Evaluating and Strengthening Iowa's Power Grid for High Wind/Solar Penetration Levels

Prepared by

James McCalley,
Colin Christy,
Gustavo Cuello-Polo,
Dut Ajang

A report submitted by Iowa State University for the Project "**Plan Iowa Energy (PIE): Evaluating and Strengthening Iowa's Power Grid for High Wind/Solar Penetration Levels**," funded through the Iowa Economic Development Authority.

Evaluating and Strengthening Iowa’s Power Grid for High Wind/Solar Penetration Levels

Project Report #3
Visions, Uncertainties, and Futures

James McCalley and Colin Christy, Investigators
Gustavo Cuello-Polo, Ph. D. Student
Dut Ajang, M. S. Student

Iowa State University

January 19, 2024

Executive summary

The work of the Plan Iowa Energy (PIE) project is motivated by a desire to identify ways to expand and grow Iowa's electric energy infrastructure to provide benefits to the people of Iowa. As with any long-term expansion planning, the work must be done in the face of significant uncertainty. Adaptive co-optimized expansion planning (ACEP) is a tool designed to optimize expansion planning in the face of uncertainty. ACEP seeks to optimize the system design in order to achieve a given vision. At the same time, it considers multiple potential futures and generates a plan that is optimally adaptable to the future that actually occurs.

Employment of the ACEP algorithm requires four basic steps; 1) identification of a vision, 2) identification of uncertainties, 3) selection of a representative set of planning futures, and 4) execution of ACEP, and a plan is developed. To date, we have completed three of these four steps; five different visions have been identified and described, eleven different uncertainties have been identified, and a representative set of seven different futures have been selected.

The five visions are 1) to produce the least cost electrical energy, 2) to reduce carbon by 90% over present emissions, 3) to optimize Iowa electrical energy exports, 4) to increase system resilience, and 5) to balance of each of the first four visions. Each vision will result in a different system plan and associated cost. Comparisons of the various plans will be instructive to planners and regulators, helping all to understand potential future directions in expansion planning.

As mentioned, planning is done in the face of uncertainty. As such, eleven relevant uncertainties are identified, most of them consistent with MISO's long range transmission planning (LRTP) studies. Consideration of all possible combinations of uncertainty values results in many thousands of potential futures. Yet, most expansion planning methods can only account for a few potential futures. For example, the MISO LRTP uses three. However, ACEP can accommodate and consider, within a single computational framework, more than just three futures, e.g., for reasonably sized models, up to ten futures is typical, and up to 20 can be accommodated for simplified models. Consequently, a scenario reduction algorithm was used to select a representative set of seven futures, making sure to also retain the three that are used by MISO LRTP.

The final step in the process is to run the ACEP optimization to produce various system designs (otherwise known as a plan), one design for each vision. This final step will require the development of an appropriate power system model and associated resource data. The MISO system model, which contains many thousands of buses, will be reduced to less than a thousand buses so that the ACEP optimization is tractable in terms of computing time. At the same time, several enhancements to ACEP are planned as a part of this project and will be reported on in the coming months. Among these enhancements are task G6-1, to include inertial/frequency stability as a constraint to the optimization procedure; task G6-2, to account for resource adequacy, and task G6-3 to enhance resilience modeling in ACEP.

Acknowledgment: This material is based upon work supported by the U.S. Department of Energy's Office of Energy Efficiency and Renewable Energy (EERE) under the State Energy Program Award Number DE-EE0010072.

Disclaimer: The views expressed herein do not necessarily represent the views of the U.S. Department of Energy or the United States Government.

Table of Contents

1 Introduction ... 6
2 Visions ... 10
2.1 Low energy cost ... 11
2.2 High reduction in CO_2 ... 11
2.3 High energy export ... 12
2.4 High resilience ... 13
2.5 Balanced ... 13
2.6 Summary of Benefits ... 14
3 Uncertainties ... 15
3.1 Uncertainties – what they are and what they are not ... 15
3.1.1 Future ... 15
3.1.2 Influential conditions ... 15
3.1.3 Range of values ... 16
3.1.4 Decision-maker control ... 16
3.2 Categories of uncertainties ... 16
3.2.1 Policies ... 17
3.2.2 Load growth ... 18
3.2.3 Technology availability ... 19
3.2.4 Technology investment costs ... 20
3.2.5 Fuel prices ... 20
3.2.6 Climate conditions ... 21
3.2.7 Discount rate ... 21
3.2.8 Retirements ... 21
4 Futures ... 22
4.1 The many possible futures ... 22
4.2 Reduction of futures ... 22
5 Conclusions and next steps ... 25

List of Figures

Figure 1-1: Conceptual illustration of ACEP 6
Figure 1-2: Four stages of deploying ACEP 8
Figure 1-3: Illustration of PIE project visions, uncertainties, futures, and plans 9
Figure 2-1: Energy related carbon emissions for Iowa 12
Figure 3-1: Illustration of global and local uncertainties 16
Figure 3-2: Demand growth versus energy growth for three different MISO load growth scenarios 19
Figure 4-1: An illustration of the 34,992 **possible futures generated by nine uncertainties** 22
Figure 4-2: An illustration of the representative futures chosen by the futures reduction algorithm 23
Figure 4-3: The seven futures chosen by the futures reduction algorithm 24

List of Tables

Table 2-1: Average electricity prices in Iowa compared to the U.S. average 11
Table 2-2 Benefits of each vision to the state of Iowa 14
Table 3-1: Summary of Uncertainties 17
Table 3-2: Retirement age for various fossil-fueled generation technology 21

1 Introduction

The work of the Plan Iowa Energy (PIE) project, motivated by a desire to identify ways to expand and grow Iowa's generation (G), transmission (T), and distribution (D) electric infrastructure to provide benefits to the people of Iowa, is predicated on the deployment of a certain kind of computational modeling approach referred to as adaptive coordinated expansion planning (ACEP) which generates an investment plan. In this report, we identify and describe essential high-level inputs to ACEP without which the model cannot effectively be used. These inputs are visions, uncertainties, and futures, described in Chapters 2, 0, and 0, respectively. The ultimate investment plan is provided as a function of these three basic ACEP inputs. In this introductory chapter, we provide some ACEP overview concepts to facilitate the reader's understanding of the need for these three basic inputs.

ACEP is a computational (computer-based) model that enables exploration of different GTD investment strategies and identification of their relative benefits/advantages and costs/disadvantages. Figure 1-1 provides a conceptual illustration of the model, where we observe that GTD investments, represented by the pictures along the time-axis, are made at specific years between the initial and final years of the planning horizon, in this case, 2025 and 2050, respectively. We make two additional observations in relation to the "core" investment trajectory (the thick dark line) of this figure: (1) it is directional, i.e., it is "pointed" by the analyst, who in the figure is represented by the person looking through the binoculars; (2) it is between two "futures." The significance of these two observations is briefly addressed in the remainder of this introductory chapter and more fully addressed in the subsequent chapters of this report.

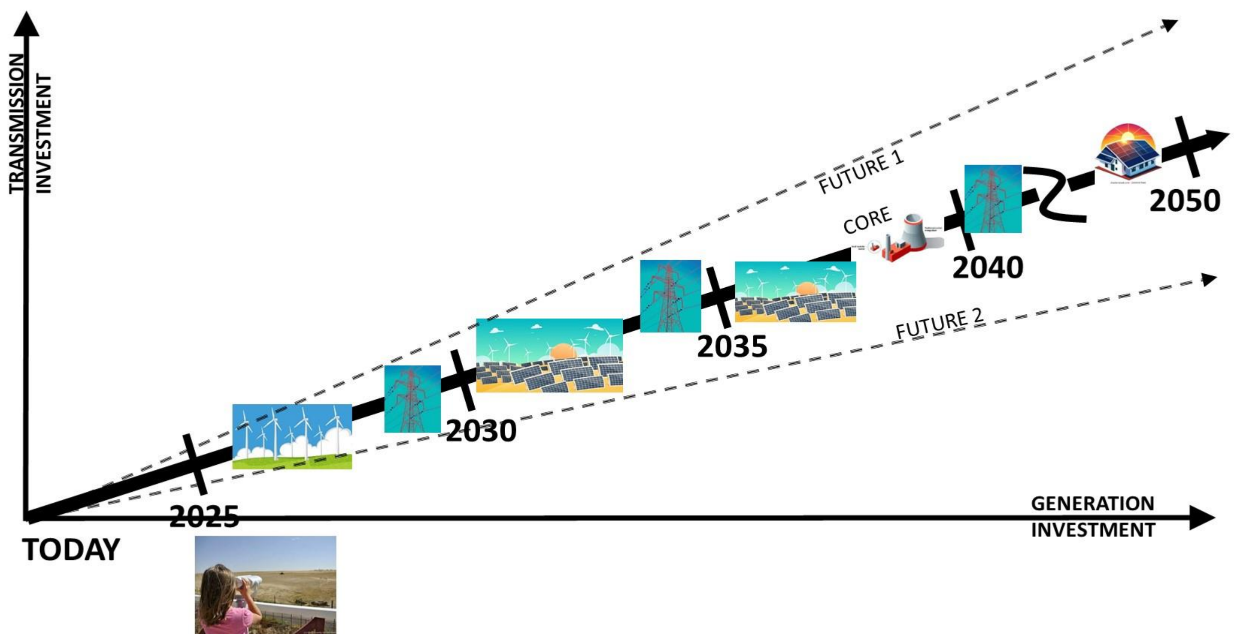

Figure 1-1: Conceptual illustration of ACEP

Visions

ACEP, as a planning tool, should not be thought of as a *predictive* tool but rather as an *exploratory* one. It is exploratory in that, to identify good investments, it must be "pointed" in a particular direction. The exploratory direction is defined by assumptions made on the model in terms of what types and how much of the various GTD technologies may be included in the plan.

For example, one may like to explore a 100% renewable investment plan. In such a case, only G-investments in wind, solar, and hydro (where possible) generating technologies would be allowed, i.e., investments in natural gas-fueled and/or so called "new" nuclear-power generation would not be allowed. We refer to the "direction" of exploration as a "vision." We will explore at least five visions in this project, as described in Chapter 2.

The notion that ACEP is not predictive should be qualified. ACEP is not predictive in the sense that ACEP does not predict what will happen in the future. Rather,

- ACEP identifies, *given the particular vision and futures being explored*,
    - the investments to be made (*what* - GTD and which technology; *when* - which year; *how much* - capacity, in MW; and *where* - which branch or which substation)
        - to achieve a feasible (serves the intended load without violating any equipment limits) GTD infrastructure system
            - at the least total cost (present worth of total cost of investments plus total cost of operating, over the entire 25-year decision horizon).

The implication of the above statement is that ACEP allows exploration of what will happen given the vision and futures, assuming all decisions are made to achieve the least total cost.

Uncertainties and futures

Since ACEP is necessarily characterizing conditions in the future, it is not possible to characterize these conditions with certainty. Therefore, uncertainties exist. Of course, we might identify thousands, or even millions or billions of uncertainties about the future. But here we are interested in only those which significantly affect the GTD infrastructure investment decision. To this end, we have identified five categories of uncertainties: (i) policies; (ii) demand growth; (iii) retirements; (iv) fuel price; (v) technology investment costs. Under each category, there may a single uncertainty, or there may be several. For example, there is uncertainty related to the extent to which the federal and state governments might subsidize the purchase of electric vehicles, and the same can be said about the purchase of rooftop solar panels. These would represent two uncertainties falling under the first category of "policy." As another example, there is uncertainty related to the future costs of all technologies, which would fall under the last category of "technology investment costs."

This discussion leads to the notion of a future. A future is the selection of a specific value for each and every uncertainty considered. Consider the simple case of n=1 uncertainty, say demand growth, and assume that demand growth may have only v=2 values: high (H) and low (L). Then there are a total of $v^n=2^1=2$ possible futures: {H} and {L}.

Figure 1-1 above shows the "core" plan (the solid line with the pictures) positioned between two "future" plans (the dashed lines). Only two future plans are considered to maintain simplicity in this conceptual illustration. The future plans represent investments that should be made if it were known that the corresponding future is certain. The core plan represents investments that should be made to best position the system for adapting to either future. If it is believed that one future is more likely than another future, then the core plan would lie closer to the more likely future plan.

In reality, it is typical to have many uncertainties. Consider the simple case of n=3 uncertainties, say demand growth, fuel cost, and solar cost, and assume that each one has only v=2 possible values: high (H) and low (L). Then there is a total of $v^n=2^3=8$ possible futures. If we identify a future as an ordered triplet {demand growth; fuel cost; solar cost}, then the 8 possible futures are specified as {HHH}, {HHL}, {HLH}, {HLL}, {LHH}, {LHL}, {LLH}, {LLL}.

It is common in performing planning studies to have significantly more than 3 uncertainties. Consider having 8 uncertainties; then, if each uncertainty can have only two possible values (e.g., high or low, on or off, yes or no), then having 8 uncertainties results in 2^8=256 possible futures. As another example, having 15 uncertainties results in 2^{15}=32,768 possible futures.

Therefore, the number of possible futures in grid planning ranges from hundreds to thousands. Yet, most regional transmission organizations (RTOs) limit the number of futures used in their studies to 2-3, or at most 4-5, because every future represents a set of studies that an engineer must conduct, and these studies are extremely labor-intensive. Therefore, it is of great significance to select the futures to be studied that are most likely and/or that, in some sense "bookend" the possible futures that may occur. To this end, it is common to choose one future as "business as usual" where uncertainties are assigned values that reflect changes or growth consistent with that of recent history. It is common to choose another future that represents significant change, e.g., a "high-renewable" or a "low-carbon" future.

ACEP offers the attractive feature of allowing 5-10, or possibly even 10-15 futures. Although this represents a significant improvement over the number typically used in RTO planning processes, it is still limited relative to the total number of possible futures. Thus, the choice of futures modeled within ACEP is critical.

Four planning stages

The result of this discussion is that there are four planning stages to the process associated with using ACEP: vision, uncertainties, futures, and plan. These four stages are represented in Figure 1-2.

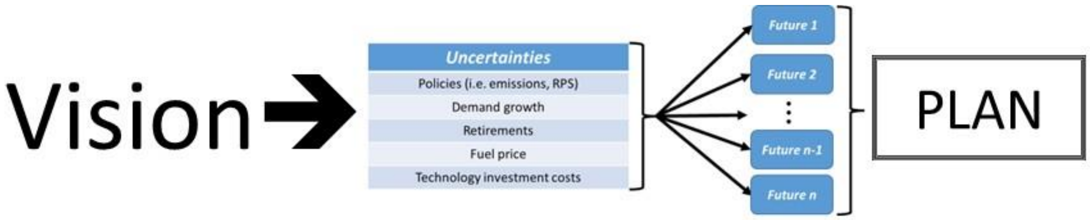

Figure 1-2: Four stages of deploying ACEP

We have performed three of these four stages for the PIE project, and results of our work are illustrated at a high level in Figure 1-3. This figure shows that five different visions are identified, and for each one, uncertainties are expressed, futures are determined, and lastly, ACEP is run, and a plan is developed. We describe these five visions in Chapter 2. Uncertainties are described in Chapter 0. The development of futures is described in Chapter 0. Conclusions and next steps are provided in Chapter 5.

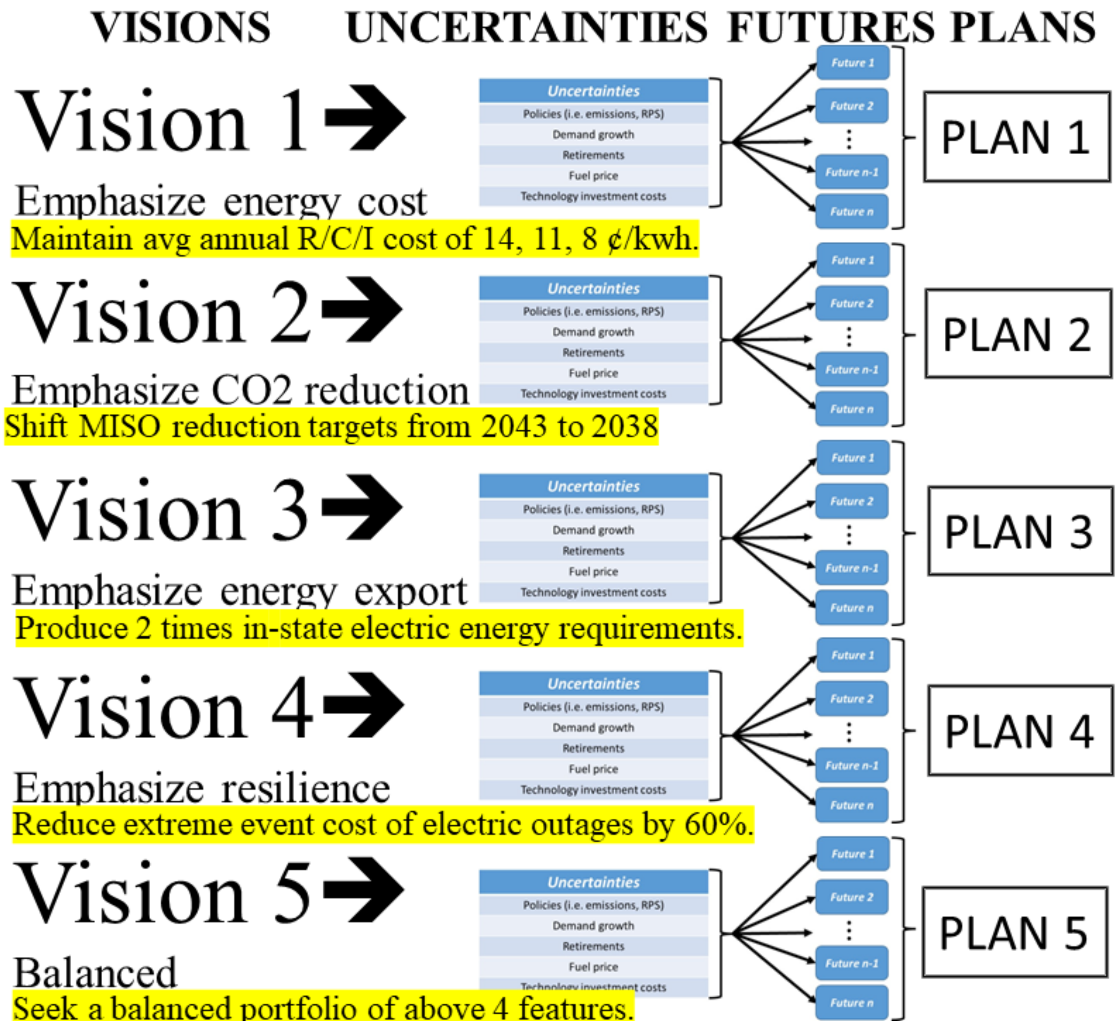

Figure 1-3: Illustration of PIE project visions, uncertainties, futures, and plans

2 Visions

As described in the previous chapter, the vision is a means of pointing the ACEP optimization in a desired direction; or of guiding it toward a preferred orientation. Essentially, it is a means of defining a possible preference. It is beneficial to explore such potential directions through ACEP simulations to creatively think about preferences that the people of Iowa may have. A particular vision is defined by the constraints that are lifted or imposed related to five areas: (i) generation investments; (ii) discretionary generation retirements; (iii) CO_2 emission reductions; (iv) desired energy export level; (v) emphasis on resilience. Constraints that are certain and nondiscretionary (e.g., those on meeting demand, Kirchhoff's laws, network performance under contingencies, and resource adequacy requirements) will of course be imposed. The same futures will be used for all visions. Furthermore, ACEP always seeks the least-cost way to satisfy the constraints, independent of what vision is specified.

We emphasize that the visions chosen are not an indication of preference related to the research team; and they are not an indication of what the research team thinks is the likelihood of what the people of Iowa prefer. Rather, they are possible orientations that would result in significantly different electric system infrastructure. The value of identifying the resulting electric system infrastructure for each vision is to provide the people of Iowa with the tangible implications of what each vision will mean in terms of what is likely to be built, where, and at what scale.

In this chapter we describe each vision in terms of which of the discretionary constraints are imposed. As mentioned in Chapter 1, for a given vision, ACEP obtains a core plan that represents investments that should be made to best position the system for adapting to the set of possible futures. As such, when a vision is simulated in ACEP, the constraints associated with the vision are applied to the whole set of futures. [1] Thus, in the presentation of each vision, we will specify which constraints must be added to all futures in order to implement the vision in ACEP. The constraints added will include one or more of the following:

- constraints on generation investments
- discretionary generation retirements
- CO_2 emission reductions[2]
- desired energy export level

For all visions, we will assume the investment years to be 2028, 2033, 2038, 2043, 2048, and 2053. We choose these years for two reasons. First, they align with the analysis years chosen for MISO's long-range transmission planning (LRTP) Tranche 2 study (there is benefit that we maintain consistency in modeling assumptions with MISO's LRTP Tranche 2 study, unless there is a reason not to do so). Second, this ensures that our project completion date (2026) will precede the first year of the planning horizon.

[1] Resilience is an exception. See section 2.4 for the explanation for why this is the case.

[2] Iowa-specific constraints are of particular importance with respect to the CO_2 emission reduction constraint, because we have defined the futures using CO_2 emission reductions as one uncertainty. However, whereas the uncertainty characterization of CO_2 emission reduction is modeled MISO-wide, the vision characterization of CO_2 emission reduction is modeled specific to Iowa.

2.1 Low energy cost

According to the U.S. Energy Information Administration (EIA), Iowa is among the states with low average electricity prices.[3] Table 2-1 shows a comparison between Iowa electric energy prices and the national average.

Table 2-1: Average electricity prices in Iowa compared to the U.S. average

Customer Class	Iowa (cents/kWh)	U.S. Average (cents/kWh)
Residential	14.03	16.29
Commercial	11.32	13.25
Industrial	8.25	8.53

The orientation of the low energy cost vision is to make investment decisions consistent with the singular objective of maintaining a low cost of electric energy for retail, commercial, and industrial customers over the duration of the study period. To this end no extra constraints are applied to the set of futures, and ACEP identifies the minimum-cost investment strategy for the given set of futures. Note that this does not mean that the optimization is unconstrained, because the futures inherently form a set of default constraints, based on identified uncertainties.[4]

2.2 High reduction in CO_2

The vision to reduce carbon dioxide emissions is not uncommon among electric utilities. In fact, many have made the goal to become net-zero in greenhouse gas emissions (or carbon neutral) by 2050. Furthermore, as explained in Chapter 3, all visions will achieve a certain level of reduction in carbon dioxide emissions through the set of futures. Specifically, these futures are based on decarbonization uncertainties identified in the MISO LRTP studies where three different potential levels are identified; 71%, 76%, or 80% decarbonization by 2043[5]. However, the vision identified in this study involves a particularly aggressive constraint on the carbon dioxide emissions for electricity generation in Iowa, forcing emissions to decrease to these levels by 2038, five years sooner than the timeline used in the MISO LRTP studies. To implement this vision in ACEP, this constraint on Iowa emissions will be added to all futures.

As of 2019, annual energy-related carbon dioxide emissions in Iowa were 77.3 million metric tons. A graphic breakdown of the sources of Iowa carbon dioxide emissions are shown in Figure 2-1.[6] The figure provides an effective way to analyze the various sources of carbon emissions. In terms of electricity generation, the majority of carbon emissions are from coal-fired generation. Thus, in this vision we could expect ACEP optimization to favor earlier retirement of coal-fired power plants and to favor renewable generation over natural gas.

As shown in Figure 2-1, industrial activity and transportation are also major sources of carbon dioxide emissions. This vision does not constrain these sectors directly, but they will be indirectly

[3] Iowa Profile (eia.gov) (Electricity prices as of September 2023)
[4] This concept is explained in chapters 3 and 4 of this report.
[5] 2005 baseline
[6] Carbon Flow Charts | Flowcharts (llnl.gov) Source: LLNL/U.S. Department of Energy, June, 2023.

impacted through futures that include electrification. These are further explained in Chapters 3 and 0.

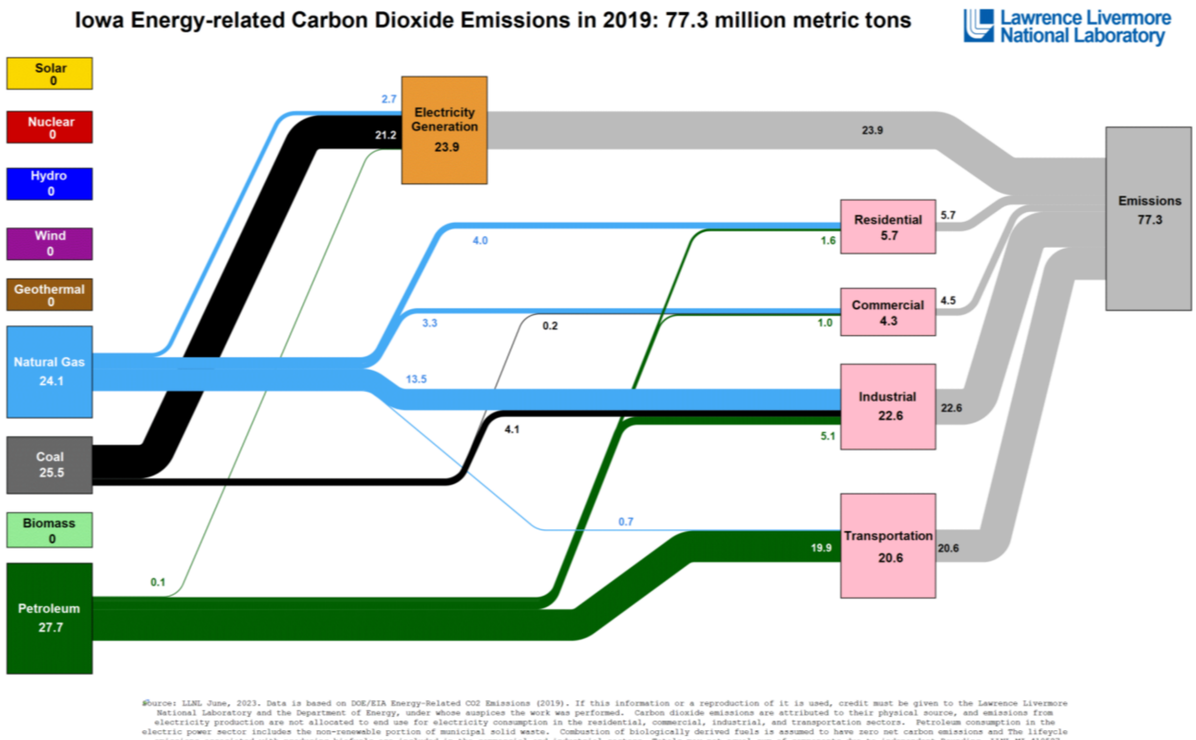

Figure 2-1: Energy related carbon emissions for Iowa

2.3 High energy export

The thought behind the high energy export vision, to produce twice the in-state consumed electric energy by 2050, is that there may be revenue streams associated with energy export that are very attractive for the state of Iowa, so expansion of the state's generation resources would be driven mainly by the economic benefits that these revenue streams may bring. In terms of implementation in ACEP, for each planning year, this constraint will be applied to all futures by first determining Iowa electric consumption and then forcing Iowa generation to increase to meet the export goal, ultimately reaching a factor of two by 2050.

According to the EIA, Iowa exported 60.1 trillion Btu (17,613,571.3 MWh) of electrical energy in 2021.[7] In the same year, Iowa's total electrical generation was 67,207,008 MWh. Thus, in-state consumption was 49,593,437 MWh[8], and exports were 35.5% of in-state consumption. To reach this vision, in which exports are equal to in-state consumption, more generation and transmission infrastructure would have to be built. For example, if the extra exports were provided by wind, which has a capacity factor exceeding 40%[9], an extra 9,127 MW of wind generation would have been needed in 2021. Furthermore, since the objective of the optimization is to maximize exports, retirement of fossil-fueled units would be slowed and diminished. This vision would then result in

[7] Iowa Profile (eia.gov) (Electricity prices as of Septemper 2023)
[8] Iowa's Electric Profile | Iowa Utilities Board, (2021 statistics, accessed in January, 2023).
[9] 20231002 LRTP Workshop - Futures Refresh Assumptions Book630366.pdf (misoenergy.org)

extra revenue brought into the state of Iowa through energy sales, investment and production tax credits, lease payments, and state and local property tax revenues.

2.4 High resilience

Climate change increases the potential for severe weather. Indeed, the increasing cost-impact of storms in Iowa was presented in Report #1 of this project, entitled "High-Risk Conditions and Events". To stem this high cost-impact, the power system must be resilient. By definition, a resilient power system can withstand extreme weather events, respond in the midst of such events, and recover quickly from any disruptions.[10] Specifically, the high resilience vision is to reduce the extreme event cost of electrical outages by 60%. This would likely require investment in transmission and distribution lines, to enable them to withstand high wind and ice events. Of the five different constraint types used in characterizing the visions, resilience has the unique feature that, whereas other constraint types are imposed (or not imposed) within the ACEP model itself, a particular resilience level is imposed through a second model called R-CEP that allows adjustment of resilience level. Since resilience is not assessed or constrained in ACEP, the ACEP result can only get more expensive when resilience is assessed and/or constrained via the second model. Therefore, excluding resilience constraints simply means not running the R-CEP model.

2.5 Balanced

Each of the visions described so far offers an appealing power system feature; either low priced, or low carbon, or generating export revenue, or resilient in the face of extreme weather events. The final vision is to identify a system that provides inexpensive power, emits minimal carbon dioxide, produces export revenue, and is resilient. In this vision, the ACEP calculation will consider all these preferences, and we will study various mixes of them. For example, we might investigate a vision that achieves a 40% reduction in extreme event costs while producing 1.5 times the in-state energy requirements.

[10] Power System Resilience | NREL (accessed January, 2023).

2.6 Summary of Benefits

Each of the visions described in this chapter provides benefits to the state of Iowa. These are summarized in Table 2-2.

Table 2-2 Benefits of each vision to the state of Iowa

Vision	Benefit
Low energy cost	Reduce the cost of living. Improve economic competitiveness.
High reductions in CO_2	Slow climate change. Improve air quality.
High energy export	Increase revenues from energy, tax credits, lease payments, and property taxes. Enhance economic growth.
High resilience	Reduce the economic impact of extreme weather events. Reduce duration of electric outages.
Balanced	A combination of benefits from the first four visions.

3 Uncertainties

In power system expansion planning, uncertainties characterize

- future
- influential conditions
- that cannot be represented by a single value,
- over which decision-makers have no control.

In Section 3.1, we expand on this definition, clarifying what uncertainties are and what they are not. In Section 3.2, we provide a taxonomy of uncertainties applicable to the power system expansion planning problem.

3.1 Uncertainties – what they are and what they are not

3.1.1 Future

Uncertainties in power system expansion planning inevitably arise because the essence of the problem is to identify needs under future conditions, and those conditions are not known. The best we can do is to characterize a range of values associated with parameters that quantify those conditions.

3.1.2 Influential conditions

We focus on the influential conditions, i.e., those conditions that have a broad enough range of values to make a difference in the decision. We specify the uncertainties associated with these conditions as global uncertainties, in contrast to local uncertainties, where the two terms are distinguished below.

- Global uncertainties are uncertainties for which different values within the range of likely values produce significantly different results; examples include emissions policies, large demand shifts, coal or nuclear retirements, extremes in fuel prices, extended drought, and dramatic change in technology investment costs.
- Local uncertainties are uncertainties characterized by a range of values a parameter may take under a global realization; for example, under a "low" load growth or fuel price scenario, the annual load growth may vary ±0.5 % and the annual fuel price change may vary ±1%. Local uncertainties may also be referred to as parametric uncertainties.

Figure 3-1 illustrates the relation between the two types of uncertainties, using demand growth as an exemplar.

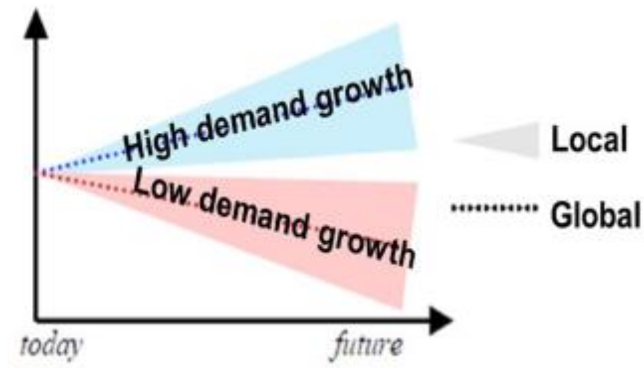

Figure 3-1: Illustration of global and local uncertainties

3.1.3 Range of values

The range of values for each uncertainty should cover the expected credible possibilities; the approach for identifying the range should consider historical values, but it should also consider reasonably likely conditions that may affect that range. The range can be captured in terms of two values, high and low, or at most three values, high, medium, low. These values can be single scalar values (have RPS policy or not have RPS policy) or they can be a growth rate (as illustrated in Figure 3-1).

3.1.4 Decision-maker control

Uncertainties should be distinguished from decision variables, as characterized below:

- Uncertainties represent influences outside the decision-maker's control; decision variables represent human-controlled choice.
- Uncertainties have ranges specified exogenous to the model (i.e., assigned by the analyst); decision variables are identified by the execution of the model.
- Except where correlation between uncertainties exist, the value of one uncertainty may be chosen independent of the value of another uncertainty; in contrast, the value of a decision value affects values chosen for other decision variables, providing the ability to "compete" or "substitute" value selections between the decision variables.

3.2 Categories of uncertainties

We have identified seven categories of expansion planning-related uncertainties[11]: (i) policies; (ii) demand growth (including electrification); (iii) technology availability; (iv) technology investment

[11] Handling uncertainty in decision problems is a very general area applicable to many different disciplines, and as a result, uncertainty characterization has very broad interest, receiving significant attention in the literature. One classification that has received what is arguably the most attention is epistemic and aleatoric. Epistemic uncertainty is due to insufficient knowledge; aleatoric uncertainty is characterized by randomness. We mention this here to identify the intersection of our work with this more general area of research. A good reference that explores this intersection in depth is S. Selçuklu D. Coit, and F. Felder, "A Classification of Aleatory and Epistemic Uncertainties in Generation Expansion Planning," September 12, 2022. Available at SSRN: https://ssrn.com/abstract=4216589 or http://dx.doi.org/10.2139/ssrn.4216589.

costs; (v) fuel price; (vi) climate conditions; (vii) discount rate; and (viii) retirements. We describe each of these in this subsection.

Table 3-1 shows a summary of the uncertainties to be considered in this study. The uncertainties and corresponding assumed values are largely the same as those used in the MISO long range transmission planning (LRTP) Tranche 2 study[12],[13]. However, five of the eleven uncertainties considered in this study are not treated as uncertain in the LRTP Tranche 2 study (see the far right column of Table 3-1). The following subsections provide detail of each uncertainty in the table.

Table 3-1: Summary of Uncertainties

Parameter	**No. of values**	**Value 1**	**Value 2**	**Value 3**	**Uncertain in MISO LRTP Futures?**
RPS	2	0		50	Yes
Carbon Reduction (%)	3	71	76	80	Yes
Load Growth Energy (CAGR) Demand (CAGR)	3	Low 0.63% 0.77%	Medium 1.25% 1.14%	High 1.95% 1.63%	Yes
Electrification (% of total energy growth)	3	2.0	15.2	31.8	Yes
Emphasis on Fossil Retirement	3	Low	Medium	High	Yes
DER:	2	Low		High	Yes
Wind/PV costs reduction	3	0.75	1	1.25	No
Battery Costs Reduction	3	Low	Medium	High	No
Natural Gas Price	3	Low (0.75)	Medium (1.0)	High (1.25)	No
Climate Change	2	Low		High	No
New-Nuclear Investible?	2	Low (No)		High (in 2040)	No
Discount Rate	N/A				No

3.2.1 Policies

Governments tend to change policy over the many years covered by a long-term expansion plan. We have no way of knowing what the policy changes will be, but prior to such changes, various

[12] 20231002 LRTP Workshop - Futures Refresh Assumptions Book630366.pdf (misoenergy.org), last updated September 27, 2023.

[13] The LRTP Tranche 2 study period extends to 2043, but the study period of this project extends to 2050. We will therefore match MISO-related uncertainties up until 2043 and then extend them judiciously out to 2050.

proposals and political sentiment are widely distributed in the media. Thus, it is prudent to consider ways policy may shift to account for the potential impact of these shifts on infrastructure investments. A case in point is potential policies to reduce carbon emissions. In MISO to date, only Minnesota and Illinois have statutory greenhouse gas emissions goals, while Michigan and Louisiana have non-binding decarbonization goals. However, the majority of MISO load is served by member utilities with decarbonization goals.[14] Furthermore, the MISO Futures Report identifies three potential levels of carbon reduction relative to a 2005 baseline; 71%, 76%, and 80% for futures 1A,2A, and 3A, respectively (These reductions pertain only to the electric system and do not include transportation, industry, or agriculture.[15] MISO has already achieved a 29% reduction from the 2005 baseline)[16]. Thus, for this study, we have identified decarbonization as a policy uncertainty, and, per Table 3-1, we have adopted the same three potential decarbonization levels.

3.2.2 Load growth

Load growth can be broken into two categories; one is traditional load growth based on economic factors. The other, which is relatively new, is load growth due to electrification. For the purposes of this study, each type of load growth will be considered a separate uncertainty. Traditional load growth is estimated by econometric models based on various factors such as average personal income, population, employment, gross state product, natural gas and electricity prices, and historical weather and electricity consumption. A good example of this type of load growth projection is the MISO Independent Energy and Peak Demand Forecast[17], which is produced by the Purdue University State Utility Forecasting Group. A useful feature of this report is that it breaks down energy and demand growth by state and MISO load resource zone (LRZ). For example, the 2023 report projects Iowa to have a 1.5% compounded annual growth rate (CAGR) in electricity sales out to 2043.

Load growth involves both demand growth and energy growth, but the two are highly correlated. Figure 3-2 shows the correlation between energy and demand growth projections used in the MISO Series 1A Futures Report. Due to the high correlation between the two, load growth can be considered a single uncertainty, as shown in Table 3-1, where growth is simply designated as low, medium, and high. In each case, each of the three categories involve specific quantities of demand and energy growth, which will be modeled in the uncertainty characterization of the ACEP simulations.

---

[14] Series1A_Futures_Report630735.pdf (misoenergy.org) (Published November 1, 2023.)

[15] Carbon reductions in these other sectors will occur through electrification, which is treated as a separate uncertainty. As such, their carbon emissions will not be constrained, but can be calculated and will vary with the level of electrification.

[16] This uncertainty is a MISO-wide carbon reduction that could be imposed as a matter of policy. It pertains to all visions in this study, whereas the carbon reduction of vision 2 pertains specifically to the Iowa electric system.

[17] Independent Energy and Peak Demand Forecasts to the Midcontinent Independent System Operator (MISO) (purdue.edu) (Published each November with the latest edition published November, 2023.)

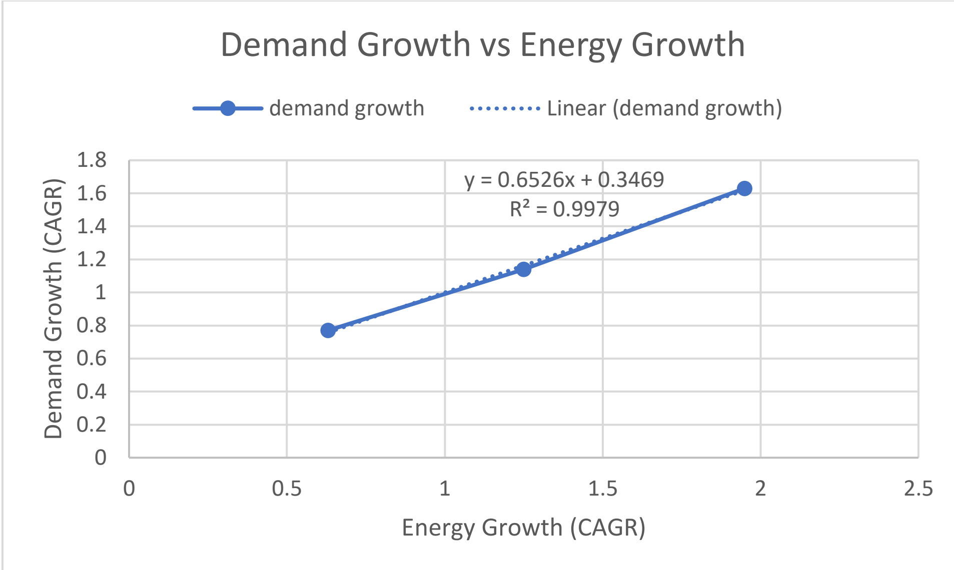

Figure 3-2: Demand growth versus energy growth for three different MISO load growth scenarios

Electrification is the conversion of an end-use device from a fossil fuel to electricity. This conversion has the potential to affect residential, commercial, and industrial load. Examples of residential electrification would be the conversion of a vehicle from gasoline or diesel to electricity, the conversion of a stove or clothes dryer from natural gas to electric, or the conversion of home heating from natural gas to electricity by employing an electric heat pump (either air-source or geothermal). Commercial and industrial electrification could be in the form of vehicle fleets or heat pumps. Finally, and probably farther into the future, heat for industrial processes would be provided using electrical devices. Heat pump water heaters may play a role in all three load classes.

For the purposes of this study, particular values for load growth and electrification will be drawn from the MISO Series 1A Futures Report. A summary of these growth rates is provided in Table 3-1. Note that in the ACEP method, which will be used for this study, a separate probability can be assigned to each potential uncertainty value. For now, each of the MISO uncertainty values will be considered equally probable, but if at some time in the future we deem one of the uncertainty values more probable or less probable, the probability of that uncertainty value can be adjusted. Thus, even though we are adopting projected load growth values from the MISO studies, a layer of flexibility exists to easily refine the study without changing the actual load growth projections.

3.2.3 Technology availability

Uncertainty in technology availability means that it is uncertain whether a particular technology will become widely available or not. Some technologies are promising but have not yet been commercialized or built.

One promising technology that is uncertain is what we will call "new nuclear". New nuclear generators are relatively small modular nuclear reactors coupled with a synchronous generator.

They have the potential to provide dispatchable base load generation without carbon emissions. At the same time, the new designs may be standardized and pre-approved by the Nuclear Regulatory Commission (NRC). Several companies are currently offering new nuclear generation, but none have been built. Until these new designs are built and operated, a significant amount of uncertainty remains. Thus, for the purposes of this study, we will consider the case where new nuclear is unavailable and the case where new nuclear is available, starting in 2040. Specifically, ACEP imposes this constraint through a setting, which deems a technology investible (or not) in each investment period.

A second promising technology is vehicle-to-grid (V2G). V2G, which is seeing widespread testing and research, would allow electric vehicle batteries to return power to the grid when a shortfall in renewable generation occurs. This is a potentially significant technology because it would allow millions of battery electric vehicles (BEV) to be used for reserve generation. Specifically, the batteries would be used as a distributed energy resource (DER) in times when the system is otherwise short of generation. Consequently, for this study, the uncertainty in V2G availability will be captured by an uncertainty in DER. In the case that V2G matures and finds widespread usage, levels of DER will be high.

3.2.4 Technology investment costs

In some cases, a technology has been proven by usage, but the future price of the technology is uncertain. This may be due to limitations in the material supply chain, a limited manufacturing capacity, or high demand. At the same time, such technologies also have the potential to be improved and made less expensive. Some examples of uncertainty in technology investment costs include wind generator costs, solar PV costs, and battery costs. These technologies have the potential to speed grid transformation and decarbonization at competitive investment costs. For that reason, if wind and solar generation costs or battery costs move lower, fossil fueled generation will be used less, partly through earlier retirement of existing plants. However, if these technologies are relatively expensive, more money will be invested in relatively low emission fossil fueled technologies and fossil fueled generation will be retired more slowly.

In this study, we will separate the uncertainty of wind and solar generation from the uncertainty of battery investment costs. Various battery technologies have been commercialized and implemented, on both utility and distributed scales. However, battery technology is generally younger and less mature than wind and solar generation technology. Thus, separate consideration is appropriate.

3.2.5 Fuel prices

While coal and natural gas generation will see less usage with decarbonization, natural gas generation has relatively low emissions and provides dispatchable baseload generation. Thus, we expect that the future price of natural gas, clearly an uncertainty, will be an influential one. With low natural gas prices, we may see continued investment in natural gas generation, while retirement of natural gas generation may proceed more slowly. Of course, high natural gas prices would have the opposite effect, causing the overall investment in and usage of natural gas generation to diminish more quickly.

3.2.6 Climate conditions

The extent and nature of climate change is uncertain. For example, various global climate models (GCMs) have been developed, with each having different implications for future temperatures, windspeeds and irradiance levels in Iowa. Thus, in this study, we will consider climate change an uncertainty. This will require further study of the GCMs available to obtain the data necessary to characterize this uncertainty.

3.2.7 Discount rate

Future discount rates are uncertain. However, relative to the other factors considered, uncertainty in the discount rate may have less influence in final investment outcomes. Thus, for the purposes of this study, uncertainty in the discount rate will not be considered. A fixed discount rate will be assumed for all calculations, which is similar to the practice used in MISO LRTP[18] studies.

3.2.8 Retirements

There are various reasons for retiring generating units; including age, economics, and policy. We will adopt the practice of the MISO LRTP Tranche 2 study in considering three different retirement timelines[19]. We identify this uncertainty as "emphasis on fossil retirement", so that the higher the emphasis, the sooner the various fossil technologies are retired. Table 3-2 shows the retirement schedule assumed by the MISO LRTP Tranche 2 study, along with the corresponding level of "emphasis on fossil retirement" designation used in this study.

Table 3-2: Retirement age for various fossil-fueled generation technology

	MISO Future 1A Retirement Age	**MISO Future 2A Retirement Age**	**MISO Future 3A Retirement Age**
Coal	46	36	30
Natural Gas - CC	50	45	35
Natural Gas - Other	46	36	30
Oil	45	40	35
"Emphasis on Fossil Retirement" (ISU designation)	Low	Medium	High

[18] Series1A_Futures_Report630735.pdf (misoenergy.org), (Published November 1, 2023).
[19] 20231002 LRTP Workshop - Futures Refresh Assumptions Book630366.pdf (misoenergy.org), Last updated: September 27, 2023.

4 Futures

The identification of uncertainties leads to a multitude of possible futures. For this reason, most planning studies only consider a few uncertainties and a few futures that serve to bookend the extremes in uncertain parameters. Adaptive co-optimized expansion planning (ACEP), on the other hand, allows modeling of more futures than are typically used in industry studies. Ultimately, ACEP chooses generation and transmission investments that are adaptable to the set of futures modeled. But even though ACEP enables modeling of an increased number of futures, that number is still limited. Thus, the many possible futures need to be reduced to the number ACEP can model without becoming computationally intractable. This chapter addresses this problem.

4.1 The many possible futures

Uncertain parameters tend to multiply the set of possible futures faced by a power system planner. For example, if load growth is uncertain and designated to take on three potential values (high, medium, and low), uncertainty in load growth accounts for three different possible futures. But when a second uncertainty, such as carbon reduction is simultaneously considered, the number of possible futures grows to 9 (3^2, since carbon reduction can also take on three different values). In our case, we have identified seven uncertainties that can take on three different values and four uncertainties that can take on two different values (see Table 3-1). Consequently, 34,992 combinations of uncertainties exist, which implies that 34,992 possible futures exist. This is illustrated by the heat map in Figure 4-1 where the relative value (high, medium, low) of each uncertainty is represented by a different color.

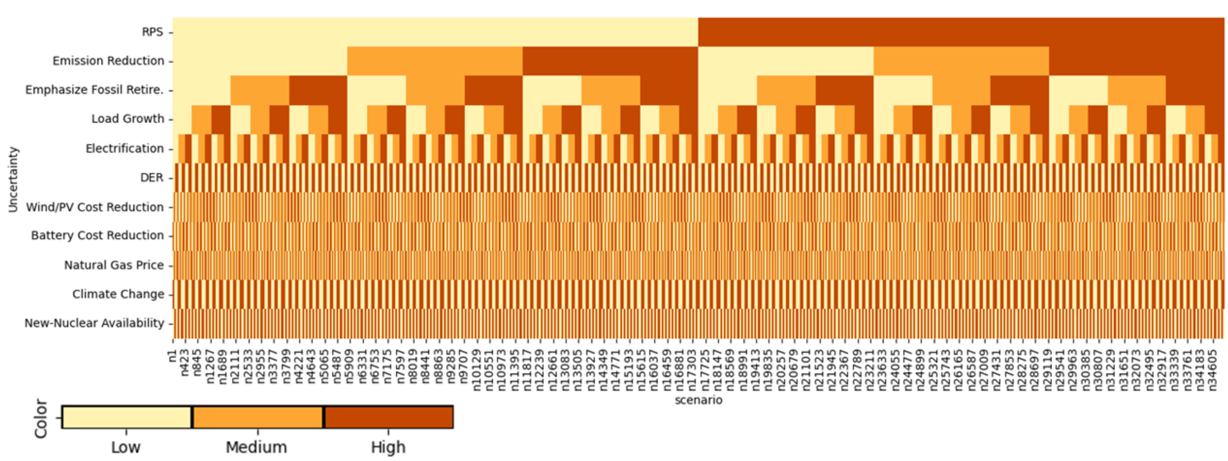

Figure 4-1: An illustration of the 34,992 **possible futures generated by nine uncertainties**

4.2 Reduction of futures

We desire to reduce the number of futures to seven; this number is chosen because, for the network size we intend, we believe it will result in a computationally tractable ACEP model. In addition, it allows us to represent the futures that MISO has studied in their LRTP process (1A, 2A, and 3A), plus four more. If we find our model solves quickly (e.g., in less than an hour), we may increase the number of futures beyond seven.

To reduce the thousands of possible futures to seven, a subset of representative futures must be chosen. This is accomplished using a scenario reduction technique[20], which is implemented as SCENRED2 in the GAMS programming platform. The technique has been successfully applied in expansion planning studies of the MISO and Bonneville Power Administration (BPA) systems[21] [22]. In choosing the subset, we assign an elevated probability to the three MISO planning futures (1A, 2A, and 3A) to ensure that they are chosen. All other futures are assigned an equal probability (other futures may be assigned different probabilities if information is available that suggests doing so). The scenario reduction algorithm SCENRED2 searches to find scenarios that best "cover" the probability space. The output of the SCENRED2 algorithm is represented in Figure 4-2, which illustrates the 34,992 futures together with the seven that were chosen.

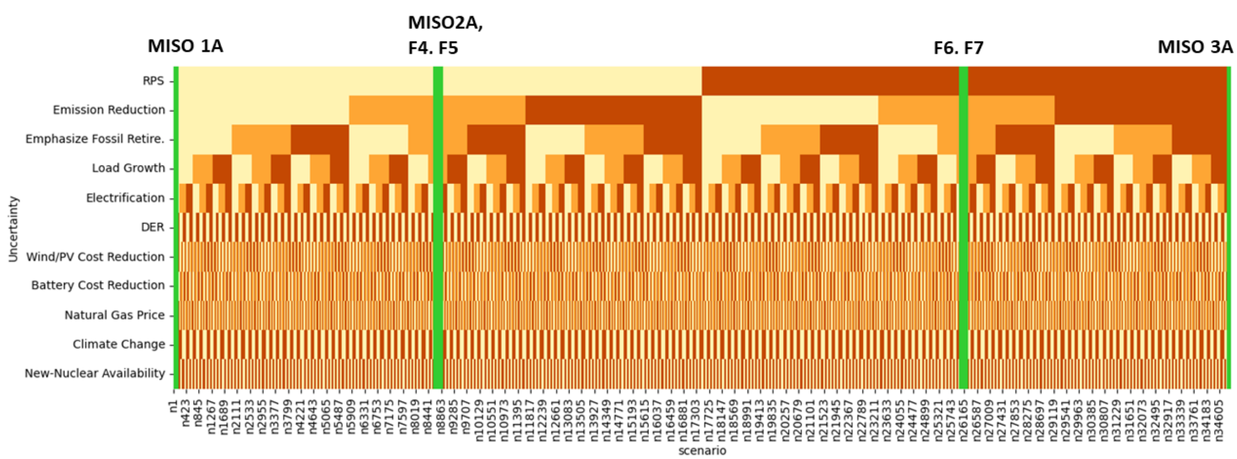

Figure 4-2: An illustration of the representative futures chosen by the futures reduction algorithm

As seen in the figure, some of the chosen futures seem to be positioned near to one another, e.g., [MISO2A, F4, F5]; and [F6, F7]. This is a result of the fact that each of these groups of futures have the same realizations of uncertainties at the top of the tree (RPS, emission reduction, emphasize fossil retire, and load growth). It is not possible from Figure 4-2 to determine whether the uncertainties toward the bottom of the tree are the same or not. To make this determination, Figure 4-3 provides the uncertainty realizations for only the seven chosen futures. Here, it is observed that the uncertainty realizations at the bottom of the tree (below Electrification) are generally varied for the two groups of futures [MISO2A, F4, F5]; and [F6, F7]. By selecting seven futures instead of just three, the space of possible futures is better represented.

---

[20] N. Growe-Kuska, H. Heitsch, and W. Romisch, "Scenario reduction and scenario tree construction for power management problems," in 2003 IEEE Bologna Power Tech Conference Proceedings, vol. 3, 2003, pp. 7 pp. Vol.3.
[21] C.J. Newlun, "Co-optimized expansion planning for power system resilience and adaptation," Ph.D. dissertation, 2022. [Online]. Available: Co-optimized expansion planning for power system resilience and adaptation (iastate.edu).
[22] P. R. Maloney, "Methods for cooptimizing planning and plan validation under uncertainty," Ph.D. dissertation, August 2019. [Online]. Available: https://lib.dr.iastate.edu/etd/17505/

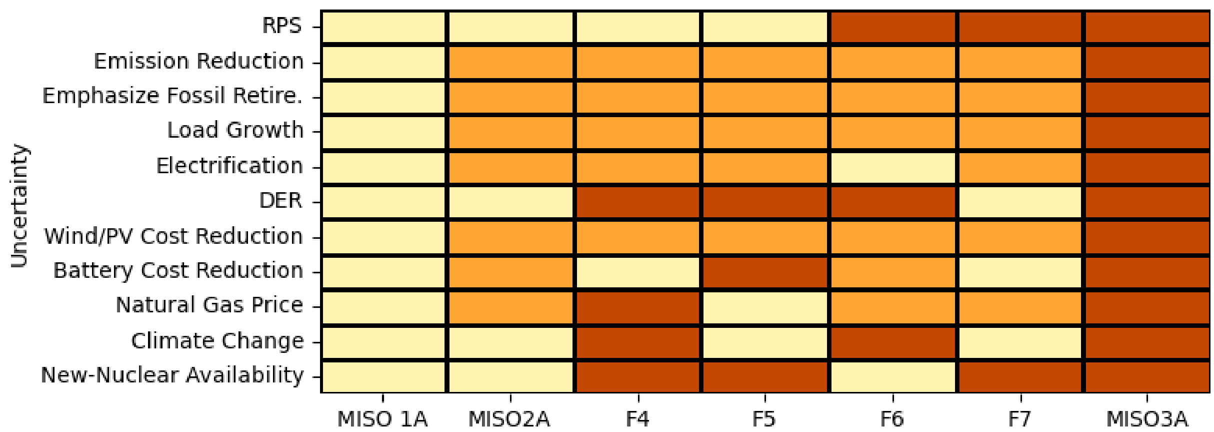

Figure 4-3: The seven futures chosen by the futures reduction algorithm

5 Conclusions and next steps

The work of the Plan Iowa Energy (PIE) project is motivated by a desire to identify ways to expand and grow Iowa's electric infrastructure to provide benefits to the people of Iowa. As with any long-term expansion planning, the work must be done in the face of significant uncertainty. Adaptive co-optimized expansion planning (ACEP) is a tool designed to optimize expansion planning in the face of uncertainty. ACEP seeks to optimize the system design in order to achieve a given vision. At the same time, it is able to consider multiple potential futures that capture the influence of that uncertainty.

Employment of the ACEP-based planning process requires four basic steps that have been described in this report; 1) identification of a vision, 2) identification of uncertainties, 3) selection of a representative set of planning futures, and 4) execution of the ACEP model to produce a plan. To date, we have completed three of these four steps; five different visions have been identified and described, eleven different uncertainties have been identified and characterized, and a representative set of seven different futures have been selected.

The final step identified above, step 4, is to run the ACEP optimization to produce various system designs, one design for each vision. This step will require the development of an appropriate power system model and associated resource data. The MISO system model, which contains many thousands of buses, will be reduced to less than a thousand buses so that the ACEP optimization is computationally tractable. At the same time, several enhancements to ACEP are planned as a part of this project and will be addressed and reported in the coming months. Among these enhancements are task G6-1, to include inertial/frequency stability as a constraint to the optimization procedure; task G6-2, to account for resource adequacy, and task G6-3 to enhance resilience modeling in ACEP.

There are two significant steps to be taken following execution of the ACEP model. The first is to assess the robustness of the plan identified by ACEP. Here, folding horizon simulation (FHS) will be used to expose the plan to a large number of futures that were not used in the ACEP model. The second is to assess the plan for resilience using the "resilience-CEP" (R-CEP). The plan is typically adjusted following these two steps. We mention these steps here to provide the full view of the planning process. These steps will be addressed in the second year of the project.