AC 2009-525: USING THE TEXAS INTERACTIVE POWER SIMULATOR FOR DIRECT INSTRUCTION

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Using the Texas Interactive Power Simulator for Direct Instruction

Abstract

Establishing a reliable and sustainable electricity supply is a difficult challenge. Unfortunately, discussions on this topic include wide varieties of misinformation, subjective analysis, and biased resources. The Texas Interactive Power Simulator (TIPS) provides an educational tool for direct instruction and informing public policy decisions by providing an interactive teaching and learning environment with objective instruction about the tradeoffs of electricity generation choices in Texas. The simulator is presented in a web-based, interactive format to provide easy access for the target user groups. Target groups include policy decision makers, government employees, educators, students, and the general public.

The Texas Interactive Power Simulator gives educators the ability to quantitatively compare the economic costs and environmental impacts of electricity production methods according to fuel source (i.e. coal, natural gas, nuclear, wind, sun, water). Each electricity production method is evaluated in terms of its direct cost and indirect impacts. Direct costs include the costs of new capacity, fuel, facility operation, and facility maintenance. Indirect impacts include air emissions of carbon dioxide, nitrogen oxides, and sulfur dioxide. Also included are water consumption rates and land requirements for new facilities. The analytical framework and source data provide quantitative measures by which each generation type is compared. Data are collected from government reports and peer reviewed technical literature and are updated frequently as costs change frequently.

The simulator's interactive interface allows the user to set a desired mix of fuels according to the percentage breakdown of electricity production. Based on these inputs, TIPS determines the overall direct costs and indirect impacts of a unit of electricity according to the costs associated with each fuel type. These measures provide students, policy makers, and other users with transparent and unbiased methods for understanding basic tradeoffs that emerge from different fuel mixes.

TIPS also provides a level of basic education on electricity generation. Beyond cost and environmental impact information, the Texas Interactive Power Simulator generates graphs, charts, and pictograms to effectively communicate the differences between electricity production methods via the unique characteristics of each. These educational lessons can apply to many electricity markets and provide an introduction for those who wish to become proficient in the field. Portions of the TIPS website are specifically designed for classroom use regarding the topic of electricity production in Texas. However, the simulator's flexible framework lends itself to easy expansion to cover the fuel mix for other regions, including the entire US and world markets.

Introduction

The Texas Interactive Power Simulator was designed at the University of Texas at Austin to communicate key lessons concerning the tradeoffs of electricity generation methods in Texas

The key target audiences for this project include college students, high school students, state legislators and their staff, as well as the general public. The Texas Interactive Power Simulator accomplishes the project goals by allowing the user to manipulate the electricity generation mix in the state of Texas and immediately view the economic and environmental impacts of these changes. This manuscript extends upon previous publications that described the backend components and user interface design of the basic version of the Texas Interactive Power Simulator.[1] In particular, this manuscript discusses key findings from direct instruction in an interdisciplinary course as well as introduction of the tool to members of the Texas legislature prior to the start of the current legislative session.

Background

Texas generates and consumes more electricity than any other state in the United States. In 2006, power plants in Texas generated more than 400 terawatt-hours (TWh) of electricity, with 49% from natural gas as a fuel source. Texas is also the leader in emissions of carbon dioxide and nitrogen oxide resulting from the generation of electricity, emitting 257,552,000 metric tons and 260,000 metric tons respectfully during 2006.[2] At the same time, Texas emissions rates per quantity of electricity generated (e.g. lbs CO_2/kWh) are below the average in the United States because of the extenside use of natural gas.[2] A large part of the total emissions originate from the disproportionate amount of manufacturing and oil refining performed in Texas.

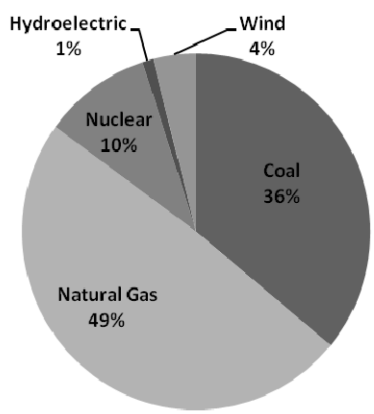

Figure 1: The fuel mix for power generation in Texas in 2006 is diverse, with natural gas as the primary component. [2-4]

Texas is and has been increasing its use of renewable electricity generation technologies including wind and solar power. In 1999, a renewable portfolio standard was established for the state requiring 2,000 MW of new installed renewable capacity by 2009. Since 1999, due largely to the rapidly growing wind power industry in Texas, the renewable portfolio standard has been amended. Most recently in August of 2005, Senate Bill 20 was passed to require 5,000 MW of newly installed renewable capacity by 2015. That bill also includes a target of installing 500 MW of non-wind renewable capacity within the 5,000 MW. Further, this bill established a long term goal of 10,000 MW of new installed renewable energy capacity by 2025.[3, 5]

To reach these goals, it would be useful to understand the tradeoffs of different generation technologies so that policy-makers can make educated choices. All existing technologies have tradeoffs, whether environmental or economic; to make informed choices, one must understand and balance these tradeoffs with Texas' priorities.

TIPS Overview

The Texas Interactive Power Simulator allows the user to change the amount of electricity that is generated using each of six types of fuels (coal, natural gas, nuclear, wind, hydro, solar). The simulator describes the current electricity generation landscape across the state of Texas. Changes can be made to the existing landscape and these changes are used to calculate the economic costs and environmental impacts.

Economic impacts are measured in terms of three categories: cost of new capacity, cost of fuel, and cost of operation and maintenance of the plant facility. Cost of new capacity includes the capital investment required to build any new power plants required by the generation mix the user specifies ("Your Mix"). Cost of fuel and cost of operation and maintenance (O&M) are calculated on a cost per megawatt-hour generated basis. All calculations use the data found below in Table 1. Costs used in the simulator are lifecycle costs, selected as a representative value from within a range of published costs for all technologies that utilize the indicated fuel type.

Table 1: TIPS uses the following cost factors to determine the economic impacts for different fuel mixes. [6-16]

	Cost of New Capacity ($/kW)	Cost of Fuel ($/MWh)	Cost of O & M ($/MWh)
Coal	1,500	15.00	5.00
Natural Gas	900	5.00	80.00
Nuclear	5,000	5.00	15.00
Wind	1,750	0	10.00
Hydroelectric	1,700	0	10.00
Solar	5,000	0	9.50

Environmental Impacts

Environmental impacts that result from power plant operations are characterized in three categories: air emissions, water consumption, and land required for the power plant footprint. Air emissions and water consumption are calculated on a per megawatt-hour basis similar to the cost calculations previously described. Values are calculated for a weighted average megawatt-hour of generated electricity and are displayed using the graphs shown in Figure 3. These environmental impact values are non-lifecycle, including only the environmental impacts at the point of generation. Lifecycle values are not used because of the very small magnitude of the environmental impacts not associated with generation. The variability of environmental impacts when measured for the entire lifecycle makes it inappropriate to use in TIPS, given the generalizations used for each fuel type. Water consumption does not refer to the total amount of water withdrawn and used for power plant cooling (pass-through water use), but specifically refers to the amount of water that is consumed during this process. All calculated values use the data found below in Table 2.

Table 2: TIPS uses the following emissions and use factors to determine the environmental impacts for different fuel mixes.[17-21]

	Air Emissions (lbs/MWh)			Water Consumption (gal/MWh)	Land Required (acres/MW)
	CO_2	NO_x	SO_2		
Coal	2,293	6.8	5	426	1.2
Natural Gas	1,146	0.03	1	223	0.05
Nuclear	0	0	0	600	0.05
Wind	0	0	0	0	25
Hydroelectric	0	0	0	0	131
Solar	0	0	0	0	4.6

Assuring Credibility and Objectivity

The Texas Interactive Power Simulator's credibility is built on its transparent and objective design. As this tool is designed for use in the classroom at Universities, the accuracy and credibility of the tool is extremely important. To strive toward website credibility, the tool designers have taken two main steps. First, they have presented all data for the user to access in order to be able to independently verify all values calculated by the tool. There are no hidden calculations or input values. The user may also contact the tool designer via e-mail using the "Contact Us" link on the website. This access allows them to quickly clarify any misconceptions or unclear concepts. Second, the data used in the TIPS website are frequently updated with changes in both market and technology. The tool is designed to be a dynamic tool, updating with frequency appropriate to maintaining a high level of accuracy in the calculated output values that are displayed to the user. Further, TIPS ensures its position as an objective and unbiased resource by utilizing only data that has been independently peer-reviewed and verified.

User Interface

The Texas Interactive Power Simulator's user interface is designed to allow for the effective communication of key lessons to the user in a self-teaching environment. The initial portal into the website is displayed below in Figure 2 and is used to provide background information and collect statistical data about the user. The Google Analytics program is also used for user information gathering[22].

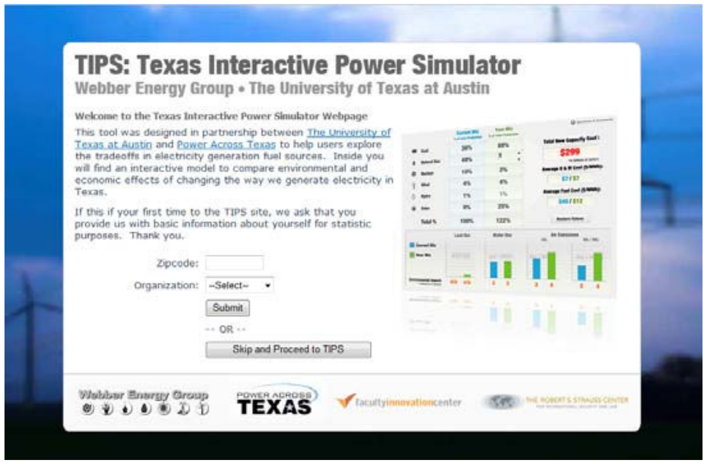

Figure 2: Welcome Page

All calculated output values defined by user inputs ("Your Mix") are displayed in green throughout the webpage with the exception of total new capacity cost displayed in red. Values for the "Current Mix" are fixed and displayed in blue to provide users with an easy way to compare the differences between their customized "Your Mix" and the "Current Mix". The simulator's interface design is displayed below in Figure 3. As the user changes values for percent of total electricity generation TIPS displays the altered impacts in real time.

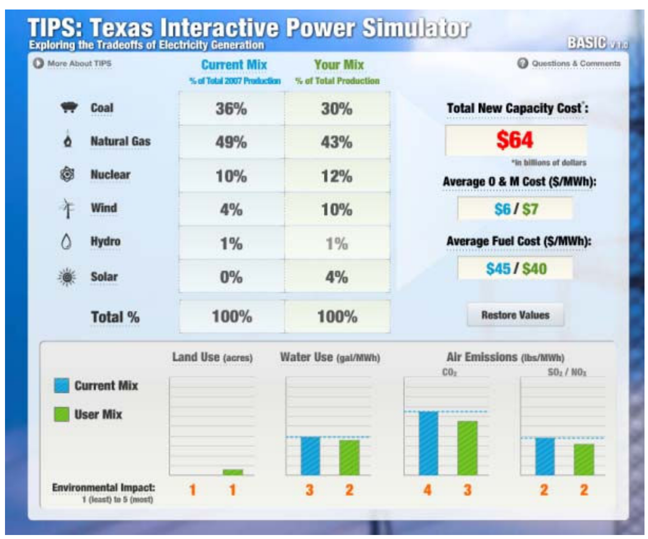

Figure 3: Simulator Interface Page

TIPS directly collects user data regarding their geographical location in the United States according to their zip code as well as their organization type (academia, industry, government, military, or other). These data are gathered on the TIPS welcome page as previously shown in Figure 3. Google Analytics is also used to monitor use of the simulator.

Classroom Use

The goal for using the Texas Interactive Power Simulator in the classroom is twofold. First, it allows students to become exposed to the key topics regarding the tradeoffs of electricity generation technologies. Second, it allows the developers to gather important pedagogical information that will enhance future versions in terms of its teaching abilities. The theoretical framework that the Texas Interactive Power Simulator draws from work by Erwin Boschmann regarding using technologies in secondary and higher education as well as industrial and government organizations[23].

At the University of Texas at Austin, TIPS is used for direct instruction in two freshman courses. The first course is an undergraduate seminar course targeted toward first year engineering students with an interest in aspects of energy, technology, and policy. The second course is targeted toward a non-technical audience in a large-section lecture format as an interdisciplinary undergraduate studies course predominantly consisting of first-year students.

Direct Instruction Feedback Survey

The Texas Interactive Power Simulator was used in a class of seventy students currently enrolled in their undergraduate degree program at the University of Texas at Austin. The students had little to no background in energy technology or energy policy at the onset of the course. The simulator was used as self-teaching aide for introducing the students to the Texas electricity landscape and to illustrate the tradeoffs in electricity generation methods. They were given a homework assignment consisting of 5 questions regarding information provided on the TIPS website and given one week to complete the assignment.

The assignment was developed by the instructors and teaching assistants for the course, two of which had extensive experience with the Texas Interactive Power Simulator. Questions were developed that would guide the students through all sections of the website including the fuel technology datasheets that are available through the website. Seven questions were asked, from each of the following learning modules: electricity generation mix (2 questions), air emissions impacts (1 question), water use (1 question), land use (1 question), total generation data (1 question), term definitions (1 question). This distribution of questions forced the students to explore all aspects of the tool including the main interface, pop-up information bubbles, and fuel technology datasheets. By exposing the students to each of these, they can then be reasonably expected to expand upon this basic functional understanding of the TIPS website to answer many more questions.

After completing the homework assignment (see Appendix), they were given a survey regarding their impressions of the website. The survey was not targeted at evaluating the specific knowledge that the students gained while using the website, but instead was geared toward impressions and feelings that the students developed during website use. The survey with compiled responses is shown below in Figure 3.

Question 1: Did you have any problem accessing the site?

a. No - 63
b. Yes – 6
c. No response - 1

Question 2: How long did you spend using the website?

a. 0 – 10 minutes - 3
b. 11 – 20 minutes - 28
c. 20 – 30 minutes - 33
d. > 30 minutes – 5
e. No response - 1

Question 3: Do you believe that the website is credible?

a. No - 3
b. Yes - 63
c. No response - 4

Question 4: Was the website a valuable learning tool?

a. Yes - 64
b. No – 5
c. No response – 1

Question 5: Do you believe that the website was useful in illustrating the environmental and economic tradeoffs of electricity generation methods in Texas?

a. Yes - 65
b. No – 4
c. No response - 1

Question 6: Did you like using the website?

a. Yes – 52.5*
b. No – 16.5*
c. No response – 1

*1 responder indicated both answers "yes" and "no" for this question

Question 7: Would you like to have more learning tools like this?

a. Yes - 56
b. No – 12
c. No response – 2

Total Number of Surveys Completed: 70

Figure 3: Seventy students were asked seven questions (noted above) about the TIPS website after using it for an out-of class assignment.

Out of the responses provided by the seventy students who were surveyed, seventy-six percent said that they liked using the tool and eighty-two percent expressed a desire to have more tools like this to use to understand energy concepts.

A distinct majority (95%) of the respondents believed the website to be credible. Comments included "I believe this website was credible because it included lots of citations and data" as well as "this website belongs to the University of Texas at Austin, so I believe it must be credible." Those who were uncertain as to the credibility of the website credited their uncertainty with the general technical structure of the tool itself as indicated by the comment "I couldn't use the tool easily and so couldn't decide if it was credible" and "the information was hard to find, so it might not be credible." In subsequent informal discussions with the students, it was apparent that having the University of Texas at Austin as the website creator produced a large effect on the perception of credibility of the site. Though not directly tested there was a strong indication from the students that a non-academic creator (especially a company from the energy industry) would have elicited more skepticism as to credibility. Future studies using students at other institutions of higher learning can test a potential bias of those enrolled at the University of Texas.

Ninety-three percent of respondents believed that the Texas Interactive Power Simulator is a valuable learning tool for those interested in the tradeoffs of electricity generation. Ninety-four percent of those surveyed thought it was a useful tool for specifically teaching lessons on the economic and environmental tradeoffs of electricity generation methods in the state of Texas.

Seventy-six percent of users liked using the Texas Interactive Power Simulator website. Of the twenty-four percent who did not enjoy using the site, frequent comments included a lack of enjoyment due to the website layout and lack of clarity of information presented. One respondent specifically commented that they “couldn’t figure out how to use the chart… couldn’t figure out how to use it.” Of those who liked using the TIPS website, frequent comments included a surprise at how easily they grasped new concepts and gained knowledge on the current state of the Texas electricity generation landscape. Comments such as “I can’t believe we use so much natural gas” and “the environmental effects were easy to see… I had no idea nuclear used a lot of water” were included in responses to the survey.

Of the students surveyed, eighty-two percent said that they would want more learning tools like the Texas Interactive Power Simulator. When asked what they learned while using the simulator via the website, the list was diverse and frequently expressed surprise as key facts such as the current amount of wind generation in the state of Texas, the fuel classifications (renewable vs. non-renewable) for the fuel types, and the variation in water use between different fuels.

Summary & Conclusions

This paper describes the creation of an online tool that was used for direct instruction at the collegiate level, along with a survey about its effectiveness. In summary, our findings imply that the Texas Interactive Power Simulator creates an objective instructional tool for the classroom and other settings. The survey given to students in an interdisciplinary course at the University of Texas at Austin has given useful feedback for the development of future educational tools such as how to increase ease of use and overall comprehension. Initial feedback from TIPS users indicates that it is seen as generally informative and credible. The ease-of-use can be improved for beginning users. Further data collection and user feedback for the Texas Interactive Power Simulator will help determine how people learn about weighing tradeoffs in conflicting scenarios such as those encountered in electricity generation. This information will be extremely valuable for understanding how people view tradeoffs between energy and the environment such that future energy policies can be more robust and responsive. Tools such as TIPS will also help explain the impacts of energy policies and choices.

Appendix

Assignment Sheet Given to Students

Texas Interactive Power Simulator (TIPS) Assignment
http://ficp.engr.utexas.edu/tips
Due1/30/2009, at beginning of discussion section

Name: ______________________________
Date: ______________________________
Section: ______________________________
Hometown: ______________________________

For questions 1-4 & 7b, please select from the following choices:

1. Coal
2. Natural Gas
3. Nuclear
4. Wind
5. Hydroelectric (water)
6. Solar (sun)

Question 1: In the state of Texas, the majority of electricity is currently produced using ________________.

Question 2: When used for electricity generation in Texas, power from ______________ emits the most carbon dioxide (CO_2) into the air per unit of electricity generated.

Question 3: When used for electricity generation in Texas, power from _________________ consumes the most water per unit of electricity generated (most gallons/unit electricity generated).

Question 4: In terms of electricity generation (power plants) in the state of Texas, power from ______________ is the most land intensive (uses the most land per power plant unit).

Question 5: What percentage of total electricity generation in Texas is currently supplied by nuclear power?

___________ %

Question 6: In the state of Texas, how much electricity was generated in 2007?

1. 41 terawatt-hours (TWh)
2. 41 terawatts (TW)
3. 1,000,000 terawatts (TW)
4. 401 terawatt-hours (TWh)
5. 401 terawatts (TW)

Question 7

a. Define cost of capacity.

b. Generation technology which uses ______________ as its fuel has the highest cost of capacity.

Survey Given to Students After Assignment was Completed

Texas Interactive Power Simulator (TIPS) Assignment #2
http://ficp.engr.utexas.edu/tips
To be completed in discussion section
GRADE: Your grade on this assignment will not be determined by your answers to the questions. You will receive full credit for the assignment by completing all of the questions

Name: ____________________________________
Date: ____________________________________
Section: ____________________________________

Question 1: Did you have any problem accessing the site?

a. No
b. Yes (explain)

Question 2: How long did you spend using the website?

a. 0 – 10 minutes
b. 11 – 20 minutes
c. 20 – 30 minutes
d. > 30 minutes

Question 3: Do you believe that the website is credible?

a. No (explain)

b. Yes (explain)

Question 4: Was the website a valuable learning tool?

a. Yes
b. No

Question 5: Do you believe that the website was useful in illustrating the environmental and economic tradeoffs of electricity generation methods in Texas?

a. Yes
b. No

Question 6: Did you like using the website?

a. Yes
b. No

Question 7: Would you like to have more learning tools like this?

a. Yes
b. No

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