CASE STUDY SOURCE: https://bit.ly/2HfjRde

PART I

Overview

The United States consumed approximately 97.4 quadrillion Btu of energy in 2016[1]. While this number is on its face a massive quantity, it surprises many people to know that energy *production* in the United States far exceeds this number in many cases, particularly at a regional level. In other words, energy that we produce does not get consumed and is therefore wasted.

Within the engineering community, there has been in interest in so-called "smart grid" technologies for at least the last couple of decades. In essence, such grids produce energy in amounts that are only slightly higher than demand, ensuring a higher operating efficiency. These systems may employ a range of technologies, including, but not limited to:

- smart meters (meters that transmit information back to the generating station(s))
- smart houses (which manage energy consumption)
- high efficiency transmission infrastructure
- localized energy generation for small-scale consumption
- generation topologies that encourage efficiency of scale (i.e. regional vs. local generation)
- advanced forecasting and algorithmic methods to determine production needs

The focus of this paper is primarily on the last two technologies listed here.

A Brief Overview of Energy Production

Besides being consumers of naturally occurring energy from the sun and Earth in the form of food, humans have long found ways to produce and consume other forms of energy. These methods of energy production generally fall into four categories, described below.

Energy Category	Examples	Renewability
Organically or Hydrologically Derived	• Wood • Biomass • Hydroelectric • Geothermal	High
Complex Hydrocarbons	• Oil • Natural Gas	Medium

[1] https://www.eia.gov/energyexplained/?page=us_energy_home

	• Coal	
Solar	• Solar Cells	Medium
Nuclear	• Uranium Reactors • Plutonium Reactors • Molten Salt Reactors	Low

Table 1 – Sources of Energy Production for Human Needs

Although a thorough exploration of each of these methods and their respective efficiencies is not given here, suffice it to say that each of these methods of energy generation has its own strengths and weaknesses.

However, one key aspect to consider when studying energy production methods is the *regional economics* associated with each source. For example, a discussion of hydroelectric power does not make particular sense when the region in consideration is one which does not have a powerful enough river to sustain production in a steady manner.

This regional nature motivates a more thorough discussion of what is meant when we hear the terms "energy efficiency".

Regional Economics as a Foundation for Understanding Energy Efficiency

Without spending too much time on the econometrics and engineering challenges of regional energy production, we can explore a basic example to understand when "the juice is not worth the squeeze".

Suppose that you have a choice between building a well to get water and building rain barrels to collect storm water. Each of these methods of gathering water has its own strengths and weaknesses, but the one that we are concerned with is the *thermodynamic efficiency*. Thermodynamic efficiency is essentially the generalization of the concept of *work* from physics (and also "work" as it is used in the everyday sense of the word).

What thermodynamic efficiency allows us to measure is how well we are getting what we want relative to how much work we have to put in to get it. In the case of gathering water, there would be several factors to consider in this equation, including:

- How pressurized the well is, thus allowing us to use weaker (or perhaps no) pumps
- How regularly rain water comes
- How far the well is from our residence
- How transportable each type of water is
- Etc…

Each of these things contributes to how much work we have to put in to get what we want (in this case, water). Now, at some point the work we put in to get the water will not be worth what we get out of the water, the sustenance it provides us. Thus, we can say that there is some threshold above which it is not really worth our efforts to collect the water in some given way. This is a case where the physics and our intuition mesh rather well together.

But how does this relate to energy production? In the case of this paper, energy production is our "water" and getting it to us is our rain barrels or well pump. Just like with the different types of water, the different types of energy production carry associated physical costs with them. These costs could be ones of distance, difficulty in raw material extraction, service life of stations, etc… All of these are considered with respect to the *region* in which the production and consumption will take place.

Generalizing this to the case of energy production, we can ask questions like:

- Is it worth opening a new coal mine to generate power for a town far away?
- Is it worth mining uranium to feed an aging nuclear power plant in an industrial center?
- Is it worth building a massive damn to supply industry with cheap electricity just next to the river?
- And so on…

These types of questions and their answers are fundamentally based on many of the same questions that the water sources were, like:

- How many lines do we need from a power station to supply a city?
- How many substations are necessary to keep power production at 10% above production at all times?
- How can we reduce physical losses to transmission, poor infrastructure, and entropy?

As we can see, this is a very complex issue with many different considerations that must be taken into account to formulate sound public policy. However, for the purposes of this paper, we will explore one case study that involves a regional power cooperative that took advantage of analytics to improve efficiency.

PART II

Overview

A case study from informs.org[2] allows us to formulate an analytics prospectus relevant to increasing power efficiency. According to the website,

"The Midwest Independent Transmission System Operator (MISO) used operations research (O.R.) to design and launch its energy and ancillary services markets. Through these markets, O.R. allowed MISO to improve reliability and to increase efficiencies in the use of power plants and transmission grid assets resulting in billions of dollars saved…

For many years, the power industry in the U.S. consisted of utilities that had a localized focus ignoring that there might be a better regional solution. This localized focus, as well as the utilities' ability to control their transmission lines, created barriers for other utilities wanting to buy and sell electricity from each other. This resulted in utilities maximizing the use of their own power plants and transmission lines at the expense of the larger electrical system.

During the 1990s, the Federal Energy Regulatory Commission (FERC), a power industry regulator at the national level, pushed to restructure the industry to reduce individual utilities' market power and to drive more efficiency into the utilization of the U.S. fleet of power plants and transmission lines. As a part of this restructuring effort, FERC began encouraging the formation of Regional Transmission Organizations (RTO). RTOs are the "air traffic controllers" of the transmission grid—they assure that power travels where it needs to go at the lowest possible cost and with the highest level of reliability, considering the physical constraints of the electricity system.

In 2001, FERC approved MISO as the nation's first RTO. Today, MISO is an essential link in the safe, cost-effective delivery of electric power across 13 U.S. states and the Canadian province of Manitoba serving approximately 40 million people. Membership of MISO includes 35 transmission owners and 100 non-transmission owners. MISO has operational control over 55,000 miles of transmission lines and over 1,500 power plants totaling 145,966 megawatts of power plant capacity.

Driven by the goal of minimizing delivered energy costs in a reliable fashion, MISO leveraged advances in computing capabilities and O.R. algorithms to launch its original energy market on April 1, 2005 and its upgraded energy and ancillary services markets on January 6, 2009.

By leveraging O.R., MISO added significant value to the midwest region through improved reliability and increased efficiencies of the region's power plants and transmission assets. Based on its annual Value Proposition study, MISO region realized between \$2.1 and \$3.0 billion in cumulative savings from 2007 through 2010. MISO estimates an additional \$6.1 to \$8.1 billion of value will be achieved through 2020."

[2] https://www.informs.org/Impact/O.R.-Analytics-Success-Stories/MISO-Applies-O.R.-to-Energy-and-Ancillary-Services-Markets

Possible Models used to create MISO

In this section, we will explore three models that may have been used to create MISO. Each of these models would have performed very specific tasks during the design phase of the MISO project, and presumably could be used elsewhere on other high-level infrastructure projects involving power.

Phase I – Understanding Geography and Consumption

Phase Description

During the initial phase, the planning agency would like to know how to best identify clusters of people living in close proximity in order to place production and transmitting stations in high-density areas. These areas would have many customers living nearby so that transmission losses per capita would be reduced substantially.

Possible Data Sources

- Satellite imagery
  - In the public domain and therefore there provides a high-quality, low information gap data source to identify areas of high-density residency.

- Historical consumption data
  - May or may not be available from utilities. These data could be used to visualize consumption trends by area. One way to gather it if it is not available is randomized surveys.

- Existing layout of generating, sub-, and transmitting stations
  - These layouts would at least give a "starting point" when considering the topological aspect of placing stations. Note that the current layout of such stations may not exist due to efficiency but perhaps due to flawed public policy, perverse incentives, or technical reasons.

Primary Models

k-Means Clustering Algorithm

Philosophy: Clustering algorithms are natural candidates for identifying concentrations of people and electricity consumption. If satellite imagery is used and historical consumption data can be reasonably approximated, then this phase of the model would produce very valuable information. This model would likely be used again after the project's "completion" (defined as the placing of stations and/or the merging of existing stations), since cities are prone to swings in population density, especially by neighborhood.

Alternative Models

Network Map

Ethical considerations: None in particular.

Phase II – Understanding Logistical, Environmental, and Energetic Markets

Phase Description

Energy production, of course, requires energy sources. And energy sources are prone to price fluctuations. Such fluctuations can be especially rapid as newer, more efficient technologies come on to the market. For example, the price of oil has experienced many ups and downs since the 1979 Oil Crisis.[3] Stability in commodities markets will inform much of the project prices for large-scale infrastructure projects like building and merging stations since these projects tend to take place on the scale of several years to several decades.

Possible Data Sources

- Historical Commodity Data
    - These data are generally available in the public domain, and thus will not pose challenges for modelling purposes. However, more advanced models that rely on options (futures) may run into difficulty purchasing historical data on the option prices.

- Logistical Pricing Data
    - Transporting raw materials to stations, especially fossil fuels, can cost a significant amount of money. Knowing what to expect when moving large tonnage every year to member stations will help individual coops decide better on a long-term strategy.

- Environmental Impact Assessment (EIA) Data
    - Building or upgrading existing infrastructure usually comes with heavy government oversight to prevent environmental problems. At the federal level, this oversight requires the production of EIAs. These proposals highlight the cost to the company of undertaking large-scale projects while ensuring compliance with environmental laws. Analysis on these contracts could help member co-ops gauge the price of compliance.

Primary Models

Time Series (Auto-Regressive, GARCH, etc…)

Philosophy: Time series are used to model historical data and help with prediction. Since the data for commodities is already in the time series format, little pre-processing and aggregation would be necessary to use these data. Time Series models used in prediction are often updated nearly daily and would probably not need to be updated that often for utility purposes (i.e. the Time Series model would really just be used to gauge 3- to 5-year price windows).

[3] https://inflationdata.com/articles/charts/inflation-adjusted-oil-prices-chart/

Linear Regression

Philosophy: Linear Regression is a great candidate for modeling factor-to-factor relationships, such as those found in the pricing data for logistics and the EIAs. Co-ops could compare their individual situation to comparable companies in the models. These models would likely run more often to help co-ops plan for logistical expenditures.

Alternative Models

Linear Regression for Time Series

Clustering for Linear Regression (Logistics and EIAs)

Ethical considerations: None in particular.

Phase III – Predicting Growth

Phase Description

The last, and presumably hardest, phase of the project might have been predicting how energy consumption would change in the future. Particularly through the lens of automation, the future of energy consumption and economic stability is uncertain in a not small number of Midwestern states (where the study was based).

Possible Data Sources

- Regional Economic Plans
    - State and local budgets give an idea of what the government will prioritize economically in the future. Planning commissions will also tend to produce predictions for their own purposes and these are usually in the public domain. Such plans will give information about where government officials think growth and contraction will occur.

- Federal Labor and Economic Projections
    - These are fairly similar to Regional Economic Plans, but tend to be more granular and contain industry-specific information that can be exploited when it is known that the region in question contains many jobs within a certain industry.

- Research Journals Specializing in the Energy Industry
    - Academia, trade associations, and industry analysts will all have something to say on where they think the market for energy will go in the future. Synthesizing information from these sources would allow for a holistic view of the energy landscape in coming years.

Primary Models

Optimization Software (ARENA, R, SAS, etc…)

Philosophy: Simulation software is often used to model many different scenarios. In this case study, it may have been used to try out different models for economic growth and contraction and the relationships that such shifts in activity have with regional energy consumption. These models would probably be run to select 3 or 4 major scenarios, then again in a year's time to assess which models seem to be performing best. The information from these would then be used to determine policy decisions.

Alternative Models

None.

Ethical considerations: None in particular.

Summary

Although energy production is a complex topic, we can intuitively understand that at some point our efforts to produce it have to match our benefit gained from producing it. Many technologies exist for producing energy, and efficiency is a huge topic in engineering and policy discussions. Understanding how physical constraints, such as regional geography and economics, affect our consumption and use will help us plan better for the future.

There were presumably many models used in our case study, each for a specific project phase. From understanding history, to modeling the present, to predicting the future, analytics surely played a role at each step of the way. Combing various data sources and using sound analytical reasoning must have helped the co-op in the case study to achieve the monumental savings that it has experienced.