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Energy Regulatory and Industrial Complex (ERIC): A New Framework

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Abstract: Climate change agreements force us to explore interconnected social, economic, and energy related transitions needed to combat the effects of anthropogenic activities on the Earth's climate. To help us understand what brought us to where we are today and guide us in our decision-making for tomorrow, we introduce the Energy Regulatory Industrial Complex model (ERIC). ERIC illustrates the transformation of energy from energy sources through to energy services, as in energy flow diagrams, but adds the emissions greenhouse gases from those transformations. ERIC includes the creation of wealth enabled by energy services, innovation that supports advances in science and technology, and activities that maintain and sustain existing systems. Policies and geo-politics can influence each decision and investment stream. At its core, ERIC relies on a firm foundation of education. Using data from the United States and India, we show how ERIC can be used to pinpoint the vulnerabilities and places for interventions in transitioning to a clean energy future.

Keywords: Climate change, Education, Energy flow diagram, Energy systems, Energy transition

For decades now we have been hearing about the increases in atmospheric concentrations of greenhouse gases that blanket the earth, trapping heat, and altering the patterns of rain- and snowfall, storm intensities, land and sea surface temperatures, glacial melt rates, and the timing of seasonal changes. Those involved in agriculture have witnessed declining yields, the increased prevalence of invasive weeds, and an influx of pests and pathogens adapted to the new (often warmer and more humid) conditions on the ground (Malhi et al., 2021). Extended droughts and desertification of land or more severe storms and floods have destroyed crops in the field (Arora 2019). While yields and growth rates of crops like rice and wheat may increase in the carbon dioxide-rich atmosphere of the present and future, the nutrient production of these crops under high CO_2 concentrations tends to decrease (DaMatta et al., 2010, Leisner 2020). One thing is clear: climate change has not left and will not leave agriculture unscathed. In a broader sense, the places in which we live are being fundamentally altered by climate change. That then leads us to question: "What has been or is being done to mitigate the impacts of climate change or adapt to those impacts?"

Recall that in 1997, the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Kyoto Protocol. The Protocol called for industrialized countries (the Annex I Nations) to limit and/or reduce emissions of anthropogenic greenhouse gases causing climate change by an average of five percent relative to 1990 levels during the first commitment period of 2006-2012 (United Nations Climate Change; UNFCCC, 1997). Under the Protocol, much of Europe, North America, the Russian Federation, and Australia needed to reduce emissions, but China and India did not. By 2022, 192 nations had ratified Kyoto. Notably, Canada, a large producer of oil shale, withdrew in 2012, and although U.S. President Bill Clinton signed the Kyoto Protocol, he made it clear he would not submit it to the United States Senate for ratification unless key developing countries also participated (U.S. Department of State 1998). Thus, although President Clinton signed the Protocol on behalf of the country, the Senate never ratified it, and the United States was not bound by its commitments.

As Figure 1 below illustrates, despite ratification/ acceptance/approval of the Kyoto protocol by no fewer than 55 parties to the United Nations Framework Convention on Climate Change (UNFCCC) by 2005 (Status of Ratification, n.d.), emissions continued to climb in most regions of the globe, but particularly in Asia.

By 2015 and the 21st Conference of Parties meeting in Paris, focus shifted from limiting emissions by industrialized nations to a global effort decrease greenhouse gas concentrations. Accelerated action was required to maintain the average global temperature rise to below 1.5 °C, or, more likely, below 2°C by the end of the 21st century (Article 2). The new mechanism created for achieving that goal: the Nationally Determined Contributions (NDCs, Article 4). Based on the "principle of . . . common but differentiated responsibilities and respective capabilities" (Paris Agreement, p. 1), and recognizing the differences in financial and technological abilities among nations, every party to the 21st Conference would submit plans for reducing emissions

from burning fossil fuels and mitigating climate change and would provide updates every five years. Key to the success of the Paris Agreements would be financial flows from the developed countries to those with fewer financial resources, technology transfers, and capacity building where needed (Articles 8 - 11). The Paris Agreement recognized the need to safeguard food security and the "particular vulnerabilities of food production systems to the adverse impacts of climate change" (Paris Agreement, p. 1). It also affirmed the importance of education and training in achieving its goals. Thus, rather than just focusing on the quantifying emission levels, the Paris Agreement forced a reckoning with interconnected social, economic, and energy systems in combatting the effects of climate change.

With so much at stake and so many moving pieces at global, national, and subnational scales, it behooves us to develop ways to think about these systems, to diagram them, to create a map that can help us make sense of this amalgamation, to help us understand what brought us to where we are today, and guide us in our decision-making for tomorrow. To that end, we introduce the Energy Regulatory Industrial Complex model (ERIC) (Fig. 2). In the balance of this paper, we explore ERIC and its value in understanding the complexities of energy systems and decision-making about energy. Using data from the United States and India, we show how ERIC can also pinpoint the vulnerabilities and places for interventions in transitioning to a clean energy future.

The Value of the Energy Regulatory Industrial Complex model

To understand ERIC and its value for examining the connections between agriculture, energy, and climate change, we will begin in the lower left of Figure 2 with the box labeled "Primary Energy Sources." Furthermore, to illustrate our points we draw on the examples of our host country, India, and our home country, the United States.

Currently, there are nine primary energy sources available for our use: (1) solar radiation, (2) nuclear now fueled by uranium or a plutonium and uranium mix (MOX), (3) hydropower (falling water), (4) wind, (5) geothermal heat, (6) natural gas, (7) coal, (8) biomass (including firewood and ethanol made from corn or bagasse), and (9) petroleum. We feed these raw sources into refining processes then transform them into forms of energy that can be tapped to provide the services we rely on for our daily existence (Fig. 3).

Note that the width of the bars and the size of the boxes in the flow charts give us an easy way to determine the relative amounts of each of the inputs and the corresponding uses by the residential, commercial, industrial, and transportation

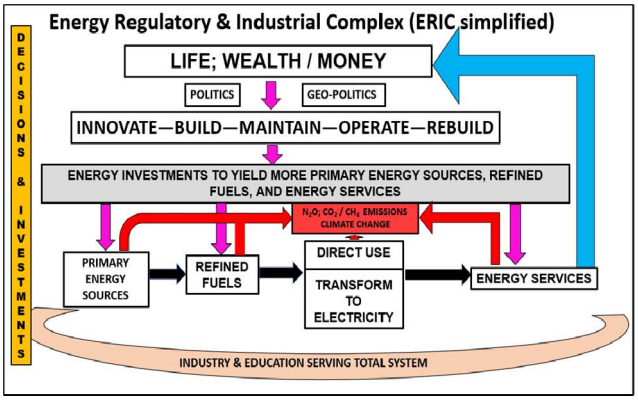

Fig. 2. Simplified Energy Regulatory Industrial Complex model (ERIC)

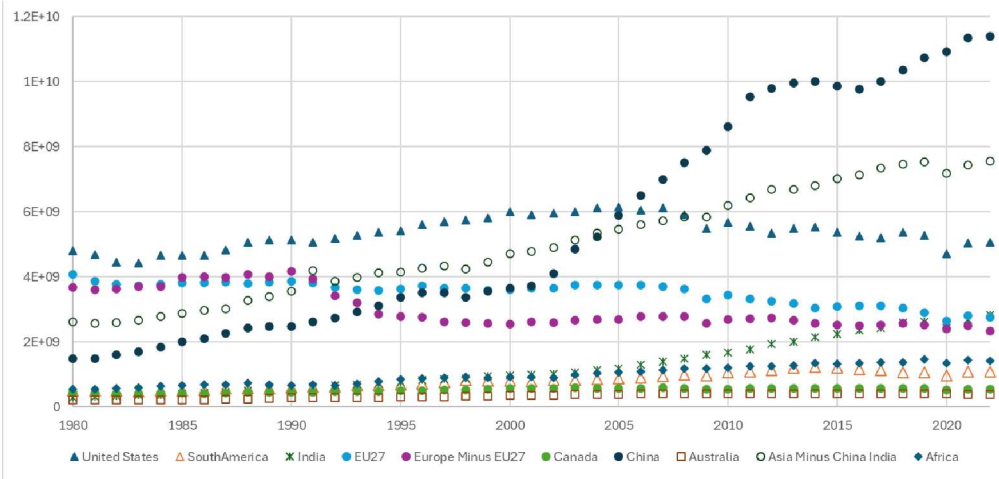

Fig. 1. Annual Greenhouse Gas Emissions, tonnes, from industry and burning fossil fuels but not including land use changes, shipping or air transportation (Source: Based on data from Our World in Data, https://ourworldindata. org/co2-emissions)

sectors. For both the United States and India, about 1/3 of the input energy provides useful energy services such as lighting, heating, cooling, or powering machinery, while 2/3 gets rejected as heat due to the inefficiencies of our conversion processes. In India, coal contributes over 43% of the energy used whereas in the United States coal amounts to 9.3% of the energy mix. Conversely, in the United States, natural gas now supplies over one third of the energy (35.7%) but only 5.7% in India.

Agriculture falls into the "Industrial" category in the Energy Flow Diagrams. In the United States, the agriculture sector relies on natural gas and liquid petroleum gas for heating and drying grain (Hitaj and Suttles 2016). Diesel and gasoline power farm machinery and electricity flows to lights, cooling systems, and pumps. In India, coal contributes to agriculture indirectly through electrical generation and as a feedstock to the production of nitrogen fertilizer. Coal enters agriculture directly in the form of fly ash, a powdery residue of the combustion of coal. Adding fly ash to soils can decrease their bulk density and aid in moisture retention (Yousuf et al., 2020) The lime in fly ash also reacts with acidic elements in soils, allowing for the release of nutrients and aiding in the remediation of severely degraded soils (Reid 2022, Yousuf et al., 2020).

Moving further along the bottom of the model brings us to energy services. The visible and yet unremarkable products of energy, energy services are the hallmarks of modern life: our ability to flip switches to turn on computers, lights, and water pumps; to traverse state or continents, or harvest grains more efficiently than using human or animal power; to access communications networks that reach neighbors, markets, or colleagues half a world away. To understand the emissions from the energy systems (Fig. 5), their contribution to climate change, we need to turn to a different type of modelling approach.

Using Life Cycle Analysis (LCA), we can focus on a particular technology or set of technologies (the "functional units"), accounting for environmental impacts throughout their expected life (Fig. 6).

Drawing the boundaries of the analysis is key to any life cycle or "cradle to grave" analysis. The boundaries set the scope of the analysis, helping researchers identify which processes and flows to include and which have no bearing on the question of interest (Hertwich et al., 2015, Nugent and Sovacool 2014). People making claims of carbon free electrical generation often isolate the generation plant from the upstream and downstream flows, draw the boundary so as to eliminate construction or decommissioning impacts from consideration, and focus only on emissions while the plant is generating electricity.

Maintaining the cradle to grave approach, we then explore environmental harms associated with resource extraction, processing, and fabrication of fuels and parts for the technology of interest. An LCA can encompass mining for non-renewable resources such as copper for wiring, lithium for batteries, chromium, and nickel (used in wind turbines).

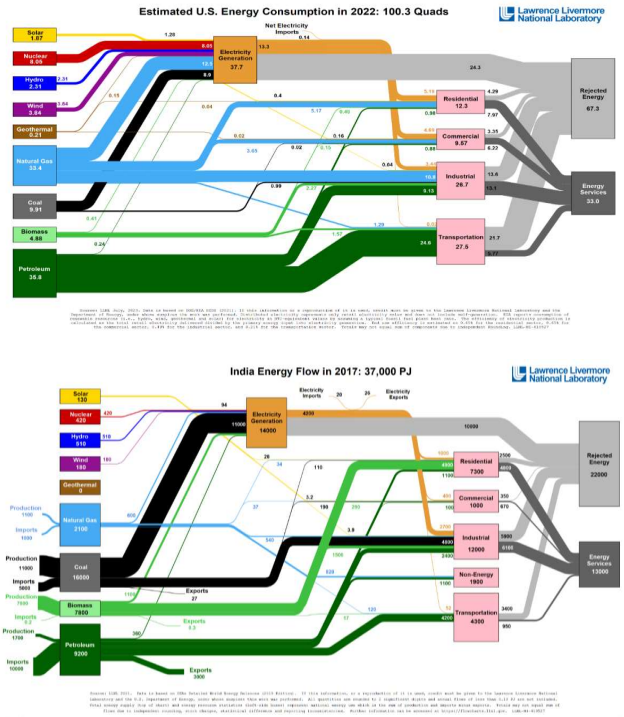

Fig. 4. Lawrence Livermore National Laboratory Energy Flow Diagrams for the (a) United States (2021) and (b) India (2017); One quad = 1.055 EE18 Joules and 1 PJ = 1.0 EE15 Joules

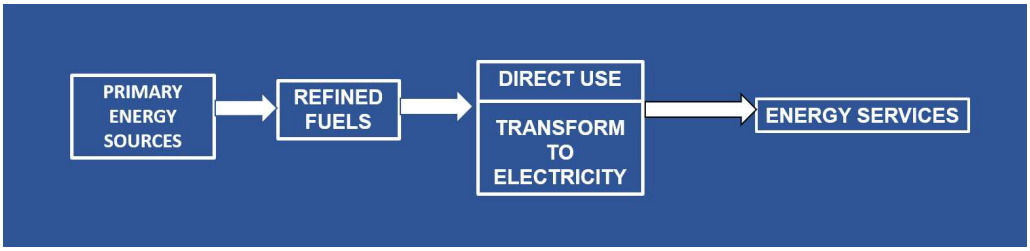

Fig. 3. Transforming primary energy (Sources into Modern Energy Services)

LCA can include emissions associated with transportation to a construction site and transformation of that site to one suited to its new purpose. Operation and maintenance of the energy facility often leads to emissions of particulate matter and emissions of carbon dioxide, sulfur and nitrogen oxides that could be incorporated into an LCA. In thermal systems, water becomes steam that spins turbines to generate electricity. Steam may escape into the atmosphere or may condense to be reused. Water flowing back to rivers or lakes may carry with it particulate matter or radioactive particles from the plant or reactor. Water also may have increased in temperature, impacting the delicate ecosystems beyond the discharge point. Finally, decommissioning or disposal of the facility carries its own environmental price tag as it gets cocooned and cordoned off, as happens with nuclear power plants, or remediated and used for other purposes. In the end, the LCA can provide us with summaries of the various inputs and outputs of each of the stages of life of the facility as well as the total throughout the life of technologies.

Drawing on the example of coal-fired electrical generation and based on a very detailed analysis of the flows of materials and energy through this system, Spath, Mann, and Kerr determined that over 97% of CO_2 emissions occur during power production (996 g/kWh for the average coal fired plant). Power production also resulted in the emission of 3.35 g/kWh of nitrogen oxides (NO_2) and 6.70 g/kWh of sulfur oxides (SO_2), both components of air pollution and smog. In contrast, 99% of the methane production occurred during the mining of the coal-equating to 0.913 g/kWh. Sequestration of methane releases during mining will be vital to reducing the impact of that potent greenhouse gas. Indeed, carbon dioxide, methane, and NO_x are some of the components of the red Climate Change box in the ERIC model.

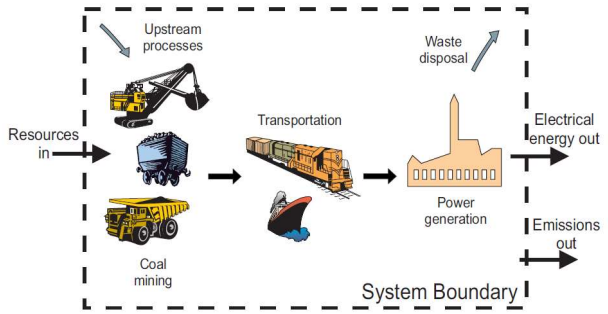

Fig. 6. Systems boundaries for a life cycle analysis of a coal fired power plant (Source: Spath, Mann, and Kerr, p. 4)

We can compare the LCAs of various electrical generation technologies on a per unit energy produced to understand their contributions to this aspect of environmental degradation. Figure 7 shows the output of numerous life cycle analyses for common electrical generation technologies, per kWh of electricity produced (NREL, p. 2). Not surprisingly, emissions associated with production from fossil fuel fired plants, even with carbon capture and storage, exceed the life cycle greenhouse gas emissions of production from renewable energy technologies.

Missing from both the energy flow diagram and the LCA are factors that give rise to selection of resources used, auxiliary benefits of particular technologies (such as heat generation or the creation of water reservoirs for irrigation (Weisser 2007)) and contextual conditions that influence decisions about technologies and investments, such as where to site an electrical production facility and whether to invest in solar or coal-fired generation. These models also fail to account for the recursive nature of the systems, the ongoing need for investments in resources, upgrades to equipment, education of personnel, and response to changing policies and demand profiles. Western economic models, built on the examples of the post-agricultural world in which economies of scale and increasing centralization brought lower costs and higher profits, tended to view "progress" and development in a unidirectional fashion. Progress meant greater amounts of goods and services offered for sale in larger and larger marketplaces, greater wealth, and thus greater prosperity (Ekelund and Hebert 2014, Lefeber 2000, North and Thomas 1970). That legacy has carried over into models like the energy flow diagram and the LCA.

However, we know that governments and legislators do step in to help move economies in desired directions when markets do not achieve desired results (the "Politics" box in Figure 2). In the case with renewable energy adoption and

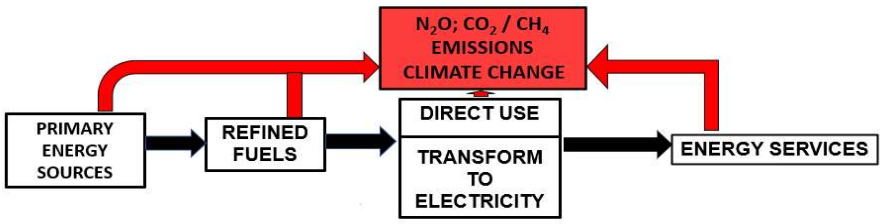

Fig. 5. ERIC, highlighting the emissions driving climate change

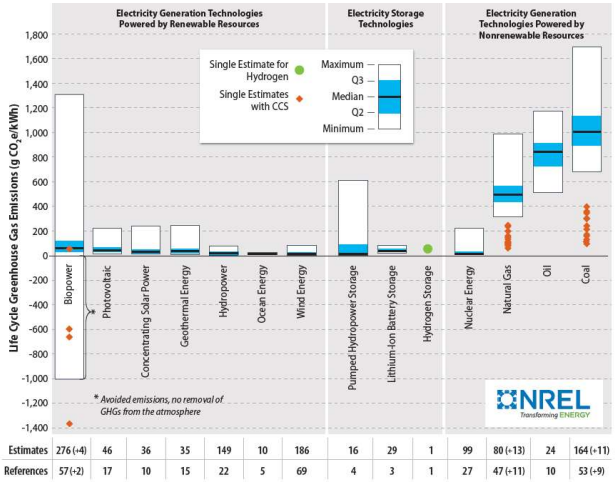

Fig. 7. Comparative life cycle greenhouse gas emissions from electrical generation technologies, gCO_2 e/kWh (Source: National Renewable Energy Laboratory, Life Cycle Greenhouse Gas Emissions from Electricity Generation: Update, p. 2)

solar photovoltaic (PV) panels, for example, initial success in the United States has been attributed to the adoption of state-level Renewable Portfolio Standards (RPS) that required utilities to include specified percentages of renewable energy in their resource portfolios (Bozuwa, Mulvaney, Estevez, Karlsson, and Malhotra, 2024). The California Solar Initiative, enacted in 2006, spurred investments in residential solar with rebates to customers of Pacific Gas and Electric, Southern California Edison, and San Diego Gas and Electric (Mendes 2022). The goal of 1940 MW of new solar capacity was reached two years ahead of schedule. President Obama's American Recovery and Reinvestment Act (ARRA) of 2009, which provided tax credits for solar technologies, really focused attention on the technology and its adoption. Figure 8 below shows the cumulative installation of solar PV across the United States, from a near negligible amount prior to the enactment of ARRA to the present. As the adoption of solar PV expanded, the economies of scale in producing solar panels helped reduce prices by more than half for residential

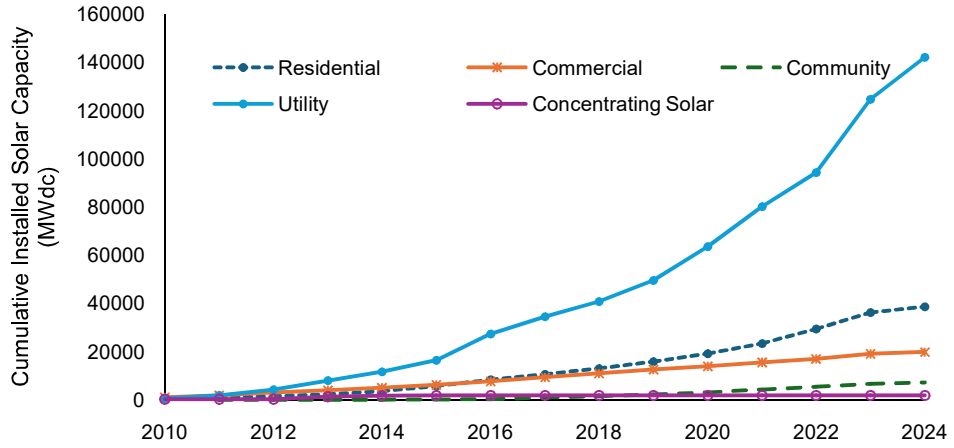

Fig. 8. Cumulative solar capacity in the United States 2010 through the first half of 2024, MWdc (Data Source: Solar Energy Industries Association, Solar Industry Research Data)

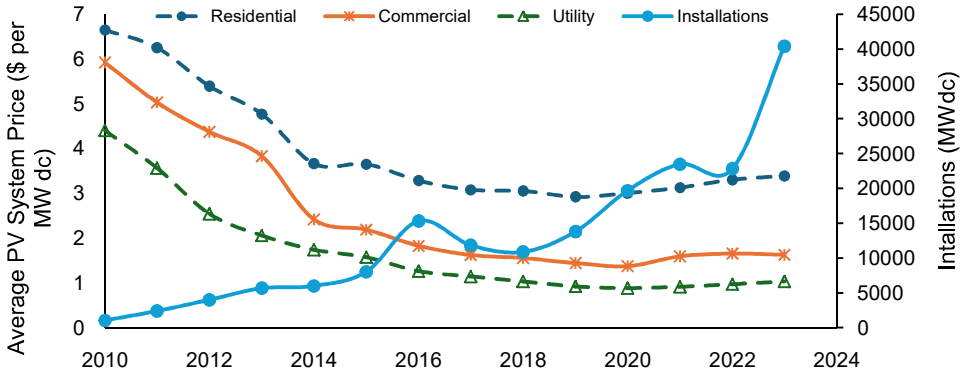

Fig. 9. Average Solar Photovoltaic (PV) System Price and Numbers of Installations, 2010 through 2023 (Data Source: Solar Energy Industries Association, Solar Industry Research Data)

customers and about 75% for commercial and utility-scale customers, further stimulating investment (Fig. 9; see also Gerarden 2018).

While many of us think of solar installations on rooftops as serving the needs of those dwelling or working in the building below, utility-scale solar parks have become increasingly common as nations strive to meet decarbonization goals. India's Bhadla Industrial Solar Park in Rajasthan, covering 5,700 hectares of the Thar desert, has a capacity of 2,245 MW (Dauphin 2022). This “ultra mega” solar installation can be seen from space (Fig. 10). One challenge for any facility of this size will be to ensure the electricity generated reaches awaiting customers through modernized transmission and distribution networks. Additionally, only time will tell what impact the construction of the arrays and shading of such a large swath will have on the desert ecosystem below and around it.

Fig. 10. Satellite Imagery of the Bhadla Solar Park, Rajasthan, India, 26 January 2022. (Source: Lauren Dauphin, https://earthobservatory.nasa.gov/images /149442/soaking-up-sun-in-the-thar-desert)

As the example of solar PV demonstrates, we can no longer assume static or equilibrium models, or even models that assume progress towards some nebulous goal of better and more, but instead need to think in terms of models that capture change over time and place. We need models that allow us to reflect the complexity of the system of interest sufficiently so that we can identify the important “leverage points.” According to systems theory, leverage points provide opportunities for change (Meadows 2008). They are “points of power” where small changes can ramify through the system to result in large shifts (Meadows, p. 145). Our question then becomes, “Where are the leverage points in the Energy-Regulatory-Industrial-Complex that will accelerate the transition to a clean and renewable energy future?”

ERIC Points Towards a Clean Energy Future

ERIC enables us to follow the impact of policies enacted at the federal, regional, state or even the local level, on pathways of innovation, decisions to invest in new technologies or to maintain existing systems (recall the top portion of Fig. 2). For example, while the government of India has espoused programs to bolster the growth of clean energy, it continues to subsidize fossil fuels, in part by

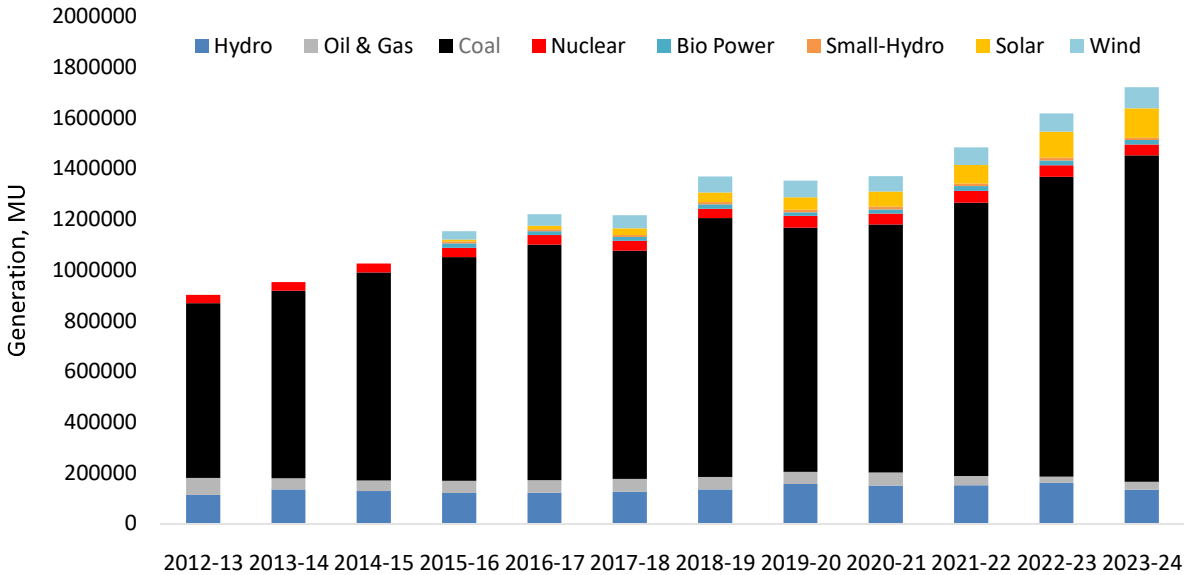

Fig. 11. Electricity Supply in India through May 2024 (Source: India Climate and Energy Dashboard, https://iced.niti.gov.in/energy/electricity/generation/power-generation)

capping their prices rather than letting supply and demand (i.e. market forces) set prices. In FY 2023, "clean energy subsidies remained less than 10%, while subsidies for coal, oil, and gas contributed around 40% of total energy subsidies" (Raizada et al., 2024). In the electricity sector in 2023, coal subsidies reached INR 50,000 crore (USD 6.2 billion) while subsidies for renewable energy installations amounted to only INR 14,843 crore (USD 1.8 billion). In July of 2024, the Modi government requested that power companies fast track equipment investments for about 31 GW of new coal-fired electrical generation (Singh 2024). That figure dwarfs the 2 – 3 GW added annually over the past decade (Fig. 11). To cover the expected growth in electrical demand--due in part to a need for cooling in response climate change driven heat increases--and to be able to fulfill campaign promises of stable electric supplies, Modi and the BJP party are backing coal rather than investing those funds in renewable sources and battery storage solutions (Arasu 2024, Mathur 2024).

While caps on the prices of fossil fuels in India keep the prices low for those who cannot afford high prices, the rural poor and small farmers, those price caps lead to a continued dependence on fossil fuels rather than an expansion of renewable energy supplies. We also know that the rail lines in India ship coal from the mines to the electric generating facilities (Adhikari 2024). The revenues from those shipments subsidize rail fares for human passengers. A push to phase out the use of coal could impact about 23 million people who ride the trains daily (Times of India 2023). In systems language, price caps and the revenues from coal transported by rail serve as balancing or stabilizing feedback loops-loops that push back against change from the current state (Meadows, pp. 28-30) (Fig. 12).

In the United States, the bi-partisan Inflation Reduction

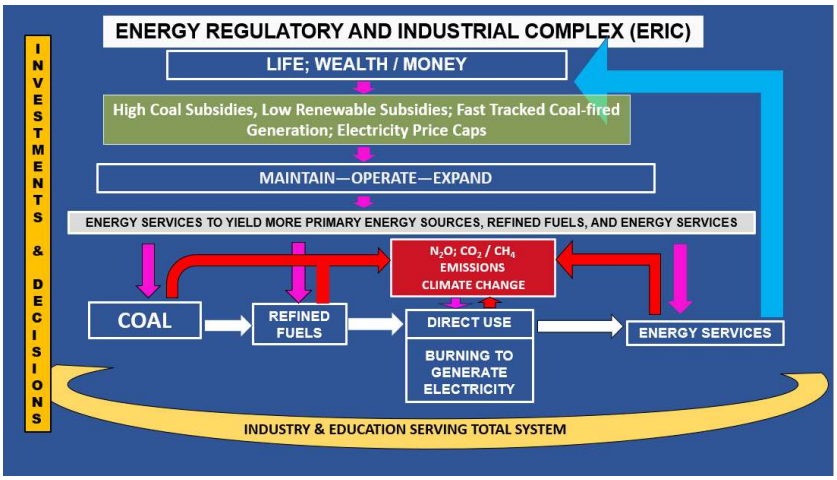

Fig. 12. An overview of the Indian coal economy as captured by ERIC

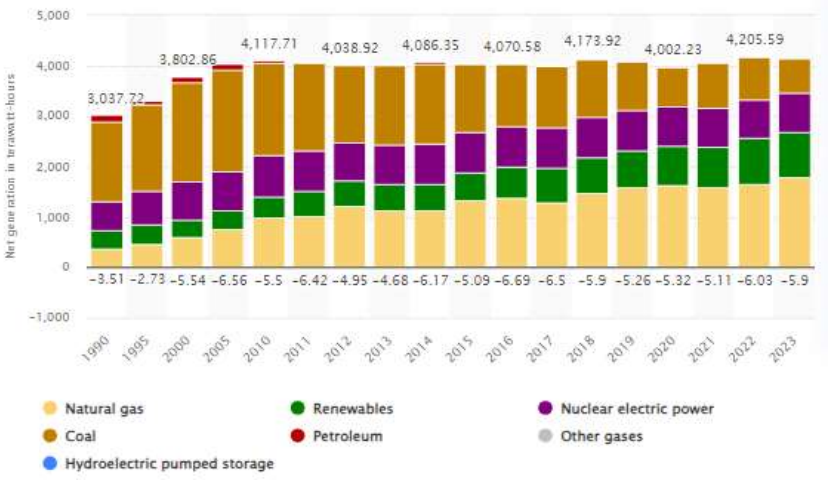

Fig. 13. Electrical Generation in the United States, tWh (Source: Statista 2024) (Note: Negative numbers at the bottom of the figure represents the contribution of hydro/pumped storage)

Act (IRA) of 2022 provided investment or production tax credits for those investing in solar or wind technologies, energy from municipal solid waste, geothermal electric programs, and tidal or hydrokinetic energy (U.S. EPA, 2024). Investment tax credits were also available for fuel cell technologies, combined heat and power, micro-turbines, micro-grid controllers, and energy storage technologies. Tax credits also spurred sales of electric vehicles, with 1.4 million new electric vehicles registered in 2023, 40% more than in 2022 (International Energy Agency, 2024). Unfortunately, fossil fuel companies, particularly oil and gas firms, still benefit from tax credits for continued pumping out of marginal wells, low lease rates on public lands, tax credit for investments in carbon capture and sequestration projects, and sales tax exemptions. The International Monetary Fund estimated that fossil fuel subsidies amounted to about $757 billion in 2022 (Brind'Amour 2024). Despite the focus on a cleaner future, Americans remain addicted to fossil fuels, as shown in Figure 13.

To de-carbonize our energy future, we tend to think first of policy-based leverage points. However, to achieve economic growth without destroying the environment will take a much more concerted effort at enacting policies that redirect investment away from fossil fuels and towards solar thermal and photovoltaic facilities, like the Cochin International Airport in Kerala (Lombard Odier 2024) or the almost 15 GW of utility scale solar systems that came on-line in the first half of 2024 (Gupta 2024). It will require on- and off-shore renewable energy developments, and new, as yet undiscovered technologies. It will demand a firm financial and technological commitment to clean, renewable energy countrywide, for electrical production, industry, and transportation. It also will necessitate agricultural practices that don't depend so heavily on fossil-fuel derived fertilizers and pesticides, and fossil fuel powered equipment.

To accomplish all of that we need to focus on breaking down the biggest barrier to a clean energy future: the mindset that gave rise to the large scale, centralized, fossil fuel dominated energy systems on which we now depend. We need to start by questioning the very premises on which that system relies, such as the “need” for endless supplies of cheap material goods and instantaneous satisfaction of personal wants. We need to think about the sources of our energy and the financial, social, and environmental costs associated with them. And then we must act.

Recall that at the base of the ERIC model lies a vital key to change: education. The students of today will be the decision-makers of tomorrow. We must teach them about these systems and the impacts on the environment--like the drawdown of groundwater supplies and the climate changing emissions of greenhouse gases. We need to instill in them the value of preserving the earth today so that the people of tomorrow have adequate supplies of nutritious food to eat. We must use tools like ERIC to continue engaging with students, exciting their creativity, spurring them to question what was once taken for granted, and ensuring they are suitably equipped to face the challenges of the future.

CONCLUSION

I am reminded of the words of Eleanor Roosevelt:

Surely, in the light of history, it is more intelligent to hope rather than to fear, to try rather than not to try. For one thing we know beyond all doubt: Nothing has ever been achieved by the person who says, 'It can't be done.'

The Energy Regulatory Industrial Complex model (ERIC) allows us to visualize the interconnected elements that comprise the world's energy systems. ERIC allows us to understand the factors that have led to our current energy dilemmas. ERIC also helps us make informed decisions about policies; investment in technology, innovation, and education; and how we will confront the challenges presented by our changing climate. Armed with ERIC, it can be done.

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