

TEACHING BASIC QUALITY CONTROL TOOLS BY ANALYZING THE ELECTRICITY SECTOR

Nicolas Dominguez-Vergara

Departamento de Sistemas, Universidad Autónoma Metropolitana (Mexico)

Abstract

There are many formidable and complex worldwide problems which can be analyzed using quality control tools that spark the interest of engineering students because they are currently important problems which impact their lives. Nowadays, there is a very important discussion on the phasing out of fossil fuels and the increment in the use of renewable energy sources to produce electricity. Solar and wind sources have the disadvantage that they are intermittent and on some days there may not be enough electricity produced from them. Therefore, the supply is reduced despite that the demand is constant or even increased during extreme weather conditions. In Mexico, there is a national debate about modifying several constitutional amendments to the Mexican energy reform of 2013 which allowed private generators to take over most of the electricity market. Among the main questions to answer in Mexico are: is it true that generating electricity from renewable energy sources leads to lower prices for the population? In the case of Mexico, why does the government complain about the electricity generation schemes legally allowed for private generators? The students must learn how to use engineering tools to reach the root of these problems and that there is also the need to search for hard data. The issues are so numerous and complex that a large part of the population is confused about who is right. In class the analysis is sketched, the students are very interested, and participate very actively in the discussion. However, the problem is not analyzed completely because of the time constraints. In this paper we show the analysis of these problems using industrial engineering tools. The objective is to answer these questions. An Ishikawa Diagram, a Decision Tree, a Pareto Diagram, a Quality Deployment Function and a reduced Failure Modes and Effects Analysis have been used to answer these questions. The analysis shows that despite the prices for generation of electricity from renewable energy sources the country does not benefit from most of the electricity businesses given to the private sector in Mexico. The quality control tools taught in engineering courses allow to analyze complex problems if used properly with the data needed for the analysis.

Keywords: *Teaching, engineering, tools, electricity.*

1. Introduction

Some of the most important problems society faces are usually very complex and students must learn methodologies to analyze them and sometimes try to solve them. In engineering quality control courses, students learn several basic quality control tools to analyze current problems in industry (Gutierrez & de la Vara, 2013). However, those same tools are useful for other fields of knowledge beyond engineering (Dominguez-Vergara & Dominguez-Perez, 2021). In class, students are asked to analyze some problems and some assignments are given to them so they can practice the use of those tools. In this paper we present an analysis of a very complex issue in Mexico regarding the electric sector of the country, which is partially reviewed in class. The Mexican government is trying to change the Mexican Constitution to reduce the generation of electricity by the private sector. However, some people consider that private generators are needed because they claim that their electricity is cheap and is generated with clean sources. Although most of their generation is using natural gas, while part is by intermittent sources and both are heavily subsidized by the Mexican public company, Comisión Federal de Electricidad (CFE). The issues of the Mexican electric sector are so diverse and important that the Mexican House of Representatives has spent more than one month since the beginning of the year 2022 inviting people against and in favor of the Mexican President's proposed bill to offer their independent analysis to them (Morales, 8 February 2022). In this paper the results of using some quality control tools to clarify and understand some of the issues regarding the proposed bill are presented. That understanding is necessary in order that the Mexican representatives take the right decision in accepting, rejecting, or modifying the initiative and that Mexican citizens understand what it is at stake.

2. Problems of the Mexican public electric company due to private electric companies

CFE reduced its production of electricity from 100% to 38% of the total generated in Mexico from the year 1999 to the year 2021 because the private sector has been gradually generating more electricity. In December of 1992 the Mexican government allowed the participation of private generators called Independent Energy Producers (IEP) and the generation by private companies of electricity for self-supply, against what the Mexican Constitution mandated at that time. In December of 2013 an Energy Reform was promulgated that legalized the IPE and self-supply companies and mandated economic incentives for the generation of clean energy by private companies. In Mexico, the electricity whose generation produces little, or no emission of carbon dioxide (CO₂) is considered clean energy. The 2013 energy reform also mandated to split the public company legally and functionally in several parts and did not allow to make many businesses among them. Supposedly, some of the fragmented parts of the CFE and the private companies would compete among them in the generation of electricity, and that would reduce its price, -that is what the Mexican Government assured- when it was asking for support to approve the 2013 energy reform. However, only 10 companies currently generate the 40% of the total electricity by privates and all of them are transnational companies and the price of electricity increased due to the 2013 energy reform in 35% from the year 2015 to the year 2018. Since the IEP started to produce electricity CFE had to shut down some of its plants because the CFE was required to buy all the electricity produced by the IEP (31% of the total generated in Mexico) in very long-term contracts; so a market of competition is only a fantasy. The self-supply companies produce 12% of the total generated electricity in Mexico. Also, one of the CFE branches is required to buy all or almost all the electricity generated by privates as result of three long-term auctions carried out some years ago (4% of the total electricity generated in the country). Aside from this, there is a daily (short-term) auction in which the electricity that is first dispatched through the transmission network is the one that has the least variable cost (basically the cost of the fuel used to produce the electricity, which is about 0 pesos for wind and photovoltaic solar sources), without considering the fixed costs (for constructing the plants and others) but at the end of each day all participants are paid the price of the most expensive electricity dispatched (which could be 6.50 pesos per kWh for gas turbine with diesel technology). One US dollar is worth 20.50 Mexican pesos. With this order of dispatch based in the increasing variable cost of the electricity, the electricity from solar and wind gets transported first because its variable cost is about zero, but they are paid as if they used the most expensive fossil fuel dispatched in the day, so the propagated low price of clean renewable energy it is just a myth in Mexico. This order of electricity dispatch favors privates and the CFE cannot sell part of its production; however, if the total cost of generation, that is, the levelized cost were considered, the CFE would be favored. All of this has caused that CFE does not produce 45% of its potential (loosing 215000 million pesos yearly) and that it must buy electricity from private companies to comply with the current law (loosing 223000 million pesos yearly). A lot of the 239 private companies with self-supply permits, against the regulations, sell electricity to more than 77000 clients which they misguide as partners. Most of economic incentives to privates, like the Clean Energy Certificates (CEL), are indeed subsidies to private companies, because privates receive them for generating clean energy but not the parts of CFE which produce clean energy with plants constructed before the year of 2014 and then another branch of CFE is required to buy the CEL from the private companies to demonstrate that they provide clean energy to its clients. Since 2014 the CFE has subsidized 6000 million pesos to private companies by buying their CEL. Also, self-supply companies producing clean energy do not pay fair transmission tariffs and have refused to pay more and the CFE must absorb the economic loss, that is, CFE subsidizes the transmission of electricity of those privates. The levelized price of the wind energy kWh by privates is of 1.52 pesos, more expensive than the levelized prices for hydraulic, nuclear, coal, combined cycle, photovoltaic, geothermic and gas turbine technologies, so not all electricity by the private sector is cheap. The proposed energy reform would end the abuses by private companies and would assure a better planning to assure clean and affordable electricity. On top of that, the CFE must provide backup power at its own expense when the private intermittent sources do not produce electricity. The main issues that the Mexican President has exposed in his initiative are shown in Figure 1 using an Ishikawa Diagram. Due to the subsidies to private companies CFE claims that loses more than 490 billion pesos each year.

3. Subsidies from CFE to private electric companies in Mexico

The Decision Tree in Figure 2 shows how the private sector benefits economically from the goal of obtaining electricity from clean and renewable energy sources. The first question used in the Decision Tree is: how do private entities benefit from the goal of generating clean and renewable energy sources in Mexico? The answer is: by supposedly offering that energy at low prices. Then the answer is posed as the

question: how do they benefit by offering that energy at low prices? The answer is: by the 2013 energy reform. The answer is then posed as the question: how do private entities benefit from the 2013 energy reform? The answer is: by obtaining subsidies from CFE ordered by that reform. The answer is then converted to the question: how do privates benefit from the CFE? And then the answers are listed, as well as the identified damages for CFE.

Figure 1. Problems to CFE due to the participation of privates in the Mexican electric sector.

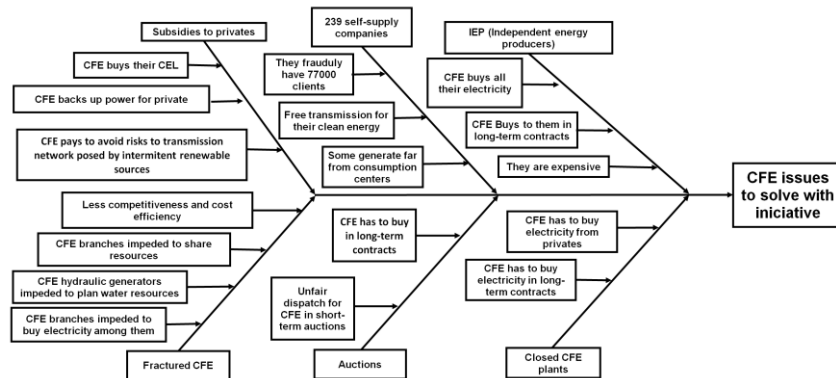
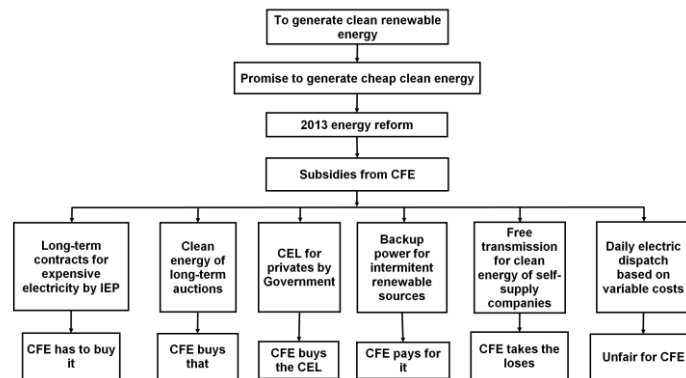


Figure 2. Decision Tree to identify how privates benefit from CFE.



4. Energy sources and requirements for electricity

In Mexico, the main sources of electricity are photovoltaic solar (PV), wind (W), running water (H), earth's heat (G), nuclear (N), natural gas (NG), oil (O), coal (C) and diesel (D). The desirable requirements of the present initiative is that electricity be affordable for all Mexicans, to have low production of CO₂, to not produce damaging contaminants to human health such as nitrogen oxides, sulfur oxides and particle matter (healthy), sporadic outages (continuous), to not produce problems to the transmission network (reliable), and without risks to the physical integrity of people and their assets (safe). In Table 1, an evaluation of the different electricity sources (in the first row) in complying with those requirements (in the first column) is provided using a Quality Deployment Function (Gutierrez & de la Vara, 2013). The priorities of the requirements are given in the second column with numbers from 1 to 6 (being 6 the highest priority). From the third column to the last, marks from 0 to 5, are given to each energy technology according to how each technology complies with each of the requirement of the first column. For example, in assessing how natural gas technology complies with the requirements, it is necessary to consider that nowadays natural gas is about twice as expensive than it was in 2019 but electricity can be produced almost continuously when burned, although CO₂ is emitted.

None of the electrical sources have the highest marks in all the requirements; that is, none is still perfect, which is why a very diverse basket of energy sources is needed in Mexico (and in almost all the countries in the world). This is highlighted in the values of Importance, which is the result of multiplying the value of the priority (the number in the second column) with the impact of the technology on each requirement (the number in the column of each technology). The Relative Importance of the scores is obtained by giving the value of 10 to the technology that has the highest value of Importance and 9 to the one with the second highest value obtained in Importance, and so on.

5. Electricity generation by source and CO2 emissions in Mexico

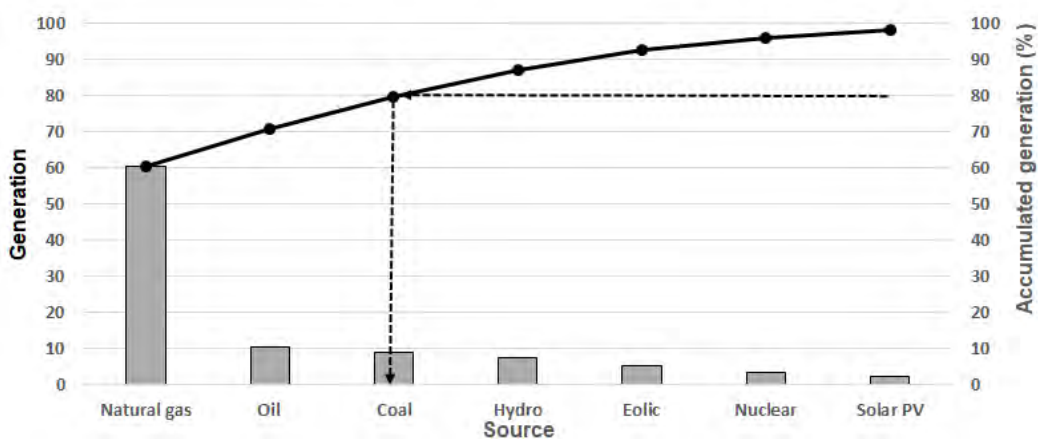
The total amount of clean energy produced in Mexico is of 86 Tera watts (TW) in hydroelectric, geothermal, wind, nuclear, photovoltaic solar, natural gas, oil, coal and diesel plants. Of the total clean energy generated in Mexico 55% is produced by CFE and 45% by private companies. The production of electricity by natural gas is 185 TW. Of the total energy generated with natural gas (using combined cycle turbine plants), 25% is by CFE, and 75% by private companies. The CFE contributes with 44% of the CO2 emissions, while the private ones with 56%. CO2 emissions by the CFE in one year is of 41188686 tons (combined cycle 40%, diesel 12%, fuel oil 21% and coal 28%). CO2 emissions by private entities in one year is of 52464220 tons (combined cycle 95% and diesel 6%).

The data shows that it is not true that private entities generate most of the clean energy in Mexico. On the contrary, the CFE generates most of that energy. Currently, the 38% of the electricity generated by CFE is clean while only 18% of the electricity generated by private entities is clean. The electricity generation in Mexico by source is, natural gas 60.3%, petroleum products 10.4%, coal 9.0%, hydroelectric 7.6%, wind 5.3%, nuclear 3.5%, photovoltaic solar 2.1%, geothermal 1.7%, and other sources 0.2% (Morales, 8 February 2022). This is shown in Figure 3 using a Pareto Diagram. Thus, more than 80% of the electricity is produced by fossil fuels (natural gas, oil, and coal). Some people incorrectly claim that México produces a lot of its electricity using coal, when that is not true. For comparison, the generation of electricity with coal in 2019 was of 66.1% in China, 73.2% in India, 37.5% in the United States and 31.8% in Germany (Bermejo, 17 February 2022).

Table 1. Electricity sources and requirements.

Requirements (below)/ Technology (right)	Priority	PV	W	H	G	N	NG	O	C	D
Affordable	6	4	4	5	4	4	5	5	4	5
Clean (CO2)	3	5	5	5	5	5	4	2	1	1
Healthy	6	5	5	5	5	3	4	2	1	1
Sufficient	3	2	2	3	3	3	4	5	4	4
Continuous	5	0	0	5	5	5	5	5	5	5
Reliable	4	0	0	5	5	5	5	5	5	5
Safe	2	5	4	5	5	4	5	4	4	4
Importance		85	83	139	133	119	133	116	98	104
Relative Importance		4	3	10	9	8	9	7	5	6

Figure 3. Electricity generation by source in Mexico.



6. What could go wrong in the Mexican electric sector?

The question posed in the subtitle is answered using a reduced Failure Modes and Effects Analysis (Dominguez-Vergara & Dominguez-Perez, 2021); that is, taking the main questions which the analysis poses and answer them. The needs are clean, healthy, sufficient, continuous, reliable, and safe

electricity and in order to satisfy them it is necessary to have appropriate electricity sources and a good electricity transmission network which requires not only good planning for the electric sector but also investment to develop it.

Which are the functions, purposes, and requirements? A national electric system which provides clean, healthy, sufficient, continuous, reliable, and safe electricity.

What could be wrong? Inappropriate laws could lead to faulty planning and lack of investment to assure the appropriate electricity generation and reliable, safe, and sufficient transmission network to satisfy the requirements.

How severe is it? Outages and high electricity prices can produce energy poverty, inflation, and social unrest. Large CO₂ emission contributes to climate change. Faulty planning of intermittent electricity sources may cause stress to the transmission network and make it unreliable.

Which are the causes? Private entities seek earnings through subsidies and lobbies to have CFE destroyed (by fracturing it and making it to pay subsidies to them) and bad planning for the national electric system, as documented in the many generation permits for intermittent sources (far more than the needed demand) far from consumption centers.

How often does the failure occur? As often as laws are the result of lobbying by privates and the corruption of decision makers (as it is alleged it was the way the 2013 energy reform passed).

How could it be prevented or detected? Enacting good laws through informed decision makers (in the Mexican congress) and stake holders (the population, industry, and social sector).

What can be done? Making laws that assure planning and financing for the electric system, avoiding subsidies to privates to assure resources to finance a reliable, safe and sufficient transmission network and enhancing the public company instead.

What indicators will be appropriate? The price of electricity, coverage of electricity in the country, percentage of electricity from clean renewable sources and the advance towards having electricity as a human right.

Who will be the responsible people? The Mexican government responsible for planning, regulating, and controlling the electric sector and in particular the legislative branch to make laws which benefit the developing of the country, strengthening the public company because privates care just about earning for their shareholders. The Mexican government to assure an ordered and gradual energy transition from fossil fuels to clean renewable energy sources and to develop, adopt or adapt technologies to store energy from intermittent sources.

7. Conclusion

Basic quality control tools are useful to analyze complex issues like the ones regarding the Mexican electric system.

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