many of them. "They are all in Hebrew," he said. "We're translating them into Chinese, but we're not finished yet, even after two years of work."

Walking into any structural engineer's office on site, the two most conspicuous objects were clusters of rock samples on the floor and piles of engineering codes and standard documents on the table. The documents, their pages worn with use, might be in Chinese, English, or Hebrew. Standards and codes arguably play the most crucial role in engineers' work. In the engineering world, standards are the sets of technical guidelines governing efficiency, safety and reliability. In this case, engineering standards also constitute a means for Chinese firms to exert growing influence in the future direction of energy infrastructure around the world.

In 2017, China's State Council issued "Opinions on Promoting the Sustainable and Healthy Development of the Construction Industry" (China State Council 2017). This guideline was designed to strengthen the connection between Chinese and foreign standards. The guidelines call for "giving priority to promotion and application in foreign investment, technology export and construction assistance projects; actively participating in international standard certification, exchange and other activities; and carrying out bilateral cooperation in engineering technology standards" (ibid., 5). The guidelines further stipulate that, by 2025, all of China's national standards for engineering construction will be available in foreign languages. A recent policy analysis (Cai 2017) concluded that one of the least understood aspects of the Belt and Road Initiative is the Chinese government's desire to use this initiative to export China's technological and engineering standards around the world.

We asked the engineers on site in Israel how they defined and conceptualized the term "standards," and participants offered a range of narratives underscoring the importance of standards in their work. Standards were seen as "the baseline," "a line you should never cross," and even as "the Bible." Engineers routinely discussed the rational and objective nature of standards, underscoring the fact that these technical guidelines are grounded in mathematics and physics. For Chinese engineers in particular, "standardization" (*biaozhunhua*) was seen as a key goal. However, in discussing how they actually applied formal standards in their day-to-day practices, engineers often struck a very different tone, noting that standards were not always "black and white" and describing how standards could sometimes be applied in flexible ways. Chen, a 38-year-old Chinese structural engineer with thirteen years of experience, reflecting on the application of standards in his work, noted:

> For a particular section of reinforced concrete, the amount of inside steel bar is calculated to be three in theory, but you may have four according to the practical construction requirements. So, should it be four or five or three? There is a gray area, which depends on [engineers'] different understandings. In reality, even if a factor does not meet the required value in the standards, we may do the analysis again, checking whether other factors are higher than we expected, or re-considering other related calculations, to provide an explanation that the outcome could be "regarded as" meeting the standard.

The actual process of applying standards and technology thus depended to an extent on engineers' subjective interpretation within a specific context. However, that does not make their work less valuable or less trustworthy. Engineers' subjective interpretation of standards and technology was a vital part of their knowledge production process. As Ao, a 36-year-old Chinese engineer with thirteen years of construction site management experience, said, "When making judgments, inexperienced engineers might only tell you it's black or white, but experienced and qualified engineers would tell you how black or how white it is. That's [what] we need."

In fact, many engineers regarded the standards and codes themselves as distillations of previous engineers' subjective experiences. This recursive process contributes to their knowledge production. Engineers follow existing standards and believe that doing so is the best path to successful engineering practice. Meanwhile, they integrate, often unconsciously, their own subjective interpretations into these "rational" and "objective" standards, creating new patterns of practice. The new practice might later be recorded in a standard document, becoming new "objective" knowledge, a new line that one should never cross.

Similar processes of knowledge production have been documented in the STS literature within diverse contexts from microbiological laboratories to high-energy physics institutes (Latour 1993; Traweek 1992). What is unique about on-site engineering, however, is the speed of knowledge production. Engineers don't have three to five years to do experiments and research; instead, they need to finish the calculations and tests within several days and make a final decision about adopting a particular technical method to excavate a tunnel or to install a hydro-turbine. Because these are very capital-intensive projects, the construction period is subject to extreme time pressure; once the project has been initiated, the completion date is already set and a countdown starts. For the local project owner and the European financing bank, earlier completion means higher profits. For the Chinese and French contractor, failing to meet a deadline can result in heavy fines. Thus, tight time constraints force engineers from all stakeholders to apply standards in a more turbulent way, and to strike a delicate balance between speed, efficiency, and safety.

Standardized Safety, Unstandardized Risk

At 7:30 one morning, six engineers stood in the office of the project's design department discussing several geological problems that had to be resolved. On the floor were three boxes of rock samples and two pairs of steel-toed safety boots. On a whiteboard in one corner of the room, the engineers outlined the project's main geological risks and discussed strategies for ensuring an adequate margin of safety. All the engineers who participated in this study cited safety in their narratives as a primary goal. Ages, a 68-year-old Israeli engineer involved in the construction of the PSH project's main tunnel, described the tunneling process as "as much art as it is science," since underground work entails "an immediate presence of danger at all times." For design engineers, the "factor of safety" (FOS) was a focal point of every official meeting and informal discussion. Factor of safety refers to how much extra load or stress a structure will actually withstand beyond its normal or routine use.

For construction engineers, safety was the primary consideration when selecting technical methods and managing a construction site. Safety is the "absolute baseline" (*jueduide jixian*), a 50-year-old Chinese engineer named Shen, said, suggesting that, "whenever there is something related to safety, there is no flexibility at all." Some engineers even argued that "standards" and "safety" were synonymous. This relentless focus on safety reflects the potential dangers and risks inherent in energy engineering—both for on-site workers and for nearby communities. Shen summed up his career by saying,

> The greatest achievement of my career as an engineer is that no safety accident happened on all the projects I have done. People tend to think that, for technical engineers like us, preventing accidents is a basic thing we should guarantee, that it's nothing to be proud of. But we know that's not true. [Guaranteeing safety] is very hard.

Engineers work within an extensive safety system, consisting of design formulas, materials, engineering technology, modern management practices, and many other factors. Built by generations of scientists and engineers, this standardized system is designed and calibrated to prevent accidents and structural failures. Experts are trained to believe that such systems make it possible to significantly reduce the risk of accidents or structural failures, thereby avoiding loss of life or catastrophe. By extension, many engineers espouse a technocratic or techno-utopian point of view, believing that modern technology allows them to exert nearly full control over nature.

However, in practice, danger is always present in engineering work. Some engineers reflected on risk and danger in the context of their work, particularly when geologic, seismic and other natural forces were involved. Xu, a geological engineer, explained that:

> People know, deep inside, that we can never be sure about the mountain, about nature. You can calculate and establish a model and simulate the condition of rock a million times on a computer. All outcomes are positive, and one hundred percent safe. However, in reality, no matter how perfect your theory and how precise the model you use, there is still a 0.01% possibility that they won't work. It's not predictable (*bu keyuce*).

These engineers' constant struggle to ensure safety while confronting the uncertainty of nature is the kind of epistemic dilemma inherent in our modern "risk society" (Beck 1992), wherein rapid modernization forces people to confront previously unknown hazards. On the one hand, engineers, equipped with ever more advanced tools and materials, tend to believe that standardized scientific technology and technical methods can overcome risk and uncertainty, rendering predictable and controllable outcomes. On the other hand, engineers working closely with natural resources, especially geological and structural engineers, acknowledged the constant presence of uncertain, or even turbulent, situations. A very experienced geological engineer even suggested that "intuition" (*zhijue*), cultivated through years of experience, was an important asset in their work, acknowledging that risks beyond standardized knowledge will "always exist."

Perceptions of standardized safety and unstandardized risk were routinely shaped through communication among the engineers on site. Strict adherence to standards was seen as both a necessary safeguard for the project and as a means of protecting their careers and reputations. As Xu remarked, "The only reason engineers need standards is to exempt themselves from liability if an accident occurs." In other words, the primary goal was not to completely eliminate risk, but to systematically understand and manage the uncertainty of engineering work, grounding their decisions in standard practices and thus distancing themselves from potential turbulent and negative consequences.

High-End, Low-End

The pumped-storage hydropower project had a very complex financial structure, with investment from private Israeli companies, European banks, and Chinese state-owned enterprises. Project engineers from different countries had disparate ideas about how this particular energy project was situated within geopolitical relations, particularly in light of the rapid proliferation of Belt and Road projects around the world. Israeli engineers considered it a "European project," while French and Italian engineers described it as a "non-OECD project," even though Israel was actually admitted to the Organization for Economic Cooperation and Development in 2010. Meanwhile, Chinese engineers regarded the project with pride as their first "high-end" (*gaoduan*) project located in a "developed country" (*fada guojia*).

In classic theories of globalization, such as World Systems Theory (Wallerstein 1989), commodities and raw materials tend to flow from less-developed countries (the so-called periphery) to developed countries (the core); while knowledge, experience, capital and technology flow in the opposite direction. By contrast, engineering knowledge and expertise on this particular project tended to flow in a turbulent fashion rather than in a one-way direction. Because of the geopolitical location of the project and the multinational character of its personnel, engineers routinely debated whether to apply European, American, Israeli or Chinese standards in design and construction.

For instance, at one point in the project, a technical issue arose regarding the design of the surge shaft, a structure designed to prevent excessive hydraulic pressure from building up at the downstream end of the pipe as the water flows through the turbines. The engineers working on the problem discovered that none of the published standards was applicable to the situation. Ashkenazi, one of the Israeli engineers, mentioned that he had seen a similar issue on a project in South Africa years ago, so a team of Chinese and Israeli engineers studied the South African case, came up with a new plan, and successfully applied it to solve the problem. The South Africa Standard thus became drawn into the epistemic turbulence of the Israeli case, contributing to new knowledge production. About 70 percent of the engineers we interviewed had significant experience working in other countries, including Thailand, Vietnam, Morocco, Sudan, France, Italy, and Switzerland. Engineering experience and knowledge transcended the physical location of this particular project and the boundaries of nation-states, flowing from projects in other cities, other countries, and other continents to this project site. Over the last two decades, Chinese engineers have accumulated a great deal of experience working on large-scale hydropower projects. During the same period, hydropower development has largely stalled in developed countries due to concerns about environmental and social impacts; as a result, European and American engineers working in the hydropower sector may have experience on only one or two projects. Chinese knowledge production has thus emerged as a new and dominant force in hydro engineering (Tilt 2014; REN21 2020).

Many of the Chinese engineers expressed the view that their foreign counterparts on the project were using outmoded technology and standards. Ao provided an example:

> Israel borrowed its standard on rolling and filling concrete from the USBR [US Bureau of Reclamation] in the 1950s, which stipulated that each layer of filled concrete should not exceed twenty centimeters before rolling. Israeli engineers have followed that standard for more than half a century. But China developed a new rolling machine several years ago, which can roll the concrete as thick as forty centimeters. This practice has been used by engineers in many African and Southeast Asian countries. Here, our new technology confronts the old Israeli/USBR standard. Israeli engineers believe their standard is more advanced and trustworthy. So, how thick do we fill the concrete before rolling? We can't just ask them to trust us; we need calculations, tests with machines and materials. We need to make a whole new technology plan.

The fact that Israeli engineers believed their Western-derived standards to be more trustworthy shows vividly the long-standing geopolitical hierarchy in engineering knowledge. Yet on this particular project, it is nearly impossible to draw a clear distinction between "high-end" and "low-end" technology, in part because of China's rapid acquisition of expertise over the past several decades. China's emergence as a global geopolitical power has destabilized old hierarchies of knowledge and expertise. Many engineers expressed the view that engineering theory and precedents were not infallible, that no particular set of standards were superior to others, and that it was up to the on-site engineers to apply the right standards to a particular problem. Moreover, engineering standards are no longer singular; instead, through this turbulent process of application, they have become plural and subject to dialog and negotiation.

"Four Times, Seven Times, Or Fifteen Times": Epistemic Conflict

During one project meeting, several Chinese and French engineers were working out some details at the intersection of civil and mechanical engineering. One of the Chinese engineers was in the middle of a short presentation in English about the upcoming schedule when one of the French engineers stopped him, saying that the French team had been working with a different schedule in mind. For the next ten minutes, the meeting broke into two groups, one speaking in Chinese and the other in French. When both groups had reached some kind of internal understanding, the larger conversation resumed in English. This type of scene played out on a daily basis amid differences in nationality, background and language. In this case, language was merely the most obvious signifier of epistemic differences between project personnel.

Although engineers from different national and cultural backgrounds worked closely on a daily basis, it took time and effort to get accustomed to each other's professional practices. Moments of friction and conflict regularly arose. In one instance, engineers working for the main contractor clashed with those working for the project owner about the appropriate parameters for a rock-anchored beam, a crucial support structure in the underground tunnel. The argument centered on something called a "bend radius," which is the minimum amount a given material can be bent without damaging it. Narratives about this conflict varied among different groups, and provide a window into how epistemological conflicts were negotiated on-site.

Many of the Chinese construction engineers attributed the conflict to the project owner's distrust of non-Western technology. They argued that, based on Chinese standards, a bending radius of four times the diameter of the reinforcing steel bar was adequate for safety. However, the engineers working for the main contractor (both Chinese and Israeli) had already modified the plan to seven times the diameter, using the Israeli standard. Meanwhile, engineers representing the project owner (some Israeli, and some European) insisted it should be fifteen times to ensure a proper factor of safety, even though they knew that calculation was from an older European standard no longer used in practice.

In their narratives, some of the Chinese design engineers interpreted the situation as a conflict of professional ideology and culture. They pointed out that Chinese engineers' training emphasizes pragmatic experience, while Western training emphasizes theory and calculation. Israeli and European engineers, meanwhile, perceived their Chinese counterparts as too "collective," making it difficult to establish who had ultimate decision-making authority on a given problem. This conflict was much more nuanced and complicated than simply calculating the "correct" solution; what seemed on the surface like a technical problem was actually underlain by deep cultural and institutional differences.

Although engineers on site came from slightly different personal backgrounds (for example, more Chinese engineers were from rural families, while more European and Israeli engineers were from the urban middle-class), they tended to attribute conflict mostly to their national and educational differences. To reach an agreement, the engineers had to acknowledge that the bend radius was not simply a mathematical problem with only one right answer, but rather a complicated situation requiring them to be patient and understand each other's "logic" and "rationality" first. Such moments resonate with what anthropologists Holmes and Marcus (2006) have termed "para-ethnography," a process in which professionals working in complex epistemological environments must struggle to make sense of various knowledge claims.

In the end, the engineers never reached a conclusion on the value of the bend radius. Instead, they established a new working procedure accepted by each party, requiring the team to increase the frequency of material testing and inspection, setting up milestones and sub-milestones, and adding steps to improve communication and decision-making. The process, rather than the outcome, became the solution. The new process was not Chinese or European or Israeli, but a blending of these approaches designed to solve a technological conflict through non-technological means. Knowledge production took place in a turbulence—which is for engineers to understand and manage—together with critical social scholars this time.

Discussion and Conclusions: Revisiting Turbulence and Epistemic Cultures

We have suggested that "turbulence," a key concept in hydrologic engineering, is an apt metaphor for the process of knowledge production on this pumped-storage hydropower project, in part because of the rapid pace of energy development and the transnational movements of engineering concepts and personnel. Over the past four decades, China has experienced unparalleled economic growth, investing considerable financial resources and technical expertise in its domestic infrastructure projects. As a result, Chinese corporations and engineers have developed world-leading expertise in water infrastructure generally and hydropower projects in particular (Tilt 2014). The Belt and Road Initiative now provides a means for Chinese firms to apply this expertise around the world, accelerating the process of geopolitical and economic integration through infrastructural development (Rippa, Murton, and Rest 2020). Multinational energy project sites have thus become the frontier of a shifting engineering world, a new frontier for ethnographers and social scientists to explore and understand. This sense of acceleration was internalized by Israeli, European and Chinese engineers alike, who, when asked about their work schedules, often quipped "sooner is better."

From the early twentieth-century onward, transnational energy corporations, mostly of European and American origin, began to seek energy resources and business opportunities all over the globe. Yet, the geopolitical lines of energy development are no longer so clear. In the past decade, engineers from non-Western countries, including Japan, Korea, Turkey, India, and China (countries ordered by the transnational flow of engineers entering the program), have started to join in this transnational flow (Akgul et al. 2017; Park et al. 2011). On average, Chinese engineers working on this PSH plant have spent around nine years on overseas energy projects, from Southeast Asia and Africa to Latin America and the Middle East. Many of them spend over ten months per year on overseas projects, meaning that their personal and professional lives became centered on their work sites rather than back in China. Chinese engineers collaborated with both Western and local engineers on most projects, taking new knowledge, technology, and practices as well as personal experience to their next project in some other country. The global motion of engineers thus shapes and accelerates the turbulence on energy production sites across geographical and epistemic boundaries.

To understand the expansion of the rapid-development model in the energy production field, we also need to grasp the role of the climate crisis. The International Energy Agency (IEA)'s 2019 report highlights the urgent need for renewable energy sources and new energy production paradigms:

> The world urgently needs to put a laser-like focus on bringing down global emissions . . . [We need] a pathway that enables the world to meet climate, energy access and air quality goals while maintaining a strong focus on the reliability and affordability of energy for a growing global population (International Energy Agency 2019, 3–4).

Global investment in renewable energy is growing exponentially—an encouraging trend, considering that the energy sector accounts for a large share of greenhouse gas emissions. China's role in this trend is startling; a recent report by the UN's renewable energy advisory body, REN21, concluded that Chinese investment accounted for nearly one-third of total global investment in renewables (REN21 2020). Similarly, according to a 2019 report issued by the Global Commission on the Geopolitics of Energy Transformation, a commission set up by the International Renewable Energy Agency (IRENA), the geopolitical and socio-economic consequences of the rapid growth of renewable energy could be as profound as those which accompanied the shift from biomass to fossil fuels at the dawn of the industrial age. New global leaders in energy development will undoubtedly emerge, changing patterns of trade and strategic alliances. China's Belt and Road Initiative is clearly a strategic effort to place Chinese banks, corporations and personnel at the center of this emerging network.

We have suggested that, within these turbulent flows of geopolitical and technological change, a key role for ethnographers is to elucidate epistemic cultures, the systems of knowledge-production within which experts conduct their work. Understanding how engineers apply technical standards, construct notions of safety, and negotiate epistemological differences is particularly crucial in the field of renewable energy, which will shape human lives in innumerable ways in the decades ahead. Critical social scientists have suggested that engineers are often portrayed as techno-utopians, unthinking functionaries who view progress as an unmitigated good without regard for unintended consequences:

> Engineers often emerge as the villain, the technology-driven developmental program through which capitalist formations emerged and consolidated over the twentieth century . . . [They] have certainly achieved "progress" for the few at great social and environmental cost, producing what now appear to be irreversible toxic consequences that challenge our planetary future (Harvey and Knox 2015, 32).

Much of the social science and humanistic literature similarly views the practice of engineering as techno-centric, standardized, or even reductionist (Nader 2010; Harvey and Knox 2015; Wisnioski 2012). The engineers in our study, however, often described their work in moral and ethical terms, expressing the view that "we are doing good for future generations." This paradox reveals that, energy companies and engineers alike are driven, at least in part, by a perceived moral imperative to develop renewable energy sources to mitigate the climate crisis.

Their narratives also reveal considerable nuance and humility about their ability to control the uncertainty involved in complex engineering problems. Far from viewing their work as black and white, many expressed a knowledge of the limitations of engineering models and standards. At a micro level, the small molecules in turbulent flows often move in disorderly and unpredictable ways. Similarly, engineers' narratives in this study reveal the ways in which they are buffeted by macro-level forces—including market conditions, technological change, and geopolitics—that they cannot control. In the process of managing turbulence and conflict, they forge identities as both practitioners of existing knowledge and innovators of emerging knowledge.

This process of forging new identities and new connections resonates with many of the foundational ethnographic studies of globalization, including Tsing's (2004) notion of friction, which she describes as the "awkward, unequal, unstable, and creative qualities of interconnection across difference (ibid., 4)." This study highlights the fact that expert epistemologies are not static or fixed. While they are grounded in historical trends, long-term professional standards, and geopolitical relationships, they are also subject to negotiation and adjustment. The epistemic culture of the Israeli, European and Chinese engineers on this particular energy project represents one small case study of the changing global structure of renewable energy development, one in which Chinese firms are newly ascendant. The future of renewable energy development, one of the key challenges facing humanity in the twenty-first century, is not merely a technological question. Scholars in STS and related fields have a crucial role to play in elucidating how expert epistemologies in the renewable energy sector will shape the future of this vital field.

Acknowledgements

Fieldwork for this project was generously supported by the Anthropology Program at Oregon State University. The authors would also like to acknowledge the three anonymous reviewers whose comments and suggestions helped sharpen the arguments in this paper.

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