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Article

Teaching Energy Economics in the GCC: A Synergistic Approach between Engineering and Economics

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Abstract: Issues related to safe and abundant energy production have been prominent in recent years. This is particularly true when society considers how to increase the quality of life by providing low-cost energy to citizens. A significant concern of the Gulf Cooperation Council (GCC) relates to the environmental effects of energy production and energy use associated with climate change. Efforts to reduce fossil fuel use and increase the use of renewable energy, together with the price volatility of fossil fuels, have seriously impacted the economics of many oil-producing countries, particularly the Gulf States, which has led to efforts to make their economies more diverse and less dependent on oil production. In this article, we introduce a multidisciplinary energy economics course developed at the Missouri University of Science and Technology that can be easily adopted by GCC universities to enhance future generations' understanding of energy challenges.

Keywords: energy policy; energy economics; renewable energy; fossil energy; nuclear energy; hybrid energy; teaching



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1. Introduction

The question of how the Gulf States can expand their economies to reduce economic dependence on oil production is an engineering question, an economic question, and ultimately, an issue of information and education. The collaboration between engineering and economics focuses on the importance of economic diversification in energy and how to reduce dependence on oil while making GCC economies more resilient to oil price shocks.

Collective efforts from science, social science, and engineering are required to address the complex issue of improving social welfare, maintaining sustained economic growth, diversifying the economy and energy portfolio, and strengthening energy resilience in the GCC. Universities play an active role in the socioeconomic development of society, as they are sensitive to market demands and global trends [1]. We reacted to this broad energy debate several years ago by developing a course in energy economics at the Missouri University of Science and Technology (Missouri S&T) to provide a deeper understanding of the energy issues discussed above. With this paper, we aim to introduce and illustrate the design of the course and prepare the next global generation for the upcoming energy-related challenges. Our approach has been to link the scholarly disciplines of engineering and economics to provide an educational system to inform college students about the core energy issues debated worldwide. This course encourages open discussion about energy policies that countries may consider pursuing to bring the most significant benefit to their citizens. This course is available online and can easily be adopted by universities in the Gulf States.

Efforts have been made to enhance the teaching and understanding of energy-related topics in the literature. Energy-related issues were comprehensively discussed within the scope of economists by the authors of [2–4], who developed one of the earliest works

providing a curriculum with four teaching units for high school teachers and students. Gigauri et al. [5] highlighted the importance of including sustainability issues in college education and explored the integration of the Sustainable Development Goals in different countries and regions. Yli-Panula et al. [6] comprehensively reviewed articles on geography teaching and sustainable development, and De la Torre et al. [7] analyzed how to apply learning tools such as simulation and serious games to teach concepts such as the circular economy and sustainable energy. Hernandez et al. [8] introduced a case study of Mexico's energy transition with an innovative methodology. Jafarinejad et al. [9] described a set of renewable energy simulation and analysis tools that can be taught to help to train and prepare engineering students for renewable energy system engineer jobs.

The present study makes two major contributions. First, previous research on teaching energy economics has mainly been conducted by social scientists. Energy economics is not a traditional field in economics. We developed a team with instructors from the disciplines of both economics and engineering. Therefore, not only are economics concepts discussed, but we also discuss beyond-textbook stories within the scope of engineering with which a typical economist would not be familiar. Second, most existing energy education literature discusses a limited number of case studies, concepts, and tools. We have developed an energy economics course that differs from previous work. This semester-long interdisciplinary class represents a systematic effort to comprehensively present, discuss, and analyze a complete list of energy-related topics throughout the scope of key economic concepts. Although Hoople et al. [10] described a similar effort to provide an introduction to energy specifically for engineering students, students enrolled in our class have distinct backgrounds, such as in biology, business, chemistry, economics, engineering, history, and mining. Teachers with economics and engineering backgrounds collaborate and discuss the issues at the nexus of economics, engineering, and energy. The diversity among both faculty members and students enables vivid discussions and diverse viewpoints.

Underlying our teaching approach to energy economics is a firm belief that engineering and economics are synergistic disciplines that, together, combine the ideas of new technologies with a framework for understanding whether these technologies will enhance quality of life. One example is thermoeconomic analysis, which optimizes the thermodynamic energy system by considering economic factors [11,12]. We believe a collaborative approach to teaching energy economics will yield a more informed debate on the best directions to take in energy production and use policies. Our class presents informed subject matter on all forms of energy production, including fossil, nuclear, renewables, and bioenergy. We have provided study-abroad opportunities focusing on energy issues in Dubai and Oman. We also take our energy economics students on field trips to solar microgrids, nuclear reactors, and biofuel plants. The class is divided into groups that are assigned a current energy-related topic on which they conduct detailed research to produce a final report and oral presentation for the class.

During a previous U.S. presidential election, a prominent U.S. newspaper ran an advertisement showing pictures of the two final candidates. It included a headline stating, "*Energy, Bigger than Both of Them*". A key component of educating the future workforce is providing an unbiased view of energy from an economic viewpoint. Economists teach students to ask, "does the benefit outweigh the cost?" In particular, the primary task of environmental and energy policies is to properly identify and value externalities and provide energy consumers and producers with the incentives to accurately internalize extra social costs. D'Adamo et al. [13] discussed this issue in the context of bioenergy; they pointed to the importance of accounting for the spillover effects of clean energies and policies themselves. For example, will bioenergy production lead to increased food prices and labor exploitation? Policies with good intentions may lead to undesired outcomes if opportunity costs are not fully recognized [14,15].

In energy economics, we use these criteria when discussing renewable energy (i.e., wind, solar, and biomass), fossil energy (coal, natural gas, and petroleum), and nuclear energy. Broadly, we examine several serious energy-related questions, including:

1. How can we supply clean secure energy to a world with more than nine billion people (see Figure 1)?
2. How can a country best support its economic activity with available energy resources?
3. How can a world dependent on fossil energy evolve to reduce climate impact?

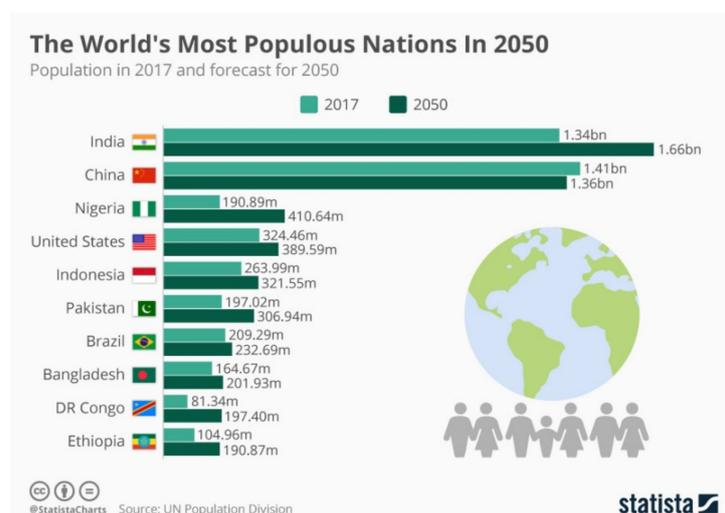


Figure 1. World population estimates for 2050 [16].

The topics addressed in the energy economics course need little introduction. Every day, we are bombarded with news reports dealing with energy and natural resources. Familiar issues include high gasoline prices, wind versus coal energy, the impact of fossil fuels on global climate change, air and water pollution, oil spills, energy production and consumption, and nuclear waste, to name a few. We address each of these issues during classroom lectures and discussions.

The energy economics course examines issues of particular significance to Gulf countries concerning oil and natural gas markets and associated electricity generation. As a major energy-exporting area, the GCC's current and future benefit heavily depends on global policy trends, as well as energy supply and demand elsewhere. As concerns about climate change increase worldwide, policies aiming at combating greenhouse gas emissions are being implemented in top energy-consuming regions, such as China, Europe, and the U.S. These regional policies are likely to lead to increased use of clean energy and reduced use of fossil fuels in the long run, which could severely damage the welfare of the GCC welfare and bring up the issue of energy resilience. Furthermore, international climate change agreements have been constantly discussed in recent decades. As a result, numerous participants have made ambitious carbon net-zero commitments, in which GCC countries have also participated. For example, Saudi Arabia committed to achieving 50% clean energy by 2030, along with the Saudi Green Initiative and the Middle East Green Initiative. The global attitude toward fossil fuels emphasizes the urgency of educating GCC students about the current situation and trends to develop necessary adjustments and adaptations. With all these challenges, the future generation of the GCC needs to be trained and prepared for the trend of coordinating across formerly independent sectors, such as electricity, industry, and transportation, to provide reliable, resilient, clean energy at affordable prices [17].

The theory of perfect competition is discussed as it relates to energy markets, the economic theory behind market failures, and the reasons energy markets are subject to governmental regulation. We also discuss critical issues in the GCC relating public policy to energy production. Furthermore, we compare the efficiency of various energy forms and discuss possible energy policies that can be applied in the GCC. With this information, we believe students can become better equipped with the necessary background to make informed decisions as they move into the workforce.

This class is designed for both economists and engineers. Therefore, it is taught collaboratively by an engineering professor with a background in chemical and nuclear engineering and an economics professor with a background in energy and experience in the GCC. Our course textbook is *Energy for Future Presidents: The Science Behind the Headlines* by Richard Muller (<https://www.amazon.com/Energy-Future-Presidents-Science-Headlines/dp/0393345106>, accessed on 20 September 2022). We also use selected readings from various journals and technical reports that examine general energy-related issues. The collaborative teaching approach for this course gives it an experimental flavor, which we enhance with outside visits to nearby energy production/use facilities.

2. Course Contents and Requirements

The energy economics course is designed to help students learn about key issues in the GCC related to various forms of energy and the political/social externalities (defined as a side effect or consequence of an industrial or commercial activity that affects other parties without this being reflected in the cost of goods or services involved, such as pollination of surrounding crops by bees kept for honey) associated with each. Specific learning objectives for the course are shown in Table 1.

Table 1. Energy economics learning objectives.

#	Learning Objectives
1	Learn and apply economic principles to assess economic sustainability for energy resources.
2	Learn and apply the life cycle analysis methodology to assess the environmental sustainability of energy resources.
3	Learn how to use the GREET software to conduct sustainability assessments.
4	Examine multiple forms of energy to understand limitations related to each energy resource.
5	Consider the evidence for climate change and discuss the impact of fossil fuels on this issue.
6	Work in a team environment to conduct a technoeconomic analysis of selected energy technology.
7	Demonstrate understanding of the principles discussed in class through a written report based on the group project.

Students are assigned to read selected materials available from online sources related to the learning objectives designed to support in-class discussions (see Table 2).

Table 2. Outside reading topics to supplement in-class discussion.

#	Topical Areas for Outside Reading
1	Energy demand and supply
2	Competitive energy markets and problems of market failures
3	Government policies designed to correct for price inefficiencies
4	The issue of scarcity of rent
5	Global warming and climate change
6	Natural gas, shale oil, and fracking
7	Solar energy, wind energy, and energy storage
8	Nuclear energy, including fusion energy
9	Biofuels
10	Tidal/wave power, hydrogen fuel, and geothermal energy

In addition to classroom lectures, students are assigned to work in groups to complete a major research project with a written final report and an oral presentation. This activity is

considered the course's final exam. Students are provided with a list of potential research topics to consider (see Table 3). They may also select a topic of their own if desired.

Table 3. Research topics for the major class project.

#	Research Topics for Major Project
1	Examine in detail the renewable energy policy in Massachusetts. Provide a summary of the policy; what does it contain; what has been the impact on prices and how does it compare to other renewable energy policies?
2	There now appear to be two functioning cellulosic ethanol plants in the United States. Both appear to be using corn stover to produce alcohol. What is the future of cellulosic ethanol production in the world? Can these processes produce ethanol efficiently?
3	Perform a policy analysis of the global warming issue. What are the theories on both sides of the question? Is there any validity to the sunspot theory?
4	Analyze the technical and economic issues related to hybrid energy vehicles. For instance, consider the following: Natural gas vehicles, Plug-in electric vehicles, and fuel cell vehicles among others.
5	Do an economic and technical analysis of small modular nuclear reactors (SMRS). Are they cost-efficient? What are their advantages and disadvantages? Are SMRS the future for advancing nuclear's share of electricity production?
6	Do a technical and economic analysis of deriving energy from fusion. What are the different technologies? Look in particular at the new technology presented by the grad student at MIT (ask Dr. Smith about this technology).
7	What is the impact of cheap energy on the world economy? Consider short and long-run. What impacts might cheap energy have on carbon emissions and global warming?
8	How serious a problem is energy poverty? Analyze whether we can alleviate energy poverty without the increased use of fossil fuels.
9	Analyze whether replacing ethanol production from corn with butanol would increase efficiency. What are butanol's advantages and disadvantages as a fuel over ethanol?
10	One solution that some economists have suggested as a way of accounting for the social external costs of fossil fuels has been carbon taxes or cap and trade. The carbon tax was used for many years as an environmental policy in Australia. The EU established a cap and trade policy, which had serious problems but may still exist. Examine the theory behind their initiatives, analyze their effectiveness to date, and make policy prescriptions based on your analysis.
11	Several years ago, an article appeared in Scientific American advocating the construction of a 60,000-square mile project of photovoltaic collectors and concentrated solar thermal units in the Western U.S. with the purpose of producing one-half of the U.S. electricity consumption. Since the article was written, fossil fuel prices have dropped dramatically, but at the same time, photovoltaic efficiencies have improved. Is this project, or something similar, viable for energy production in the U.S.? Consider the technical challenges and the economic issues.
12	Perform an environmental and economic analysis of oil and gas fracking. Fracking has been a successful energy-producing technology in the United States. What are the chances of its success in other countries and economies?
13	Analyze the issues surrounding carbon sequestration versus carbon utilization.
14	Explore current policy related to microgrids and conduct a LCA for a microgrid in a large urban market and a small rural market with multiple energy resources (e.g., solar, wind, biomass, nuclear, coal, gas) available in the market according to location of the microgrid implementation.

Lastly, students participate in field trips to observe operating energy-related technologies. Two popular field trips include visiting a regional bioethanol plant and an operating solar microgrid. This approach could be applied to classes taught in the GCC.

The bioethanol plant in Laddonia, Missouri (see Figure 2), produces approximately 60 million gallons of ethanol plus corn oil, animal feed, CO₂, and electricity per year. Students see firsthand how this bioethanol plant has hybridized its production to generate multiple byproducts that improve its economic performance. Ethanol produced by this plant is blended with petroleum to meet U.S. regulations requiring 10% ethanol in all gasoline. Class members tour the plant after an introductory presentation by the plant manager. This introductory presentation provides facts about how much water and energy are required to produce a gallon of bioethanol and the current corn yield (bushels per acre), both significant factors affecting bioethanol price.

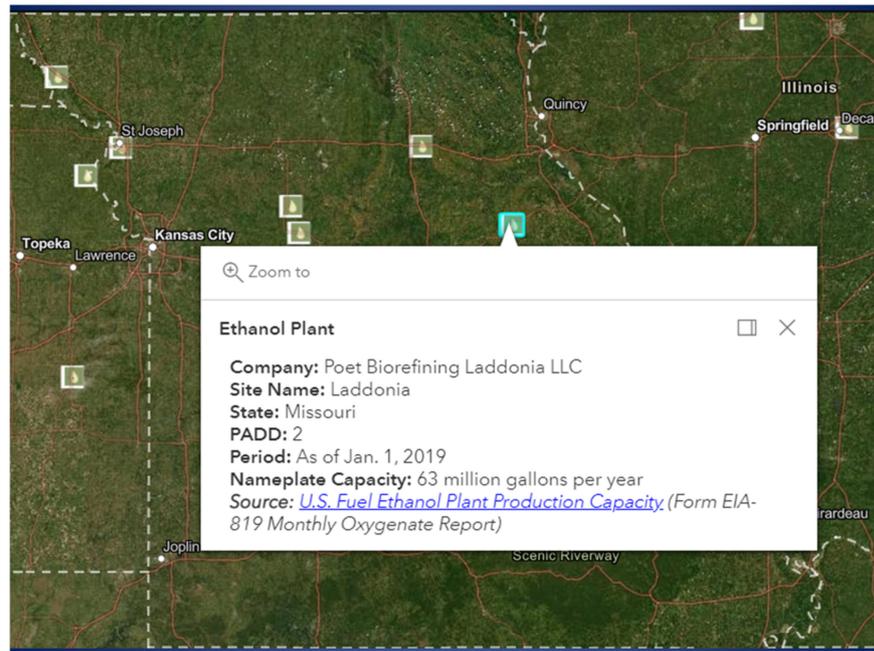


Figure 2. POET Bioethanol plant in Laddonia, Missouri (USA).

The class also visits the Missouri S&T solar microgrid (see Figure 3). This microgrid includes six homes originally constructed as part of the U.S. Solar Decathlon. Students and faculty live in these homes and generate a “real-time” load profile used to analyze energy use, grid control, and operation in residential settings. This research is available to public utilities and governmental agencies to study next-generation grid design and cyber-security.



Figure 3. Missouri S&T Solar Microgrid and EcoVillage composed of homes built for the U.S. Solar Decathlon (for a description of the Solar Microgrid located at the Missouri University of Science and Technology, see <https://cree.mst.edu/laboratories/>, accessed on 20 September 2022).

A primary goal of our course is to provide an in-depth analysis of issues related to energy economics concerning production and use and to expose students to current energy policy relevant to their location. To encourage participation, students must keep a classroom journal containing their ideas and perceptions gained from outside readings and in-class lectures. Journals are collected and reviewed twice during the course and represent the midterm exam.

3. LCA Example: Comparing the Carbon Footprint of Producing Biodiesel to Fossil-Based Diesel Fuel

A common question asked when comparing energy resources is “what is the most sustainable or has the lowest carbon footprint?”. To assess solar energy versus wind energy versus fossil energy, one might evaluate thermal efficiency, water used, and emissions produced by the plant. The most accurate approach to answer this question is to conduct a full life cycle analysis (LCA).

The LCA methodology is commonly used to quantify system efficiency in terms of thermal efficiency, water used, and associated externalities, such as carbon emissions [18,19]. A full LCA requires:

1. Defined system boundaries;
2. Relevant inputs and outputs of the system;
3. Potential environmental impacts of the inputs and outputs; and
4. Interactions between various system components.

In the class, we utilize an example comparing carbon emissions generated during the production of biodiesel with those generated in the production of conventional diesel from crude oil to illustrate how an LCA can be used to assess system sustainability and overall environmental impact.

Considering biodiesel production from soybeans using the standard transesterification method (see Figure 4) with a system that includes a farm to grow soybeans, where they are harvested and shipped to a biorefinery, where they are processed and converted into biodiesel. The system also includes biodiesel transportation and storage at the distribution point, where they enter the market. Considering this system, an LCA of biodiesel production using the GREET (greenhouse gases, regulated emissions, and energy use in transportation) software package developed by the U.S. Department of Energy [20] shows that this process generates 10.22 kg CO₂ (−0.05 kg Biogenic CO₂) per mmBtu of biodiesel [21].

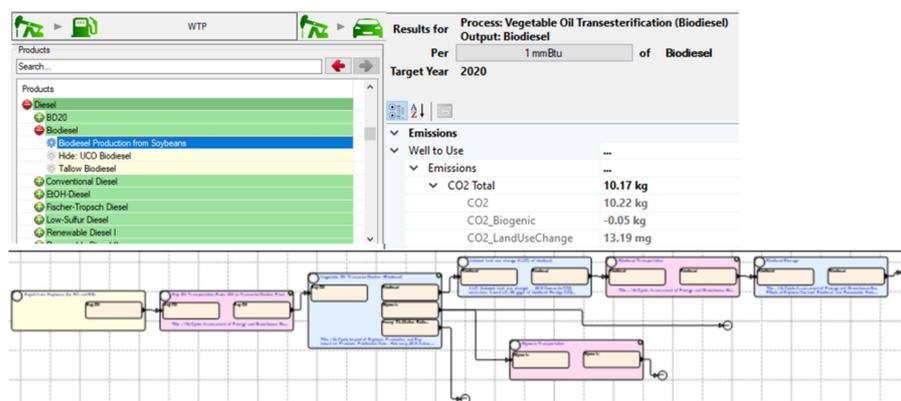


Figure 4. Biodiesel production from soybeans (produced in GREET 2020).

Comparing biodiesel production to conventional diesel produced from crude oil, the LCA includes crude supplied from standard oil reserves plus unconventional oil sands and shale oil reserves (see Figure 5). Standard diesel refining technology is assumed to produce conventional diesel, which is then shipped from the refinery to market using

various transportation routes (see Figure 6). Considering this system, conventional diesel production is responsible for 12.96 kg CO₂ (−0.02 kg Biogenic CO₂).

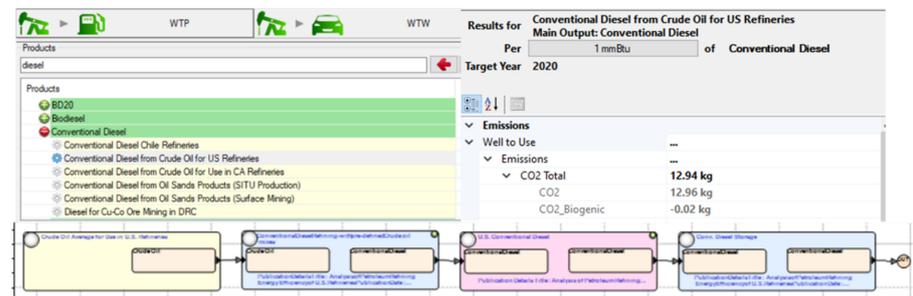


Figure 5. LCA results for conventional diesel produced from crude oil.

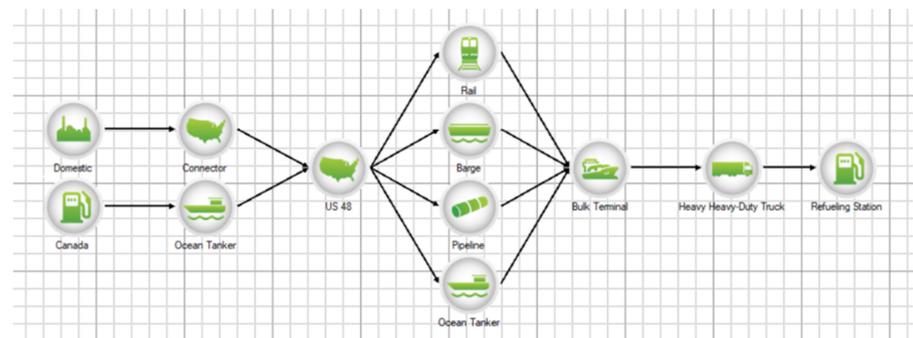


Figure 6. Shipping supply chain for diesel from production to market.

This simple comparison shows that standard refining technology produces more CO₂ than biodiesel production, as expected. However, the LCA also illustrates how important feedstock logistics are to carbon emissions and the overall environmental impact.

4. Hybrid Energy Example: Nuclear Hybrid Energy and Process Sustainability

A considerable challenge that the GCC and the world must face over the next thirty years is related to energy security. Economic activity in the GCC is directly tied to a secured low-cost energy supply. The world population, currently approximately 7.8 billion people, will grow to more than 9 billion by 2050, with most population growth occurring in developing countries (see Figure 1).

In recent years, the United States has found new energy resources, most notably, natural gas and oil from shale rock deposits. Ten years ago, the U.S. was mainly concerned with its energy supply and increasing dependence on foreign energy sources. Today, we discuss the possibility that the United States will become energy independent based on shale gas/oil resources and increasing renewable energy. A key GCC energy policy issue has become “how to move beyond oil to renewable energy”. Together, both policy discussions can be addressed with a hybrid energy system.

A novel concept discussed in our class that students find interesting is related to hybrid energy systems as a way to transition from dependence on fossil fuels to reducing carbon footprint. During the class, we discussed recent work on a nuclear-hybrid energy system (see Figure 7). Our discussion is in line with principle 9 of the Global Compact Principles, which is to “Encourage the development and diffusion of environmentally friendly technologies”. The International Atomic Energy Agency (IAEA) has identified small modular nuclear reactors (SMRs) as having improved manufacturing economics, with improved safety and reduced proliferation risk. As illustrated by an analysis of a coal–wind–nuclear hybrid system using an advanced pressurized circulating fluid bed reactor to burn coal with oxygenated combustion air and a high-temperature co-electrolysis unit

integrated with an SMR (for heat and wind machines/solar PV panels) for electricity [10]. A dynamic process model was used to examine how the system handles the variability of wind energy combined with nuclear power to meet a dynamic load profile with reduced carbon emissions and improved economic performance (see Table 4).

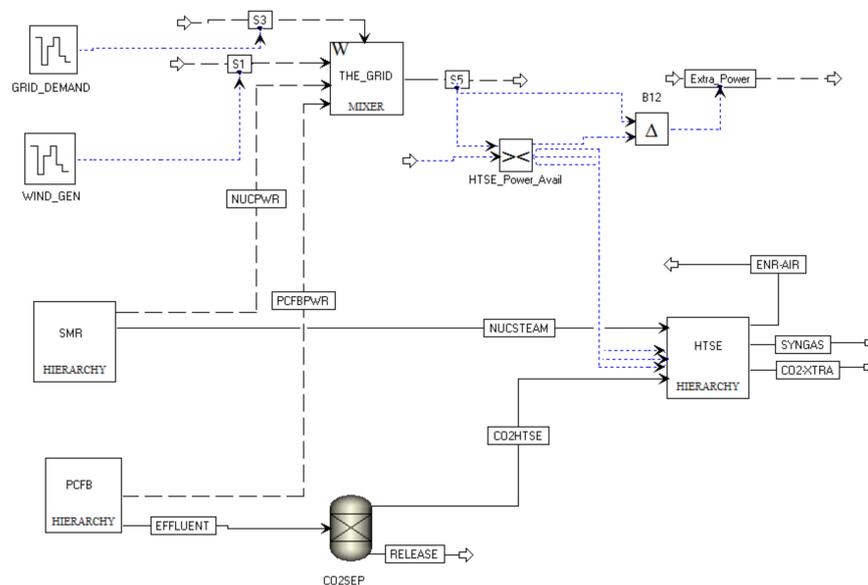


Figure 7. Coal–wind–nuclear hybrid energy system to produce low-carbon electric power plus chemicals or fuels [22].

Table 4. Cost analysis of coal–wind–nuclear hybrid energy system [23].

Cost Source	Coventional Coal (Reference Case)	Hybrid Energy (No HTSE)	Base Hybrid System (Levelized Cost)	10% Hybrid (No HTSE)	10% Hybrid
Coventional Coal	\$336.40	-	-	-	-
PCFB (Advanced Coal)	-	\$198.80	\$198.80	\$68.00	\$68.00
Advanced Nuclear	-	\$176.00	\$176.00	\$46.40	\$46.40
Wind	\$10.90	\$10,871.00	\$10.90	\$10.90	\$10.90
Advanced Combustion Turbine	\$16.80	\$16.80	\$16.80	\$16.80	\$16.80
Solid Oxide Fuel Cell	-	-	\$21.00	-	\$21.00
Hybridized Capital Cost	-	-	-	\$234.30	\$234.30
\$15/Metric ton CO ₂	\$678.90	\$330.40	\$303.60	\$330.40	\$303.60
\$30/Metric ton CO ₂	\$1357.80	\$660.70	\$607.10	\$660.70	\$607.10
Total Cost	\$364.10	\$402.40	\$423.40	\$376.40	\$397.40
Total Cost + \$15 tax	\$1043.00	\$732.80	\$727.00	\$706.70	\$701.00
Total Cost + \$30 tax	\$1721.90	\$1063.10	\$1030.60	1037.10	\$1004.50

This analysis included a complete life cycle analysis (LCA) using the GREET (See <https://greet.es.anl.gov/index.php>, accessed on 20 September 2022) software package to evaluate the sustainability of the proposed energy system. In our class, we teach students about LCA to assess system sustainability and how to use GREET. This approach applies to how GCC countries might integrate more renewable energy into their future energy production to reduce carbon emissions while maintaining economic activity.

As shown in Table 4, the total cost is the system cost for each case. The figures are comparable, although conventional coal is the most affordable option. Hybridized systems

allow for the utilization of any excess intermittent power generated by renewables. This excess power could cause grid instability by reducing the price of electricity. Utilizing the power while simultaneously reducing carbon emissions and storing energy through chemicals improves the overall sustainability of not only the system but the entire grid.

The real cost differential emerges as we include a hypothetical \$15 or \$30 per ton of carbon tax. The hybrid system reduces emissions based on co-electrolysis, so the tax effect would be less. Levelized costs were compared between cases of conventional technology and hybrid systems. This theoretical carbon tax was used to show the potential benefit of hybridization in reducing emissions. Therefore, as concerns about climate change increase globally, regions that currently do not have carbon taxes, such as the GCC, may also want to adjust investment decisions as international environmental agreements are likely to be formed in the foreseeable future.

5. Conclusions

A considerable challenge faced by society is how to provide clean, sustainable, secure energy to a growing population, including the GCC countries with minimal impact on the climate while supporting economic development. A collaborative approach to teaching students in the GCC about various energy forms and the associated externalities will help them integrate into the workforce to make more informed decisions regarding energy policy. Completely replacing fossil energy with renewable solar and wind in the GCC would have a significant economic impact on the regional economies and could cause political unrest. Imposing a carbon tax on the oil and gas industry in the GCC, which currently primarily uses fossil energy to generate process heat to refine petroleum products, would seriously impact the geopolitical landscape in the GCC. Installing next-generation hybrid energy systems promises to increase profitability and efficiency while reducing the carbon footprint of generating stations. Concepts taught in the proposed energy economics class by engineering faculty collaborating with economics faculty is one way to help the GCC prepare as they migrate from fossil fuels to renewable energy. A multidisciplinary approach to presenting a holistic picture of providing clean, sustainable, secure energy to a growing population may help avoid regional conflicts related to energy supply. This approach may also positively impact global energy poverty while protecting our climate from the adverse effects of global warming.

There are also major challenges associated with future research on teaching energy economics. First, course content must be continuously updated to include contemporary issues and recent trends. Global events, such as wars, pandemics, changes in administration, technology breakthroughs, and oil spills, all lead to a dramatic shift in public perception and therefore market behaviors. A second challenge is to improve the means of teaching in terms of satisfying various demands from students with distinct backgrounds. A third challenge is to provide and organize engaging activities, such as discussions, field trips, and case studies. Lastly, educators must develop students' skills to prepare them for their future careers. Examples include professional software training, inviting speakers from industries, and internship opportunities.

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