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Tilting at Windmills: Drivers, Risk, Opportunity, Resilience and the 2021 Texas Electricity Grid Failure

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Abstract. To put it very simply, but not at all clearly, the 2021 Texas electricity grid failure was both caused by and not caused by the use of renewable energy. In 2020, 46 percent of Texas's energy was generated by natural gas, coal 18 percent, nuclear 11 percent, and renewables wind power 23 percent, and solar 2 percent. During the winter months when power demand is lowest, renewables can rise to up to 55%. When the historic winter storms hit, the biggest problem was the lack of winterization of all types of generation systems and supporting infrastructure. All the of the systems failed to various degrees. So why weren't these systems winterized? Mostly it was a lack of incentives. The government provided no financial incentives and did not mandate winterization. These winter storms were once in a century event, and companies could not make a business case with reasonable ROI to winterize. Companies that did manage to operate sold power and gas for up to 400% more than normal due to the lack of supply and increased demand. So, there was a built-in disincentive to not invest. What happened was a complex system of systems failure the size and scale of Texas and to explain it all would require a book. This paper will look at the risks, opportunities, and drivers of Texas electric grid, what caused it to fail, and incentives to succeed in the future. We will also examine incentive systems gone wrong such as the Cobra Effect.

Introduction

When the storm hit and the power systems began to fail, different groups blamed the problem on various causes often along ideological lines. Conservatives were quick to blame wind farms and renewable energy for the power outages. One image widely circulating on Twitter and Facebook (Figure 1) shows a misleading image of a frozen wind turbine. "In Texas today... a helicopter, using fossil fuels, spraying deicer, made with fossil fuels, to de-ice a wind turbine, manufactured using fossil fuels, that is supposed to produce clean energy without using fossil fuels," one Facebook post says. But the picture actually shows ice being removed from a wind turbine in Sweden, using hot water. BBC News (2021) traced the image back to a 2016 report published by Swedish company Alpine Helicopter, demonstrating "airborne de-icing solutions" for wind turbines. Texas Monthly, (2021) a left leaning publication and others (Dillingham, 2021) blamed the governor and legislature for not mandating that the fossil fuel plants winterize their systems to ensure that the systems remained operable. Others blamed it on the wild west environment of deregulated utilities. Everyone had their own villain.

Figure 1. Mis-captioned Photo of a Helicopter De-icing a Wind Turbine

So, What Really Happened?

Winter Storm Uri hit Texas on February 13–17 2021, wreaking havoc across the entire state. Grocery shelves emptied as people stocked up; more than four million residents went without power and water; and dozens perished due to extreme cold, lack of heat, and other related tragedies. Some residents who did have access to power saw exorbitant electricity bills in the aftermath. Millions were without power, heat, and water for several days, and each of Texas' 254 counties was affected in some way. Natural gas production froze, as did the gas pipelines. Once power plants went offline, they were not able to restart in the below-freezing conditions. Demand for natural gas to heat homes and businesses also spiked, contributing to shortages. And high gas prices further disrupted generation, as operators who could not turn a profit took their plants offline. Several coal plants and one of Texas' four nuclear facilities were also knocked offline by cold temperatures since Texas does not require power plants to be winterized. (Penney, 2021)

As generation was dropping from the grid, demand hit a record high for winter, rivaling demand seen during some of the hottest summer days. The Electric Reliability Council of Texas, (ERCOT) which oversees the majority of the state's power grid, reported that demand peaked at 69,000 megawatts (MW) on Sunday, surpassing its planned worst-case scenario of 61,388. Shortly after, the grid operator instructed utilities to begin controlled power outages (load shedding) to avoid longer-term damage. Power generation dipped much lower from Feb. 14 through 17 reaching a low of 46,059 MW. In its seasonal risk assessment, ERCOT anticipated that "extreme" winter demand could spike as high as 67,000 MW statewide if conditions matched the 2011 ice storm that led to blackouts in parts of the state. The state's emergency scenario failed to anticipate the scale of outages caused by this winter storm. Normally ERCOT plans for a reserve margin of at least 13%. As the Texas energy grid and generation is unregulated, the price will vary with demand. For example, Texas reached a peak load of 74,666 MW on August 12, 2019, and the wholesale price of electricity reached $9,000 per megawatt-hour (MWhr) (compared to only $83 per MWhr on average). (Quick Electricity, 2021) The peak load during the blackout was nowhere near the summer load. According to ERCOT, the grid was "four minutes 37 seconds away from a total collapse," when controlled outages were implemented to prevent a statewide blackout. (Penney, 2021)

What About Winterization?

The storm was forecast almost two weeks in advance, and the common wisdom is that generator providers should have been able to prepare for it to ensure that the grid was able to cope. So, why didn't they? The answer is that it made no business sense. The generating plants, gas pipelines, and other infrastructure were not winterized and there was simply insufficient return on investment for these private companies to do so. Investing large sums of money to prepare for an event that may only happen every 40-100 years is just not sound business sense.

But one also must ask, “Why weren't the turbines self-defrosting?” Turbines can be equipped to deal with freezing temperatures. "The wind energy industry has almost five decades of experience designing wind turbines to operate in freezing temperatures in harsh climates," says Prof Benjamin K. Sovacool at the University of Sussex. Turbine blades can be heated, special anti-freeze fluids used, along with better insulation of gearboxes. The blades themselves can also be designed for performance in sub-zero temperatures. But this only makes economic sense in places that regularly experience extreme conditions, such as in Alaska, Canada and northern Europe. "Operators [in Texas] didn't invest in the usual weatherization or ice protection techniques says Prof Sovacool "because generally they didn't expect it to become so cold," (BBC News, 2021) This practical, pervasive and short-sighted attitude resulted in much of the energy infrastructure becoming frozen solid. This included gas drilling, gas transportation, water supplies, etc. All parts of the infrastructure were affected.

Winter months are when coal and gas plants normally go offline for mandatory maintenance as the peak is much lower. Putting them back online would have cost a significant amount of money and further delayed maintenance as well as delaying when the plant could come back online to support the summer peak load. With the Texas government unwilling to provide incentives or to mandate winterization, making this investment was a risk power companies were unwilling to take. An incentive is a thing that motivates or encourages one to do something a payment or concession to stimulate greater output or investment. Guilder (2021) commented that “Adam Smith and Karl Marx agreed that capitalism is most essentially an incentive system.” Adam Smith also pointed out that “Incentives lead as if by an invisible hand to growth and prosperity.” (Smith, 1776) What is needed is to determine and guide the incentives, which will be both carrots and sticks which we will review later in this paper.

Electric Utility Network History

Electricity as a public utility began in the late 19th century. Edison patented a system for electricity distribution in 1880, which was essential to capitalize on the invention of the electric lamp. On December 17, 1880, Edison founded the Edison Illuminating Company. The company established the first investor-owned electric utility in 1882 on Pearl Street Station, New York City. (CONED, 2011). Modeled after the gas lighting industry, Edison supplied energy through virtual mains to light filtration. With this, electric utilities also took advantage of economies of scale and moved to centralized power generation, distribution, and system management. (Borberly, 2001), (Hause, 2017) During the 20th century, configuration and relationships between these electric utilities changed. Initially, electric utilities were isolated systems without connection to other utilities and serviced a specific geographical area. They were also normally vertical monopolies providing everything from generation to distribution. In the 1920s, utilities joined together establishing a wider utility grid as joint operations saw the benefits of sharing peak load coverage and backup power. In 1934, with the passage of the Public Utility Holding Company Act, electric utilities were recognized as public goods of importance along with gas, water, and telephone companies and thereby were given outlined restrictions and regulatory oversight of their operations. This model of regulation lasted for more than 60 years. The Energy Policy Act (EPAct) of 1992 advocated de-regulation of electric utilities by creating wholesale electric markets (EPACT, 1992). It required transmission line owners to allow electric generation companies open access to their network. (Mazer, 2007), (Hause, 2017).

SCADA and Energy Management Systems

As the systems became more complex, control systems were developed to ensure continuity of supply. Supervisory Control and Data Acquisition (SCADA) systems allow the power network operator to view and control the status of many aspects of the network. These provide real-time wide area monitoring and control of power systems for grid-wide monitoring and control of the power flows, transmission limit calculations and power plant operation. When advanced control systems, system protection, communication and automation applications were developed they significantly improved the capacity and reliability of existing power transmission and distribution networks. They also allowed networks to scale to a much larger scale of geography and complexity. (El-Hawary, 1997)

The United States Energy Grid

The United States is divided into three separate electrical grids. The Eastern Interconnection grid is located east of the Great Plains. The Western Interconnection spans from the Great Plains to the Rockies and along the West Coast. A separate grid (ERCOT) provides electric power for Texas residents, where legislators prefer state rather than federal regulation as shown in Figure 2.

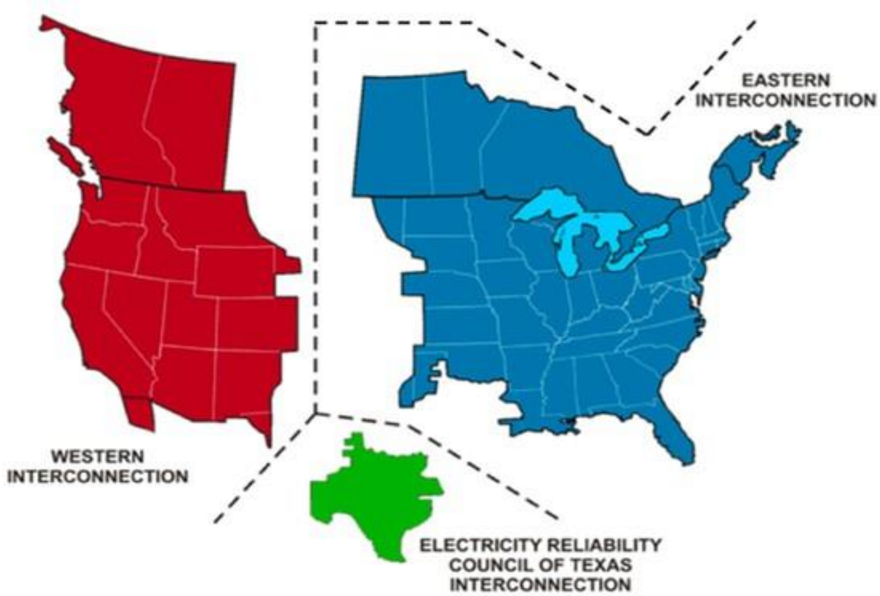

Figure 2 North American Energy Grids

Each of these energy grids has its own unique set of issues due to geography, complexity, interconnection, politics, and scale. A US News (2019) study ranked the different states' energy infrastructure. This study evaluated three major metrics: renewable energy usage, reliability of power grids and the average cost of electricity. Texas ranked number 25 overall, 9 for electricity price, 29 for power grid reliability, and 36 for renewable energy usage.

Texas is not the only region to have experienced outages. Examples are the Northeast US and Canada blackout of 2003, the Southwest outage of 2011, and recent California blackouts and brownouts. These are caused by a variety of reasons including excess demand, bad weather conditions, physical obstacles such as trees, user error, understaffing, miscommunication, faulty telemetry and so forth. Most blackouts are caused by a combination of these rather than a single reason. Causalis (2008) has an analysis model of the blackout using a state/activity model notation. NERC (2004) is a technical analysis of the East Coast US and Canada August 14, 2003, blackout. Finally, Wikipedia (2011) contains an excellent description of the Northeast blackout of 2003.

Bigger is Not Necessarily Better

Dillingham (2021) and several others have argued that ERCOT should look seriously at interconnecting to the Eastern Connection and/or Western Connection." Fairley, P (2004) published a study that found that the larger the grid, the more likely it would be to fail, and with more catastrophic results. The 14 August 2003 blackout may have been the largest in history, zapping more total wattage and affecting more customers than any before, but if history is any guide, it won't be the last. "These kinds of outages are consistent with historical statistics, and they'll keep happening," says John Doyle, professor of control and dynamical systems, electrical engineering, and bioengineering at the California Institute of Technology in Pasadena. "I would have said this one was overdue." "We will have major failures," agrees IEEE Fellow Vijay Vittal, an electrical engineering professor at Iowa State University in Ames, who is an expert on power system dynamics and control. Extrapolating from the small outages that occur frequently, one might expect a large power grid to collapse only once in 5000 years. But between 1984 (when North American utilities began to systematically report blackouts) and 2000, utilities logged 11 outages affecting more than 4000 MW – making the probability of any one outage 325 times greater than mathematicians would have expected. Thus, statistically speaking, the blackout on 14 August 2004 was no anomaly.

The brownouts and blackouts experienced by California in 2021 were not mitigated by being a part of the Western Grid. In addition, Lambermont (2020) argues that "Years of poor policy and decision making in California have culminated in a grid that is overly reliant on intermittent wind and solar and electricity imports from nearby states. California energy policy continually forces reliable "baseload" energy generation offline in favor of wind and solar, or even worse, with no replacement at all. One major cause of the rise in usage of wind and solar power in California is the state's Renewable Portfolio Standard (RPS) mandates that force utilities to adopt the use of these intermittent resource that although "greener" are less reliable. To compensate, California cycles their baseload resources up and down as the sun and wind come and go, making blackouts more likely." Texas's energy in 2020 was natural gas with 46 percent, coal 18 percent, nuclear 11 percent, and renewables of wind power and solar 23 (up from 6% ten years ago!) and 2 percent respectively. On the days leading up to Winter storm Uri, wind energy was providing roughly 25%

of the total generation. Since Texas still has a diverse set of electric generation sources, it can normally cope when one fail, but not when all fail. (Quick Electricity, 2021)

Modeling the Energy Enterprise

In order to understand this complex system of systems, we need to model some of its aspects. As an example, we will look at Austin Energy (AE). AE powers the city of Austin, Texas, and nearby areas, making it the eighth largest public utility in the U.S. Since it's a community-owned utility in a deregulated energy environment, AE sells its energy to the grid and then purchases what it needs from the grid for its community. Figure 3 shows a graphic from the AE energy plan. The company is currently executing its 2020-2025 Strategic Plan. (Jackson, 2021) One of the strongest components of this strategic plan is how the utility spends several pages fully defining the complicated environment in which they operate, and the risk and scenario planning they used to develop the plan. The document also summarizes several high-level objectives with example initiatives. (Austin Energy, 2020)

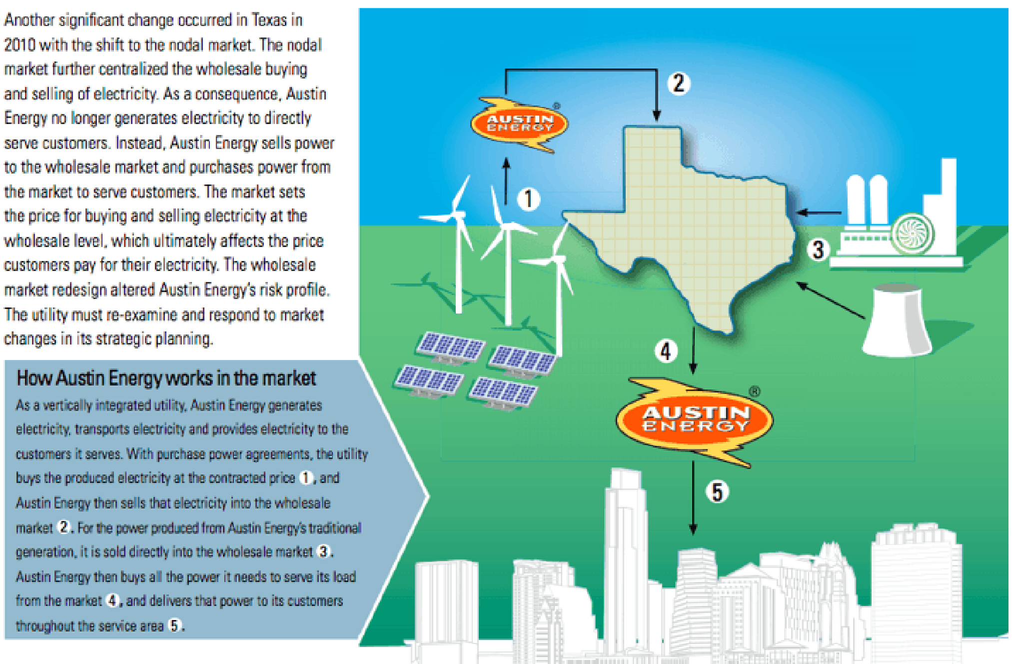

Figure 3 Excerpt from the Austin Energy Strategic Plan

The plan lists the goals and mission of AE as well as its vision. They have been modeled along with other aspects below using the UAF.

The Unified Architecture Framework (UAF)

For enterprise modeling, an architecture framework is required to understand systems of systems and how they change over time. DoDAF is the Department of Defense Architecture Framework (DoD, 2012) and MODAF is the Ministry of Defence Architecture Framework (MOD, 2020). NATO created NAF version 3 (NATO Architecture Framework) based on MODAF and has recently adopted NAF version 4 (NATO, 2018). NAF version 4 has been adopted by many European countries including the UK. The Unified Architecture Framework (UAF) is built on top of SysML and is used to define the overall goals, strategies, capabilities, interactions, standards, operational and systems architecture, systems patterns and so forth (UAF, 2019). Security and human factors (personnel) views were added to the UAF to improve the coverage of these areas of concern. The UAF was previously called the Unified Profile for DoDAF and MODAF (UPDM) and was ratified by the Object Management Group (OMG). (Hause, 2017) Several papers have been written on the UAF and its support of SoS modeling including (Hause, Dandashi 2015) and (Hause 2014). The full details of SysML and UAF are not included here for space reasons.

High Level Conceptual Model

To understand the enterprise at the highest level and in the simplest form, the high-level taxonomy diagram is used. The purpose of the diagram is to describe the main enterprise concepts in a manner that is easy to understand to ensure a common understanding. Figure 4 describes the main concepts and their relationships identified above. (Coal and solar have been removed to simplify the model.) Natural gas drillers supply gas to wholesale gas providers who supply it to natural gas generators who sell power to wholesalers who sell power to distribution providers who supply it to the customer. The elements defined here can also be used in other parts of the model such as the resources model. Renewables and nuclear generators provide power to the transmission lines which is then sold by energy wholesalers and so forth. Governance and water systems are also shown.

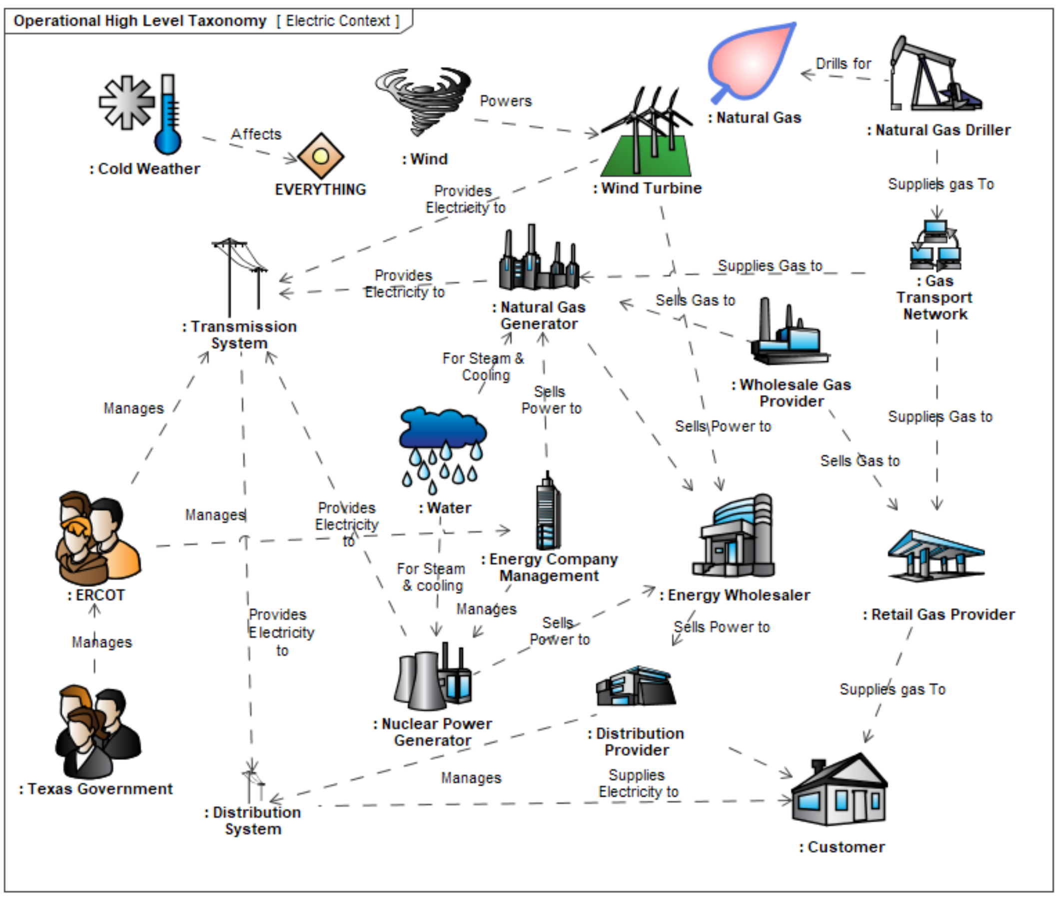

Figure 4 Electric Generation and Provision Concept

Enterprise Drivers, Challenges and Opportunities

To understand what motivates the enterprise, a common method is to identify the drivers, challenges and opportunities for the enterprise and from these determine how to add or modify capabilities to improve the likelihood of enterprise success. The measure of success is determined by knowing how well the desired effects (i.e., downstream results) will be achieved when certain capability enhancements are put into place. The UAF metamodel version 1.1 did not have the requisite model element types that represent these key up-front management concepts. These additional elements in the EA model were added in UAF version 1.2 to provide the proper justification for new and enhanced capabilities. (Martin 2021, 2022) (OMG, 2022)

Key Modeling Concepts.

Definitions for the key concepts discussed so far are as follows.

- Driver – Thing that forces to work or act; that which urges you forward
- Challenge – A demanding or stimulating situation; a call to engage in a contest or fight
- Enterprise State – Condition with respect to circumstances or attributes
- Capability – Ability to do something under particular conditions and environments
- Opportunity – A possibility due to a favorable combination of circumstances
- Risk – A source of danger; a possibility of incurring loss or misfortune
- Effect – A phenomenon that follows and is caused by some previous phenomenon
- Outcome – Something that happens or is produced as the final consequence or product

Below are examples of these items to better illustrate the intended meaning of these architectural modeling concepts when trying to capture the front-end of the architecting process.

Drivers: Industry deregulation
    Expected profit sharing with shareholders and owners
    Built up expectation over time of highly dependable power services
    Weather extremes beyond normal expectations
Challenges: Anticipate technology trends
    Protect Infrastructure & Ensure availability
    Maintain continuity during degraded or disrupted environments
    Monitor systems to ensure proper execution
Opportunities: Green and environmentally friendly generation
    Provide energy consumption information to customers
    Provide power during cold peak
Effects: Customer satisfaction with our products and services
    Increasing value for shareholders and owners
    Continuous power generation
    Resilient and efficient power grid
Outcomes: Security and well-being of the environment
    Affordable electricity
    Health and wellbeing of the populace
Risks: Lack of Return on Investment
    Grid Failure
    Supply Failure
    Generator failure & Frozen Equipment

New Architecture Views in the UAF Standard

The key improvements to UAF are the following new architecture views that incorporate the new modeling concepts discussed above. These views give additional insights into how the enterprise should move forward and help with capability planning and management activities. (Martin 2021, 2022), (OMG, 2022)

1. Strategic Motivation view (shown in Figure 5) identifies enterprise drivers and associated challenges to be addressed and opportunities to be pursued
2. Strategic Processes view defines the enterprise phases as a way to structure the phased deployment of capability configurations
3. Strategic States view defines how the desired effects will be achieved and how these relate to the challenges and opportunities
4. Strategic Information view identifies key strategic information elements that are essential to achieving enterprise goals

Driver and Outcome Modeling Concepts

Drivers, challenges, and opportunities were added to the UAF conceptual schema to allow these concepts to be incorporated into the enterprise architecture model used in the Strategic views. A summary of the key entities and their relationships is as follows:

1. Drivers present Challenges to the enterprise
2. Challenges are conditions that can be addressed by Opportunities
3. Each Opportunity can present the circumstances for new Risks to the Enterprise
4. Existing or new Capabilities can help the enterprise pursue these Opportunities
5. Capabilities can cause the appropriate desired Effects to occur
6. Operational activities and related enterprise services map to the Capabilities
7. Resources and their functions implement the operational activities
8. Effects implemented by resources will result in desired outcomes.

AE Drivers, Challenges and Outcomes

Figure 5 shows the AE goals as Provide continuous power, Customer experience, Grid Resilience, Environmental leadership, and Financial health. (Austin Energy, 2020) The new strategic elements are also shown. As an example, the Provide power during cold peak opportunity enables the Provide continuous power and Grid resilience Goals. It is motivated by the protect infrastructure challenge, which is presented by the Customer outages driver. The Winterize infrastructure opportunity enables the Goals of Provide continuous power and Grid resilience. It is Motivated by the challenges of Prevent revenue loss and Protect infrastructure. As stated previously, disabled plants did affect revenue, but damage to infrastructure was mostly temporary. What was affected was the Negative public perception Driver and Customer outages. The distribution companies largely bore the brunt of this as generation companies largely are not customer facing. Winterizing infrastructure was not mandatory, so did not enter into the calculations and cause companies to act.

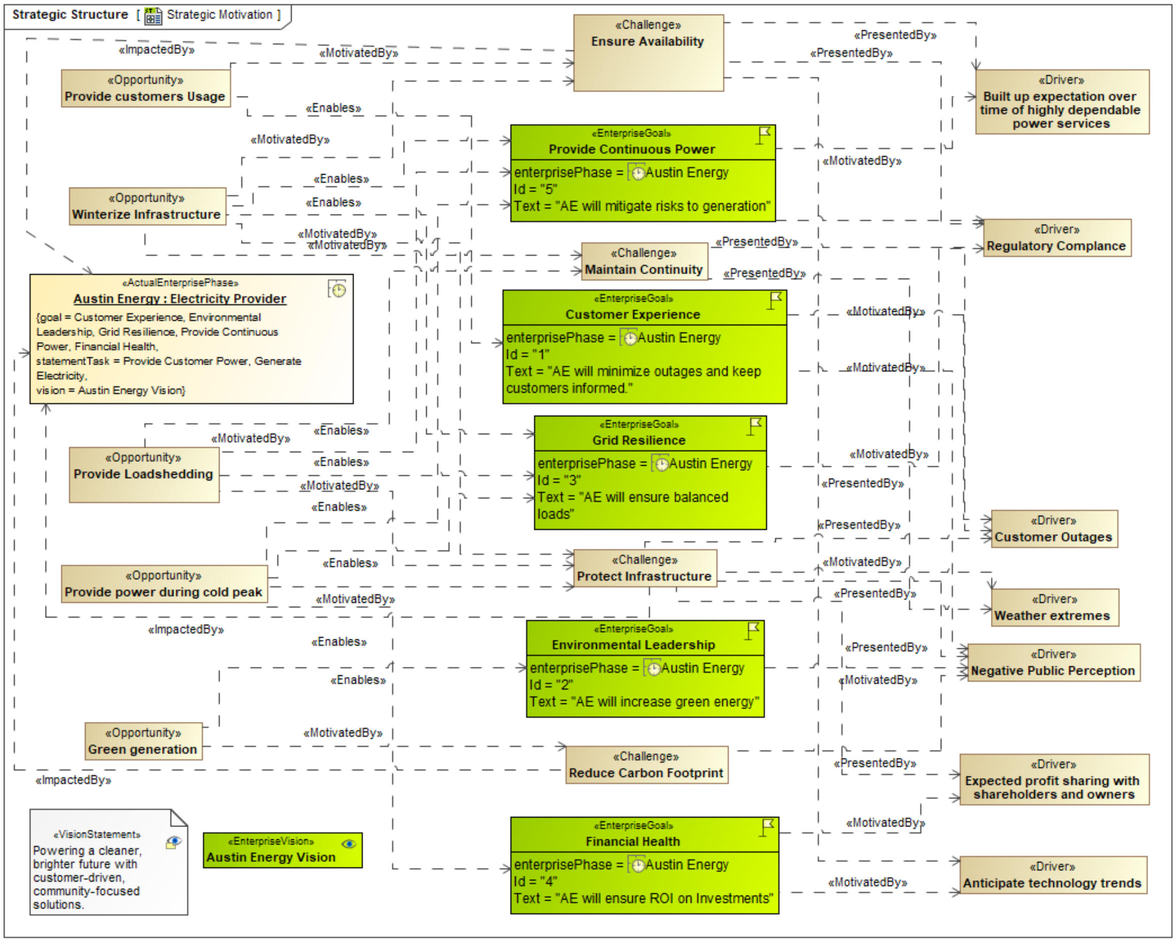

Figure 5 Strategic Drivers

Capabilities and The Resources View

Having defined the main enterprise concepts, as well as the goals, vision, drivers, etc., a set of capabilities for the enterprise has been developed as shown in Figure 6. Capabilities are the ability to achieve a desired effect realized through a combination of ways and means (e.g., systems and other elements in the resources view) along with specified measures. Capabilities are realized during the different temporal and structural enterprise phases and their supporting systems deployed by the projects (OMG, 2019). The capability taxonomy diagram (not shown) is used to define the capabilities. These correspond to the high-level abilities of the AE Enterprise as well as supporting infrastructure. Capabilities include Generate electricity, Governance, Provide Generation Gas, Provide Cooling Water, etc. The Resources view captures a solution architecture consisting of resources, e.g., organizational, software, artifacts, capability configurations, and natural resources that implement the operational requirements. The resources implement the enterprise capabilities defined in the strategic views. Figure 6 shows the capabilities and the systems that exhibit them, many of which were defined in the concept diagram in Figure 4.

Generate electricity is exhibited by Natural Gas Generator, Wind Turbine, and Nuclear Power Generator, Governance is exhibited by ERCOT, Texas Government, and Energy Company

Management, Provide Generation Gas is exhibited by Natural Gas Driller and Wholesale Gas Provider, and Provide Cooling Water is exhibited by Water Provider.

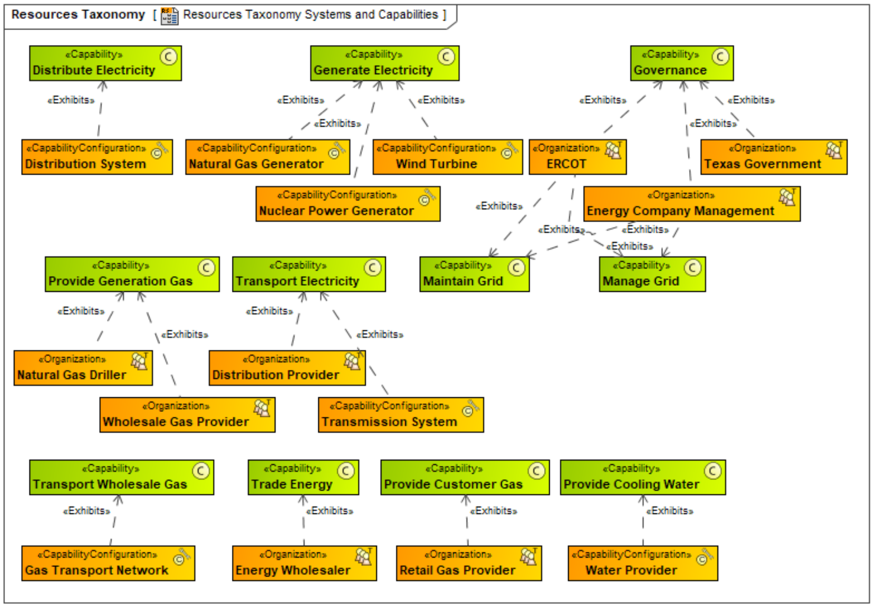

Figure 6 Capabilities and Systems

Figure 7 shows the high-level interactions between the systems that support the capabilities.

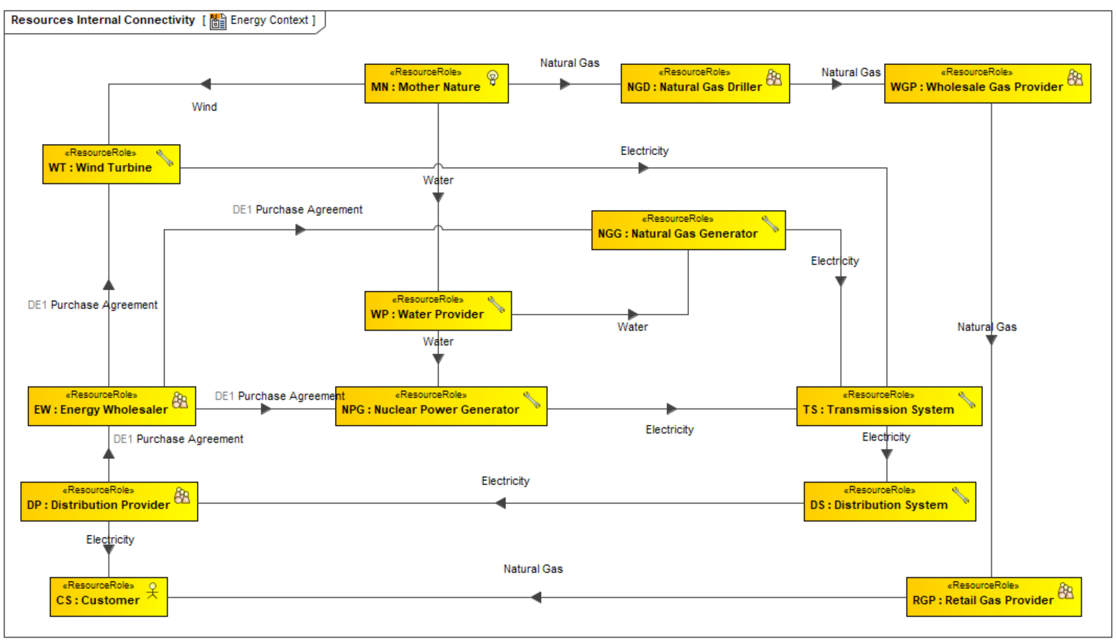

Figure 7 System Interactions and Flows

Figure 7 shows the interactions as well as the interdependencies between the different elements in the resource architecture. The loss of any of these systems will have severe consequences on the others. For example, the natural gas generators require water from the water provider and gas from the energy wholesaler in order to send electricity to the transmission system. Without gas and water, the natural gas generator cannot generate electricity. Various scenarios can be modelled to describe causal sequences of success as well as failure. And given the interdependencies, there are many ways that systems and the system of systems can fail because of interaction failures. In addition, individual system failures can occur. In the case of the grid outage, various systems failed due to frozen equipment. The risks of system failure need to be understood and modeled. These are shown in Figure 8.

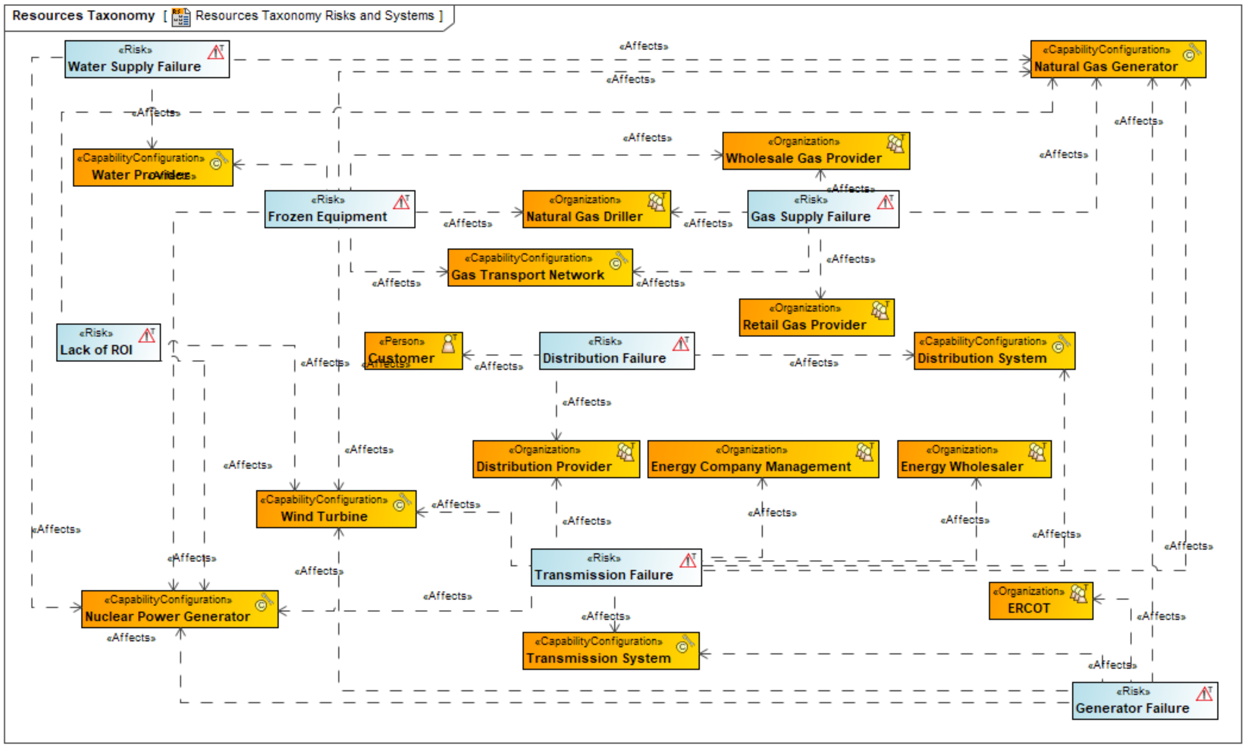

Figure 8 Risks and Affected Resources

Figure 8 shows how many of the systems are affected by Frozen Equipment such as the Nuclear Power Generator, Gas Transportation Network, Natural Gas Generator, etc. If this risk is realized, much of the electrical infrastructure will be affected, as happened with Winter Storm Uri. There are several other risks affecting multiple systems and others that will generate a causal sequence of failure such as Water Supply Failure. Risk mitigation involves defining strategies, systems and processes that will reduce or eliminate the risk. The schedule and costs for these will need to be calculated and justified as part of the enterprise management and the overall business strategy. This will be discussed later.

Legislation on Winterization

On June 8, 2021, Texas Governor Greg Abbott signed Senate Bill 2 and Senate Bill 3 to reform the Electric Reliability Council of Texas (ERCOT). "A top priority that we had this legislative session was to fix the power to prevent any other power grid failure in the future," "The legislature passed comprehensive reforms to fix all of the flaws that led to the power failure. "Senate Bill 3 (SB3) requires electricity providers operating on the ERCOT grid to weatherize their equipment and improve communication during outages by creating an alert system. Abbott said the new legislation targeted weather for all seasons. (Fung, 2021)

Strategic Processes

Having mandated that the energy infrastructure needs to be winterized, AE is now examining how to develop this strategy over a series of phases. Figure 9 Shows the Austin Energy Enterprise divided into a series of phases exhibiting capabilities, and containing a value stream providing value items and. A value stream is an end-to-end collection of activities that create a result for a customer, who may be the ultimate customer or an internal end-user of the value stream. The activities are decomposed as operational activity diagrams. There are value streams of the current phase, winterize infrastructure, and increase green generation. Value items may be positive or negative, depending on point of view. There are several different types such as Time, Cost, Quality, Revenue, Benefit, KPI, Loss, and Other

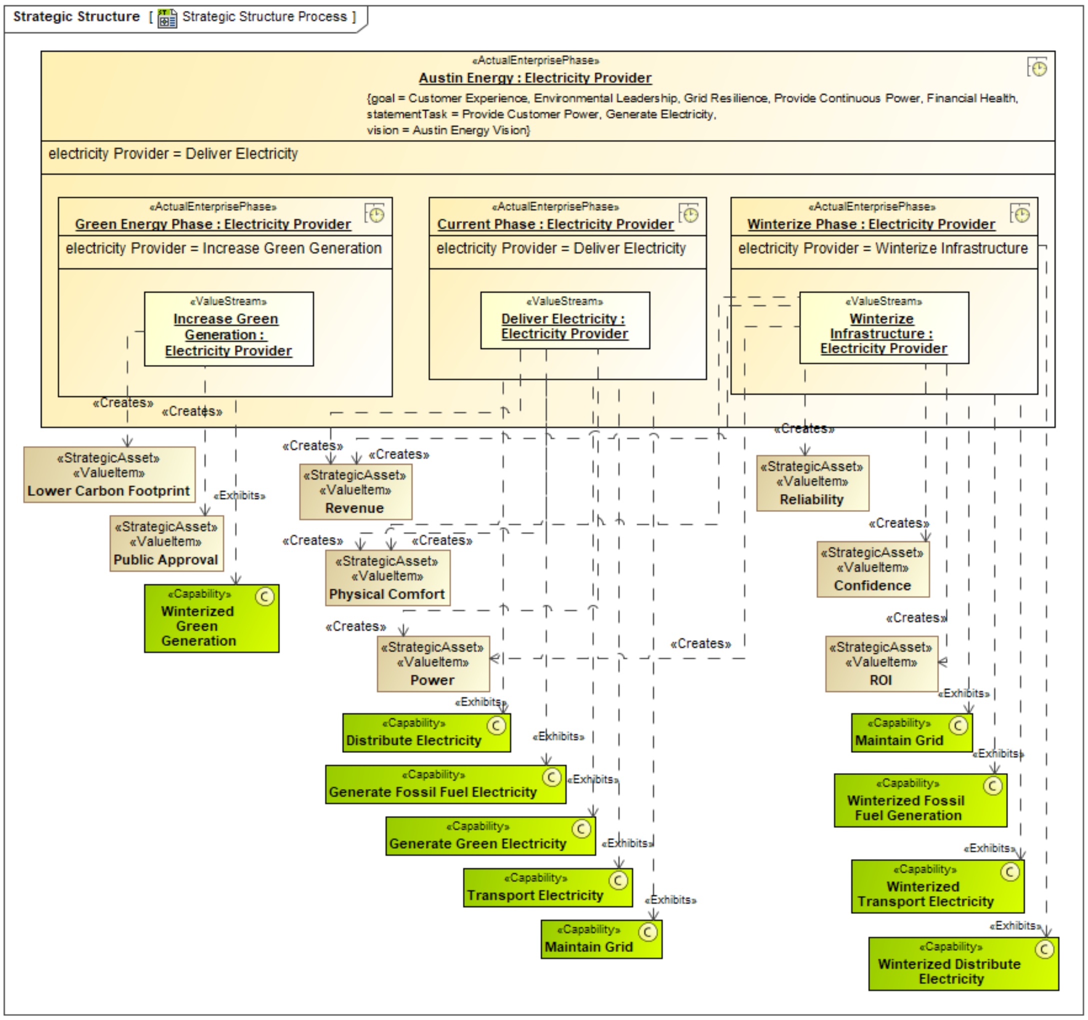

Figure 9 Strategic Processes

The phases and the value streams are limited in scope to capabilities of the power company itself. (Water provision for example is not shown.) Deliver electricity, like all the phases provides revenue to the business and shareholders, power, and physical comfort to its customers. The winterize infrastructure value stream exhibits specialized winterized capabilities shown in Figure 10. The increase green generation stream creates public approval and a lower carbon footprint. The strategic process view demonstrates the benefits as well as losses that can take place in the strategy and needs to be considered in relation to the rest of the views.

Strategic States

The strategic states diagram shown in Figure 10 shows the effects which are definitions of what the enterprise capabilities want to achieve. The effects define the measurements and are instantiated as actual effects with specific values. These affects are achieved by the deployed resources that exhibit the capabilities. For example, generate fossil fuel electricity desires specific power values and winterized generation desires systems that can operate in +45 and -20 Celsius.

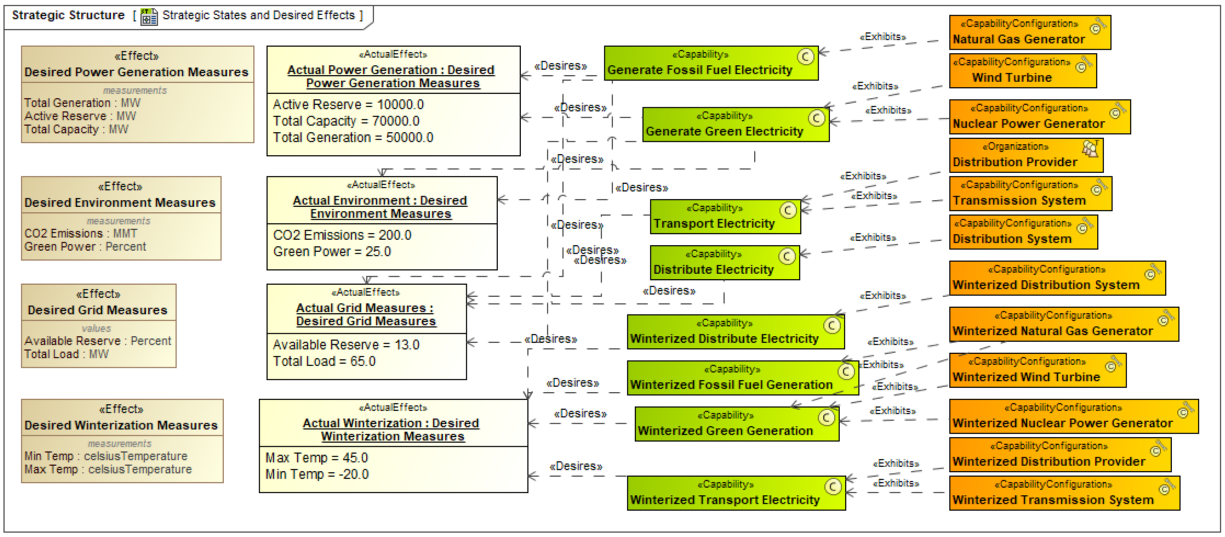

Figure 10 Strategic States, Capabilities and Desired Effects

Figure 11 shows the actual outcomes provided by the fielded resources and value streams.

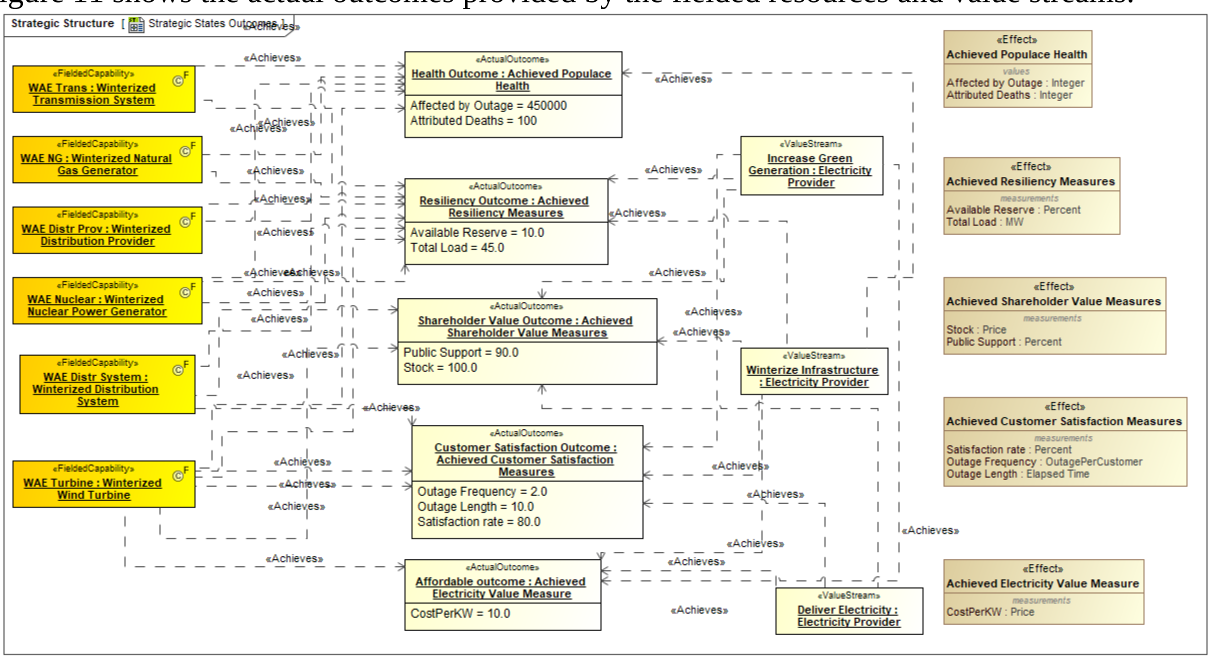

Figure 11 Risks and Affected Resources

The actual outcomes shown in Figure 11 are those that are achieved by the fielded capabilities which are instances of the resources. This set of actual outcomes are for the winterized versions of these systems. Note also that the outcomes for this system of systems are delivered by multiple systems. For example, Resiliency is achieved by all the fielded capabilities as all are required for a resilient grid and to achieve available reserve and total load. The affordable outcome is achieved by the wind turbines as they provide the lowest price per MW for generation, given the financial subsidies provided by the government, (another form of incentive). The different value streams achieve different outcomes. Additional sets of fielded capabilities and actual outcomes should be created to perform tradeoff analysis between the different solutions. In addition, parametric analysis can be performed to do tradeoffs between the different parameters. The model created to support the diagrams shown here is quite large and could not be shown in detail due to limitations of space. The examples shown are illustrative of what is required to build the strategy view that provide the early business analysis for making investments in infrastructure, new processes, and new equipment.

Quantitative Analysis of the Model

The model can be combined with quantitative analysis to demonstrate that the decisions made are sound and in the best interest of the stakeholders. An example of a simulation of the model in shown in shown in Figure 12.

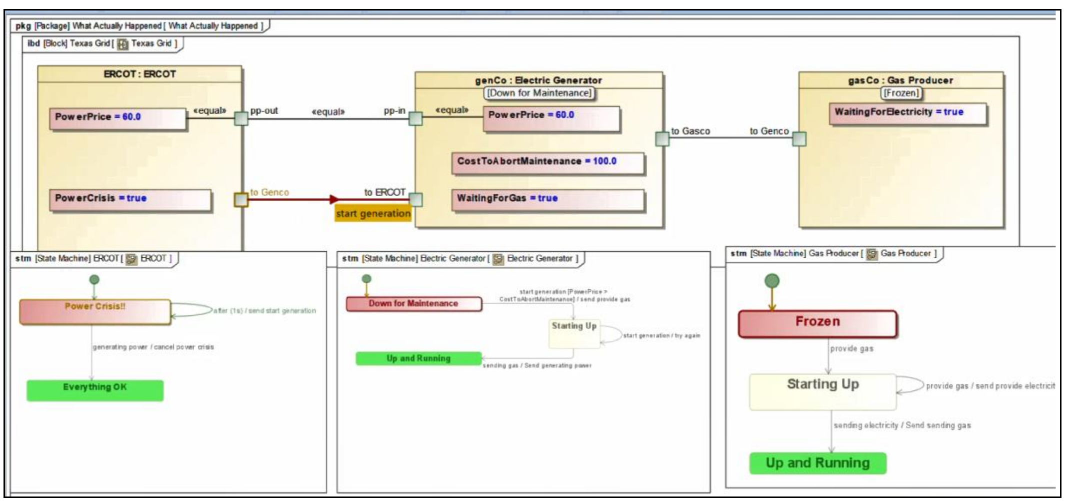

Figure 12 – Simulation of Gas Price vs. Electricity Price vs. Generator vs. State

Various scenarios were executed on the model using a combination of structure, state, parametric and behavior models. They looked at the interaction between prices for electricity, gas, as well as the availability of the two. Frozen equipment and maintenance cycles were also taken into account. Figure 12 shows the situation of a deadlock where the price paid for electricity does not justify starting the generators. Another scenario showed a deadlock situation between generators waiting for generation gas, who is waiting for electricity to pump the gas, etc. Finally, the sunny day scenario showed the system approaching a crisis until the electricity price vs. the gas price justifies starting the generation. To be sure, these simulations were simplistic involving a small portion of the grid. More complex simulations and analysis will need to be done using specialized tools as well as MBSE models to help direct the effort. (Hause, 2017)

Use and Misuse of Incentives

SB3 requires power generators and transmission lines to "weatherize" but a $2 billion plan to help power companies pay for the upgrades with low-cost loans and grants stalled in the Senate and no language is included in Senate Bill 3 to create the fund. This removes the carrot, and the stick appears to be regulatory compliance. The power industry may need more incentives to do so. No matter how they are proposed, care needs to be taken to ensure these incentives do not result in what is known as the Cobra Effect. This dates to colonial India where cobras were killing people. The government paid an incentive for each dead cobra, causing locals to start raising cobras to cash in. When the government found out and stopped the incentive, people released their cobras making the situation worse than ever. (Hartley, 2016) A similar situation occurred for a bounty paid for wild hogs in the state of Arkansas in the 1990s. Wells Fargo Bank also recently ran into difficulties when employees were paid for each financial service provided to customers. Under management pressure, employees opened phantom accounts for customers, often with additional fees and did not inform the customer. (Attorney General, 2018) More to the subject matter at hand, the Enron market manipulation in the energy trading industry where their energy traders withheld electricity to create artificial shortages and increase the cost of power. As Enron was one of the main players in such market manipulation, its energy traders were able to sell power at multiples of normal peak power prices. Finally, a lack of company and regulatory oversight caused the company to go bankrupt. (Segal, 2021) ERCOT and the Texas Legislature need to ensure that the plan is implemented with a proper balance of incentives, penalties and oversight to ensure that future energy crises do not occur.

Epilogue – What Happened in 2022?

During the winter of 2022, there was another cold snap resulting in several days of sub-zero weather. The weather was not as severe as the previous year, so the grid was not tested as it otherwise might have been. Some gas suppliers reported frozen equipment which caused the overall gas supply to drop, but it was sufficient to maintain the grid and support peak load. Also, this time, the government stepped up and provided some subsidies (the financial incentives discussed earlier) to ensure surplus gas was available in the system for gas powered electricity generators to continue running. ERCOT said it "has assessed the on-site fuel supply for some gas-fired generators," though it provided few details of how many gas-generators have secured fuel supply. (Patel, 2022) Generating companies were also paid to continue running to ensure sufficient capacity in the network. In addition, designated infrastructure was notified that $1 Million per day fines would be assessed against those facilities that did not pass winterization inspections. So, it was a combination of carrots and sticks. The fines driver and Government Winterization Funds opportunity are shown in Figure 13.

There are several additions to the architecture dealing with risk mitigation shown on the right of Figure 13. This infrastructure elaborates on the onsite gas supply. The Energy Company management own the risk for gas supply failure so have implemented a risk mitigation to store a 3-day supply of gas on site to ensure generators can continue in spite of a gas outage. This is standard practice for coal fired plants. Storage and control systems are all parts of the Gas Storage Infrastructure Resource Mitigation. The opportunity of Government Winterization Funds to ensure availability as well as the driver of fines also motivates the company to winterize fossil fuel generation. The combination of preparation and winterization of the infrastructure, and the milder winter storm meant that the grid survived with few major outages. This is a clear example of government incentives changing business behavior. The winter storm was not as severe as 2021, so did not test the grid to the same extent. It was also discovered that some of the gas suppliers' equipment froze necessitating that they burn off fuel. These need to be investigated further and fixed. Fines should be assessed to ensure proper incentive to provide winterized equipment. Work will need to continue to build up the infrastructure to ensure a resilient system of systems. In addition, supporting infrastructure will also need to be addressed.

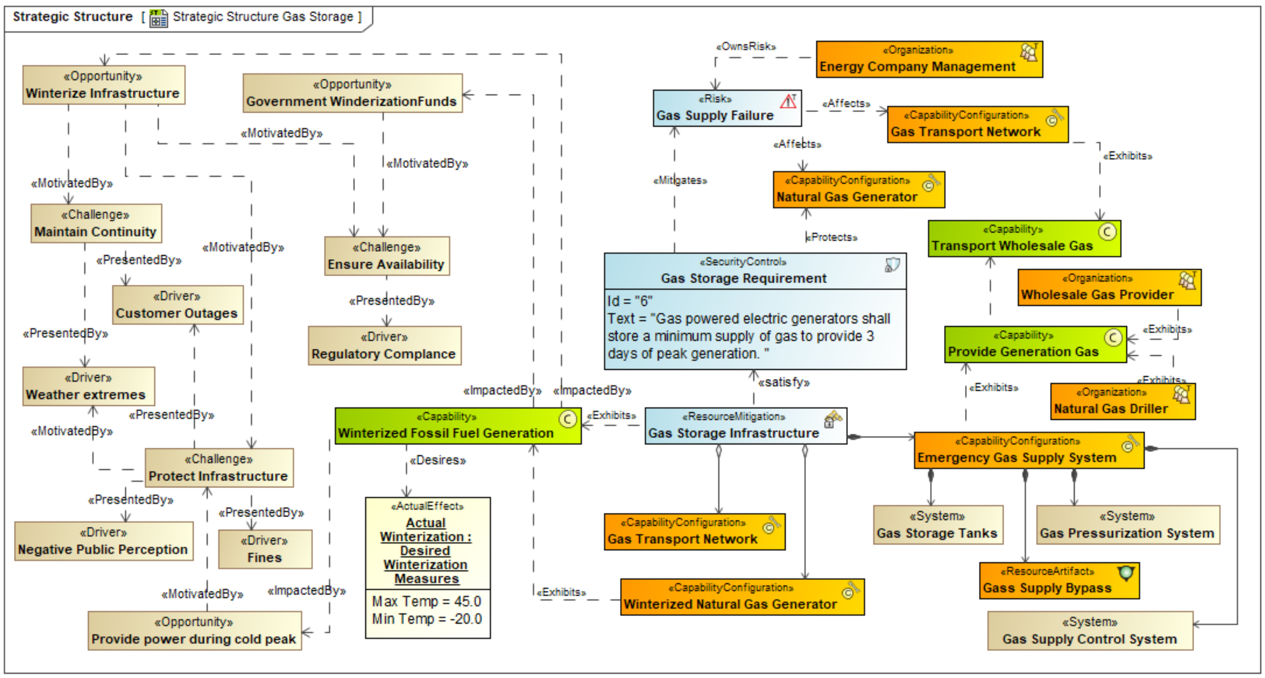

Figure 13 – Emergency Gas Storage System and Supporting Infrastructure

Conclusion

The cause of the Texas Grid failure of 2021 was a systemic failure of the system of systems that make up the electricity infrastructure. Virtually all the entities involved including the homeowners failed to invest in winterization resulting in frozen pipes and systems. As a resident of Austin, I was one of those homeowners having to deal with frozen pipes and blackouts due to a lack of preparation. Several days without hot water was sufficient incentive to ensure that I winterized the plumbing systems in my house and obtained a generator. The Texas Legislature has provided legislation mandating winterization of the fossil fuel generation systems as well as additional funding. These incentives included both sticks and carrots. However, it will require a wholistic approach to ensure that all elements in the supply chain have been winterized including those windmills. Unlike Don Quixote, we should not see the windmills as evil monsters to be battled. They were not the villains in this story. They provide much needed carbon-free generation and investing in them is the responsible thing to do. However, we cannot remain complacent and rely on them for all our generation. We need to ensure that there is a diverse, reliable, and winterized array of generation sources to ensure that we stay warm on those cold Texas winter nights, no matter how infrequent they are.

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