AN ALGORITHMIC FRAMEWORK FOR MEASURING THE FINANCIAL RISK OF CLIMATE CHANGE

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ABSTRACT

We describe a general algorithmic framework for generating climate related financial scenarios and for using them to compute the climate related financial risks to a corporation, city, country or financial institution. A key benefit is that the exact same methodology applies to a very wide variety of disparate organizations while allowing for their unique, different physical and organizational details. In this way, we guarantee that the risks of all parties may be measured in exactly the same way, thereby creating the possibility for an "apples to apples" comparison. An important contribution of this paper is a method for mapping a nonfinancial scenario, such as a 2Degree world[1], to financial factor scenarios, a problem hitherto unsolved[2].

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Keywords: Climate Risk, Scenarios, TCFD

[1] A situation in which the average increase in temperature over this century is 2 degrees

[2] See statements by The Head of the Bank of France at the ESB conference, September 2018.
(https://www.youtube.com/watch?v=00J8tQeyfZc&feature=youtu.be&t=3390)

1. Overview

In December 2015 the Financial Stability Board of the G20 established the industry–led Task Force on Financial Disclosure (TCFD). Its goal was to find a way for governments, businesses, banks and others to measure their risk with respect to climate change. This task force has met on numerous occasions over the years and has produced a number of reports and a framework for how participants should go about measuring these risks. The stated objective was to establish a methodology that: "would enable stakeholders to better understand the concentrations of carbon-related assets in the financial sector and the financial system's exposures to climate-related risks."

On one thing the participants agreed – that the measurement of such risks would require the generation of credible forward-looking scenarios that would encompass future risks and upside for each of the participants[3]. Even as recently as April 2018 at a meeting held in New York[4] there was still no agreement as to how these scenarios should be generated. The Governor of the French Central Bank, François Villeroy de Galhau, expressed the problem of mapping nonfinancial scenarios into financial ones clearly at the recent European Systemic Risk Board Panel meeting on Sustainability saying:"…we still do not know how to take nonfinancial scenarios and convert them into financial variables."[5]

Organizations Face 3 Key Challenges in Disclosing Climate Risk.
Mercer, July 2018

Organizations face a broad array of scenarios. These include, for example, systematic scenario models (such as CO_2 emission trajectories for various temperature scenarios) or event-based scenarios (that is, carbon pricing or storms and hurricane events). Predicted outcomes vary widely across even the most authoritative models. As one company noted, "In some sense, the process involves a lot of very educated guesswork, but not everyone guesses in the same way."

The primary goal of this paper is to present a complete, consistent algorithmic framework for generating and using these scenarios, to calculate the climate risk of an organization. We show, in particular, how nonfinancial scenarios may be used to generate forward-looking, multivariate, financial ones.

3 https://www.fsb-tcfd.org/publications/final-recommendations-report/ TCFD
4 TCFD Conference on Scenarios, May 1, 2018, New York.
5 Excerpt from the Third Annual ESRB Conference Panel Discussion on Sustainability (1 minute) https://www.youtube.com/watch?v=00J8tQeyfZc&feature=youtu.be&t=3390

2. THE PROBLEM

Much progress has been made recently in understanding how TCFD may be operationalized in banks[6,7], in particular for measuring credit and certain physical risks. A glaring issue is the open problem of defining and generating forward-looking financial scenarios.

For example, in the most recent report issued by UNEP, Acclimatize and 16 of the world's largest banks, a scenario is defined as a realization of a certain world climate average temperature, usually 2^0 or 4^0 centigrade by the end of the century. Given such a scenario, there are climate related factors (for example, sea level rise, extreme climate events, release of methane gas) that are possible. Put in other words, there are possible scenarios for the climate factors that affect an organization, business or country, conditioned on say the world's average temperature reaching 2^0C above 1990 levels. It is this second level of factor scenarios that is missing in all the reports I am aware of. Typically, what is analyzed is a single factor, using one extreme value such as a 1 in a 100year realization as it might apply today. The bigger issue of all the climate related factors and how they would behave at some future point in time is skimmed over.

What is needed, however, may be expressed as the following.

> ***Given an end state of (say) 4^0C warming by the year 2100, what can we say about the climate related financial factors that will affect an institution in (say) 2030?***

To measure risk effectively, we need to be able to generate scenarios on these factors, conditional on the macro climate scenarios that are expressed in terms of world average temperature at the end of the century. Usually, it is the way that factors combine that is most damaging. For example, consider significant sea level rise coupled with Category 5 hurricanes or drought coupled with high winds. So combinations of climate risk factors may become very critical and we will be underestimating risk if we do not take into account combinations of factors.

We show later in this proposal how such scenarios may be generated. We also develop ways of finding the data that are needed to generate them.
There are essentially 3 levels of scenarios that need to be examined:

1. The high level Macro Scenario such as a 2^0C world[8] by 2100;
2. The next level being the appropriate combinations of macro factors (scenarios) conditioned on the Scenario (event) in 1, such as sea level rise, extreme temperatures, number of severe hurricanes etc.
3. The micro factors that are conditioned on the scenarios in Level 1. and 2. that affect the value of the particular firm/bank/state/country in question.

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[6] Navigating a New Climate, Part 2, UNEP and Acclimatize, July 2018
[7] UNEP and Oliver Wyman, Report, April 2018
[8] We use the shorthand "2^0 world" to refer to a world that in 2100 has reached 2^0C above the 1990 average temperature level.

3. A SOLUTION

It is important to be explicit on how we define scenarios. We believe that this has been a source of confusion in the published articles on scenarios for TCFD.

A useful way of representing scenarios is a "Scenario Tree" or, more generally, a "Scenario Network". Consider the tree shown in Figure 1.

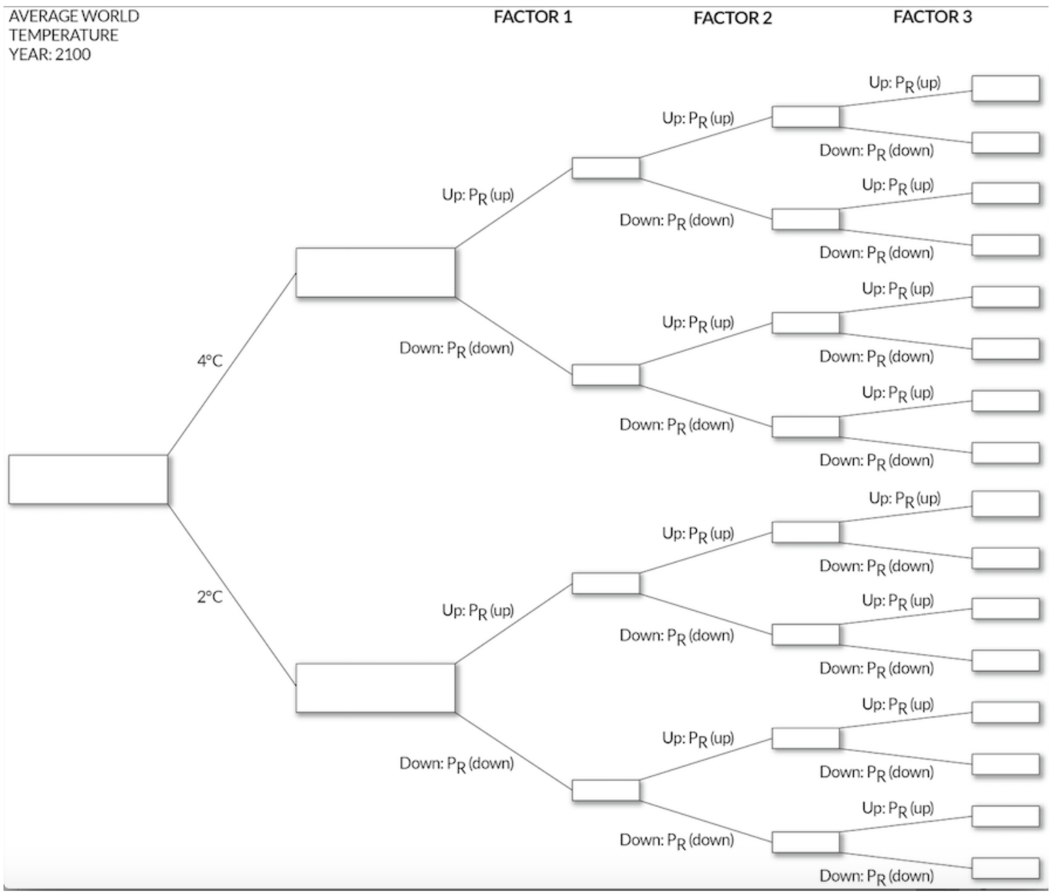

Figure 1: A scenario tree example

In the example in Figure 1, there are two possible end state scenarios for the world average temperature. Each branch of the tree resulting from the end state depicts the possible up and down movements of three climate risk factors given this end state. The order of the risk factors will be important if the they depend on one another or irrelevant if they are independent.

We place no restrictions on the factors in the tree. They could be any combination of financial and nonfinancial factors.

A single scenario is highlighted in Figure 2 below.

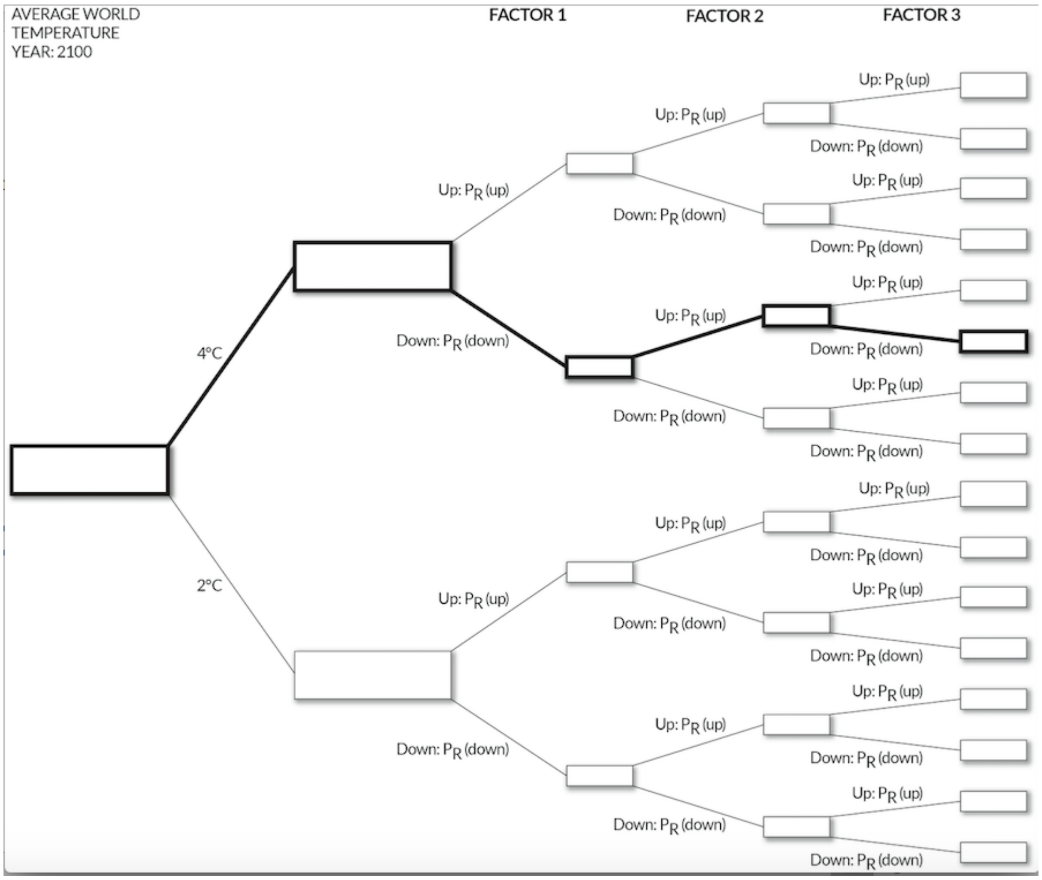

Figure 2: A single scenario

To make this concrete, assume The climate factors in the year 2030 are defined as: ***Factor 1: Sea Level, Factor 2: Hurricane Frequency and Factor 3: Average Sea Temperature as measured, relative to today, for a horizon in the year 2030***. Then the scenario highlighted in Figure 2 would read as:

> ***Conditioned on a 4^0C average temperature rise by the year 2100, we will see decreases in sea level, however simultaneously the hurricane frequency will increase and sea temperature will decrease, relative to expected levels for 2030.***

This scenario may be very unlikely or likely. We will see how this may be determined. Regardless, the essence of the management decisions that need to be taken are: should we ignore this case or should we take it into account? Ignoring it is an outright bet. Taking it into account will involve some mitigation/adaptation strategy.

The essence of the scenario problem is how do we fill in the values for the various paths in the tree. We need the probabilities of the up and down movements for each factor as well as the values associate with a the up and down branches. We show how to get this in the next section.

4. ALGORITHMIC GENERATION OF SCENARIOS

A key input to computing scenarios on combinations of climate related factors, is the individual distributions of possible values for each of the factors at some designated future point in time (the horizon). Where would we get this information from? For example, how could one generate the distribution of sea level in Southern Florida in 2030? Or, the distribution of Category 5 Hurricanes in the Atlantic in 2030 for that matter. Or, the effect on the Euro conditional on the outcome of these factors? Certainly historical information would be a source but on its own would be seriously inadequate.

There is one source that we have not tended to use but that could give us useful information and that is the ***collective wisdom*** of the people worldwide who are experts and otherwise involved in understanding the future values of these factors. If we could extract their views on the subject, we would obtain a distribution of possible outcomes that would span the range of possibilities and would show the collective skew in the distribution. Moreover, if we collected this information carefully, it would have both sides of the forecast – the general consensus and the naysayers. In essence we are looking for a discrete set of possible scenarios for combinations of these factors, so that the precise nature of these distributions is less important than their ability to capture extremes.

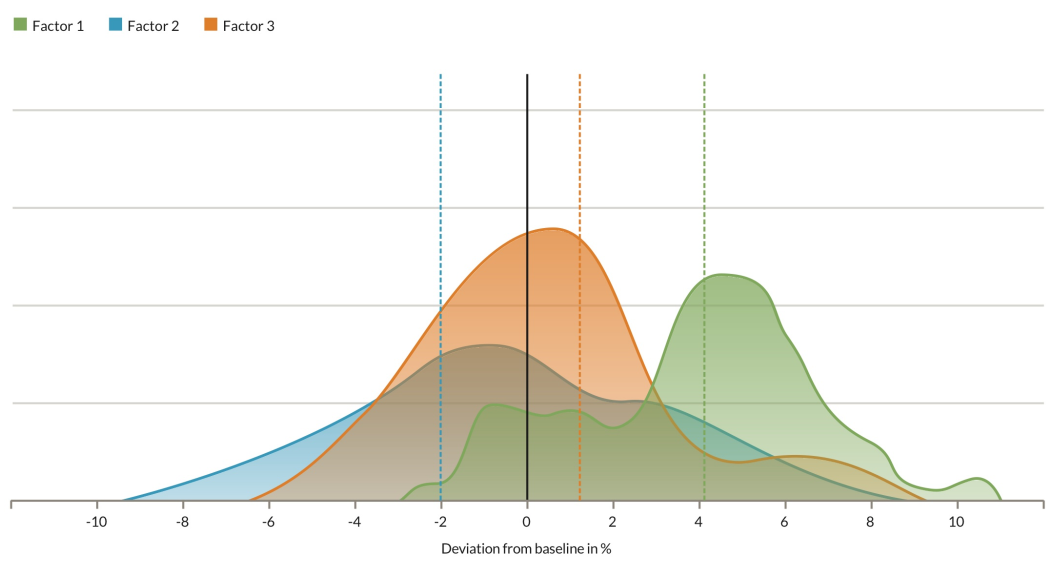

Figure 3: The probability distributions of values for the Factors 1,2, 3 at the horizon

These distributions give us estimates of four critical values which are needed to be able to develop scenarios which combine all factors that are material to the issue at hand. Namely, the possible range of Upside and Downside movements in the factors and their probability of occurrence (See Figure 4 below).

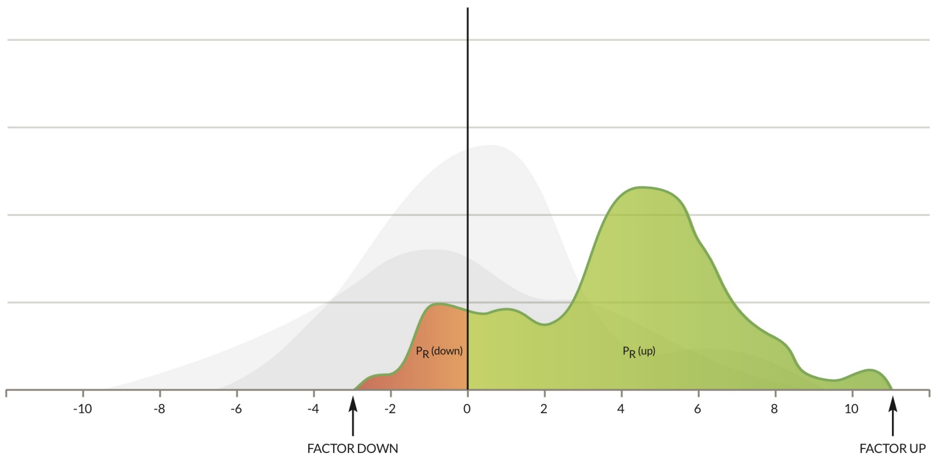

Figure 4: Useful information embodied in the forward distribution

By combining the information in the forward distributions with the scenario trees we can get both scenarios for the combinations of factors as well as estimates of the probabilities of these scenarios occurring, using the collective wisdom of the crowds. The four values – up and down ranges for the factors as well the probabilities of the up and down movements are all we need to complete the data required to evaluate the tree (see Figures 1 and 2). These extremes as well as the seemingly odd combinations (some of which humans would probably neglect) are likely to "span" the range of possible outcomes for the scenario space. Since we are primarily interested in extremes, both on the upside and downside ("White Elephants" and Black Swans") this method could be an efficient way to find them.

Whereas we have shown this using collective wisdom, there are clearly many ways of achieving the end goal, that is, deriving the distributions for the factors at the horizon. The quality of the scenarios we develop will hinge on how well we can estimate these distributions.

We now have all the ingredients to define an Algorithmic framework for stress testing/risk management in a climate change setting.

5. AN ALGORITHMIC FRAMEWORK FOR MEASURING CLIMATE RISK

The problem of how to measure the financial risk of climate change regime, such as “a 2^0 world”, may be disaggregated into two distinct phases.

PHASE A: Identifying the macro factors that are material to the risk of the institution. Generation of a decision tree that reflects the possible future paths that these factors might take between now and the planning horizon. Generating possible future values for these factors at the horizon. Generating scenarios on combinations of these factors[9].

PHASE B: Relating the macro scenarios to scenarios on the micro factors that affect a particular organization for each sector and in each geography in which it operates (I.E. translating a scenario made up of macro climate risk factors, financial and nonfinancial, into the value effect it would have on an institution).

To make this concrete, let’s take a real example[10] that is under study now.

It concerns the CALISO organization, in charge of production and distribution of electricity in California. CALISO is concerned about the unknown effects climate change, coupled with possible transitions occurring in transportation and the generation of electricity, may have on their planning and ability to deliver electricity efficiently and securely. They are considering joining their grid with other Western utilities to be able to construct a resilient grid, make more effective use of renewables and handle the possible growth of electric vehicles (EV’s).

The factors that influence their strategy have been identified as the average temperature in California in 2050 (to account for all the unknowns that might result from climate change such as higher temperatures, increased frequency and higher severity of droughts, wildfires etc.), will renewable targets be reached, the ability to form a regional grid with other Western States, and the load growth.

They start by defining a Scenario Tree that shows the different possible paths these factors might take between now and 2050, their planning horizon. (See Figure 5 below).

Note that their decision involves a mixture of climate change factors as well as factors that influence their business that are not caused by climate change.

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[9] Dembo, R., *“An Algorithm for Generating Scenarios*”, Zerofootprint Working Paper April 2017, revised May 2018.

[10] In the interest of simplifying this presentation, the example is a highly simplified version of their true issues but captures the essence of the decision making process.

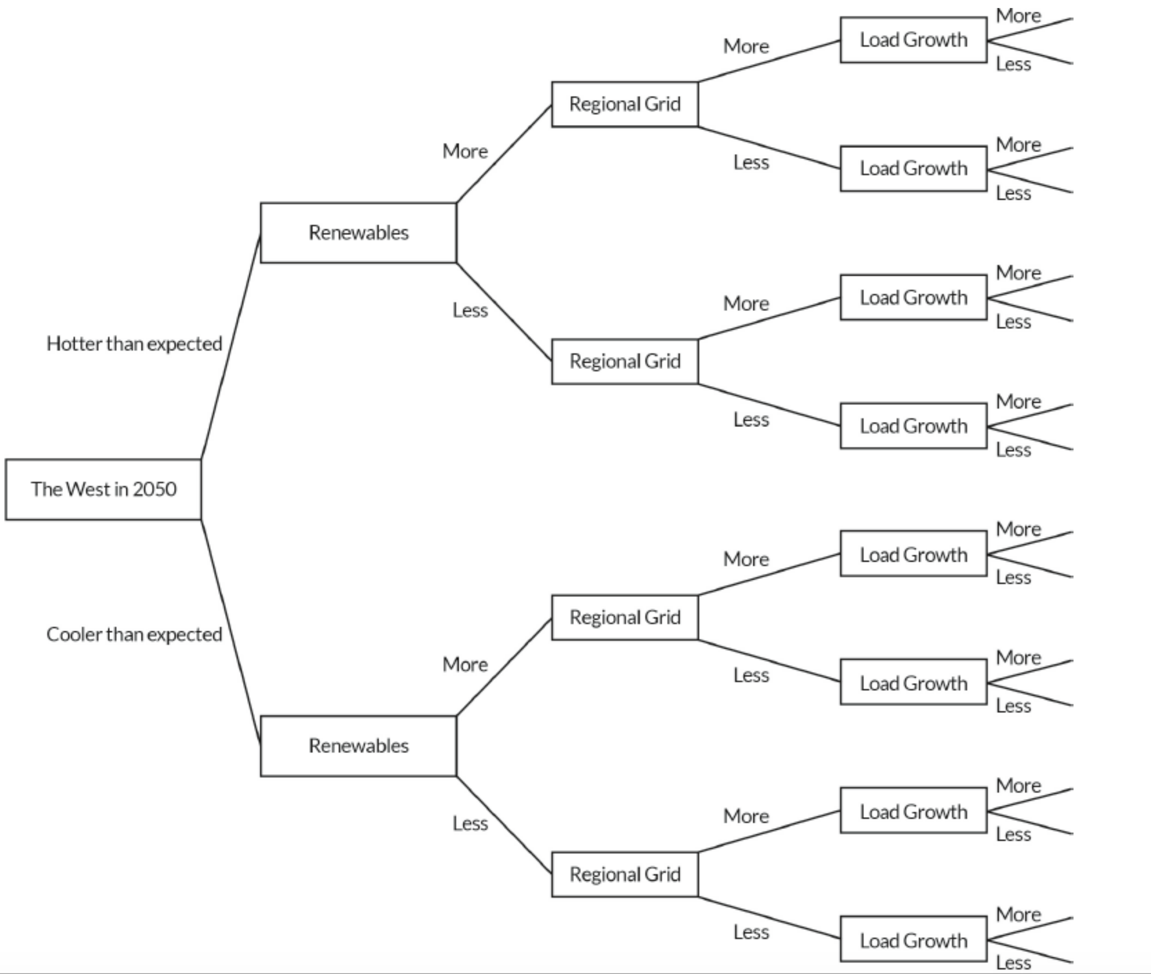


FIGURE 5: CALISO'S decision problem (key: more = more than expected)

The paths in this tree are the scenarios of the combined factors that need to be accounted for in their strategic planning.

Figure 6 below shows a single scenario and its expression in English terms.

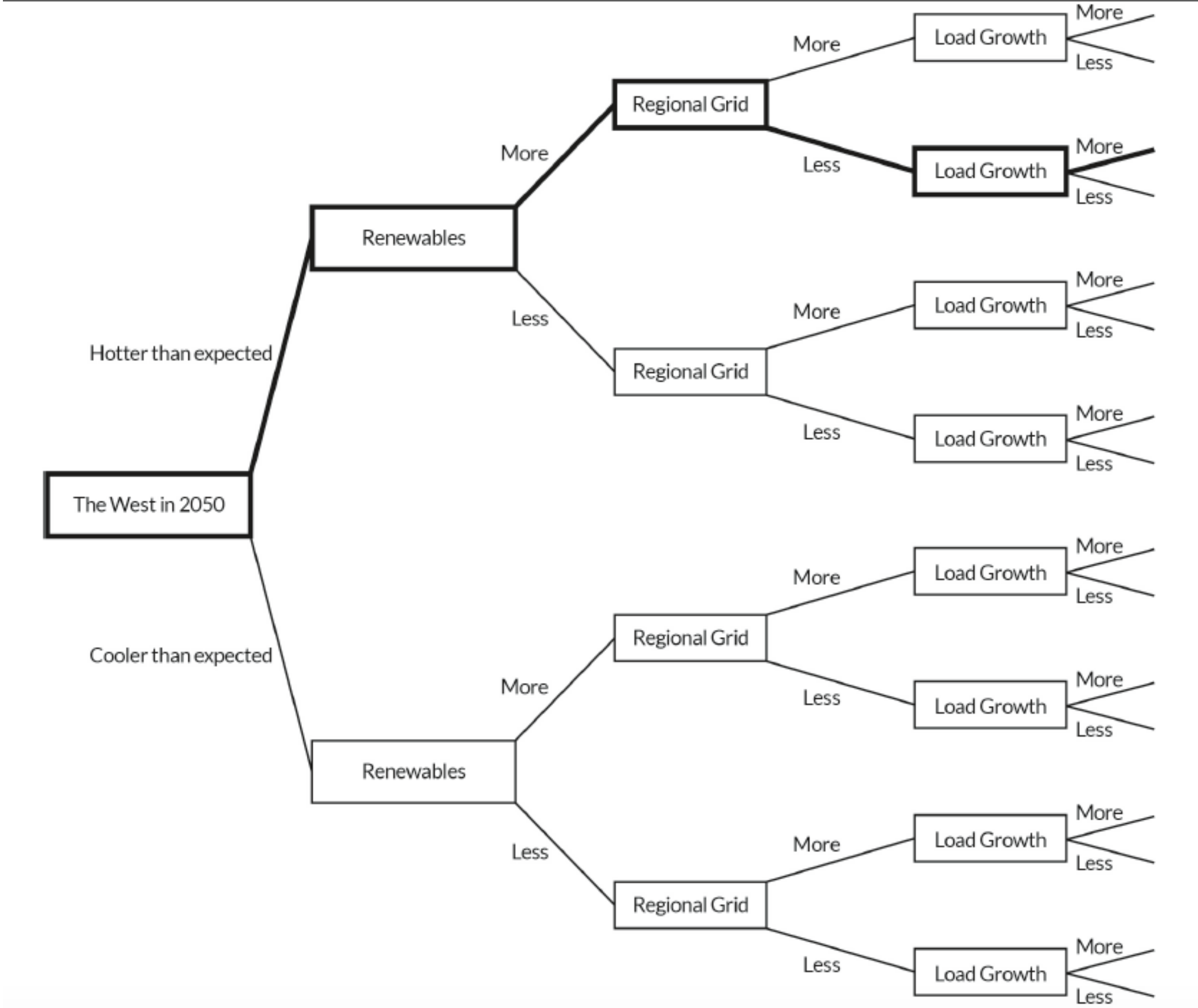


FIGURE 6: A Single Scenario (Key: more = more than expected)

By 2050 California's average temperature will have risen more than expected. The growth of renewable energy generation is more than was predicted and the regional grid has not materialized as much as was expected. Load growth by contrast is more than was expected.

In order to evaluate this tree, we need four values for each factor, the possible upside and downside values for each factor and their probabilities.

CALISO now takes a poll[4] of its members or uses a machine learning algorithm to estimate the distributions of each of these factors as at 2050, as discussed previously. With these distributions, data in this tree can be estimated and the possible scenarios that need to be examined by CALISO can now be determined.

This completes PHASE A. Note that Phase A could apply to any Californian Utility, there is nothing specific to CALISO.

PHASE B is specific to CALISO. That is, given (for the example in Figure 6):

> ***By 2050 California's average temperature will have risen more than expected. The growth of renewable energy generation is more than was predicted the regional grid has not materialized as much as was expected expected. Load growth by contrast is more than was expected;***

What will the optimal strategy for CAISO be going forward? This analysis needs to be done for each possible scenario. As time passes and the data gets better and better, scenarios will improve, and the strategy chosen today will evolve. CAISO could, of course, choose to ignore this particular scenario (IE bet that it will never occur and remain unhedged to its consequences should it or something close to it occur). Or, it could hedge its bets with respect to the outcomes that this portfolio implies. This is their business decision.

In order to then compute the actual gains or losses to the organization we need to translate the the scenarios developed in PHASE A into actual gains or losses for the organization. Whereas PHASE A is generic to all organizations (they might differ by not having exposure to some of the macro financial risk factors) It is this second phase, PHASE B, that will be **unique** to each and every organization. It will depend on the organization's strategic direction as well as the physical location of its operations.

This decomposition of the problem allows for comparison amongst a diverse group of organizations. The macro risk factors computed in PHASE A are common to all organizations but each organization is subject to the forces of only a subset of macro factors. In this way, one set of scenarios may be generated for all participants in PHASE A and resulting specific valuation scenarios are then computed by each and every organization. **This also justifies diverse organizations collaborating in PHASE A**. This allows for a level of consistency in the measurement of risk and accommodates the diversity that is found across the participants. Naturally, the risk factors will be different for different geographies and different sectors of the economy. So this exercise needs to be done separately for each geography and each sector within that geography.

Note that in the example of CALISO, the factors they consider contain factors both relevant to Transitional risk and Physical risk[11]. The procedure used to develop scenarios applies equally to both. For this reason, we question the arbitrary separation of these two types of risks in the TCFD documents.

The TCFD decomposition into Physical and Transition risks is potentially problematic. It could lead to 2 sets of scenarios (potentially inconsistent) being generated – one for Transition Risk and another for Physical risk. We suggest an alternative characterization, namely, long term and short term risk. Transition Risks as defined in TCFD documents may be short term and others may be long term. In a similar way some Physical Risks as defined by TCFD may be short or long term. The key is that a single, consistent framework is needed for both short and long term risk.

[11] https://www.fsb-tcfd.org/publications/final-recommendations-report/ TCFD

So for a particular horizon one may have both Physical and Transition Risks but the scenarios generated would need to be consistent. Also the Physical and Transition risks would both be part of the total risk. Therefore, we do not see a need for the distinction set out by TCFD. Short term in our terminology involves a horizon that is shorter than the normal strategic planning horizon of the firm. Long term involves computing risk for time horizons that are longer than the normal planning horizon of the firm.

In our approach, we compute a single set of macro financial climate risk factors at a given horizon or for many chosen horizons and the horizon selected determines whether we are looking at a long term or short term view of risk.

Algorithm for climate stress testing a corporation, bank, state, city or country.

For a given horizon (EG 2050) and given climate regime (EG A 2^{0}C World in 2100):

PHASE A: **Developing the combined factor scenarios**

STEP 1 Identify the macro factors that affect the institution in question;

STEP 2 Generate the distributions of possible values for these risk factors at the horizon.

STEP 3 Generate a set of scenarios on the combinations of macro climate risk factors.

PHASE B: **Determining the impact of the scenarios developed in PHASE A**

STEP 4 Identify all the micro financial effects on the business that are impacted by all the macro climate risk factors;

STEP 5 Value the financial effect on the company using the macro to micro climate conversion for each scenario using the analysis in STEP 4;

STEP 6 Develop a strategy based on the results of Steps 4 and 5;

6. MORE DETAILS ON THE ALGORITHMIC FRAMEWORK

Phase A: Developing the scenarios using an algorithm, is the main innovation of this paper.

Step 1: Identifying the macro climate risk factors that affect the institution in question, can usually be done well by experts in the sector and the geography under study. It can also be done well by machine learning algorithms and is fairly straightforward.

Step 2: Generating the distributions of the macro climate risk factors at the horizon, is more complex. It has the added issue of where can one get reasonable data to execute this? Historical data alone is fraught with issues. Model data has other biases, as well as heroic assumptions that are clearly a simplification. The one source of data that we have not seen used in this context is data collected from the thousands of people worldwide who are intimately involved with these factors – scientists, managers, statisticians etc. For this function we propose using information that can be gathered from these people via machine learning algorithms that can scour every scientific paper, social media statement and newspaper article on the subject. It can also be augmented by polling them (see Appendix). We propose using these tools to derive the distributions. It is important however that human curation be used as well, not to change data but to ensure that all sides of the uncertain values are covered. Their might be a market consensus in one direction but it is important that the naysayers be included in the data.

Step 3: Generating a set of scenarios based on these distributions, has also been a challenge historically. We propose a simple solution, based on combining key information from the distributions obtained in **Step 2**, with a Scenario Tree[12]. This key insight is a powerful tool for finding scenarios that span the range of possibilities and in particular are good at generating the extreme scenarios that humans find difficult to do.

Phase B, valuing climate risk scenarios, is a process in common with all scenario generation methods. One has to find a relationship between the macro factors (E.G. sea level rise) and the micro factors (E.G. location of houses under mortgage) to assess the value of any climate event.

Step 4: Identifying all the micro factors; **Step 5**, Valuing the cost or benefit of a climate event given **Step 4**; **Step 6**, Developing a strategy, are all institution specific.

Note also that our terminology differs from TCFD. In order to overcome the confusion amongst TCFD participants between the use of the term scenario for multiple things such as the "a 2^0 world by 2100" as well as a scenario on a particular risk factor, we refer to the end state in 2100 as a "climate regime" and our reference to scenarios is limited to the possible states of the various risk factors we are analyzing at a given horizon for a given sector(s) of the economy. The word scenario seems to be used for both in the TCFD literature.

[12] Dembo, R., *"An Algorithm for Generating Scenarios*", Zerofootprint Working Paper April 2017, revised May 2018.

Phase B in the CALISO case would consist of identifying all of CALISO's generating sources, transmission lines, and other infrastructure necessary to supply California with electricity, excluding the electricity generated by individuals or companies not under CALISO's jurisdiction.

The data on scenarios that are generated by CALISO on combinations of temperatures, fires, drought, etc. are then mapped onto this infrastructure data to get estimates of the costs or benefits that would result for each and every scenario.

Management would then se these scenarios as a basis for discussions with its Board to explain its decisions around the strategy that is proposed going forward.

This process would be repeated at least once a year or whenever there is an event that results in a material change in the factors that have been used.

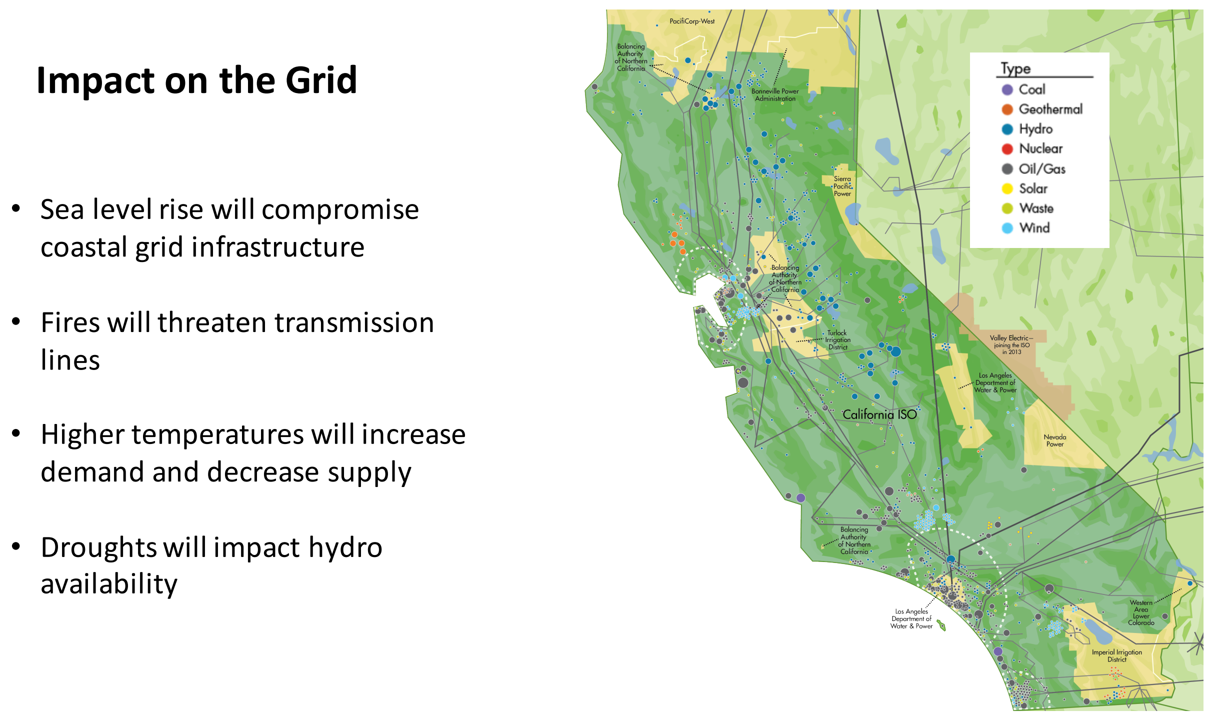


Figure 7: The electricity infrastructure in California (source: CALISO)

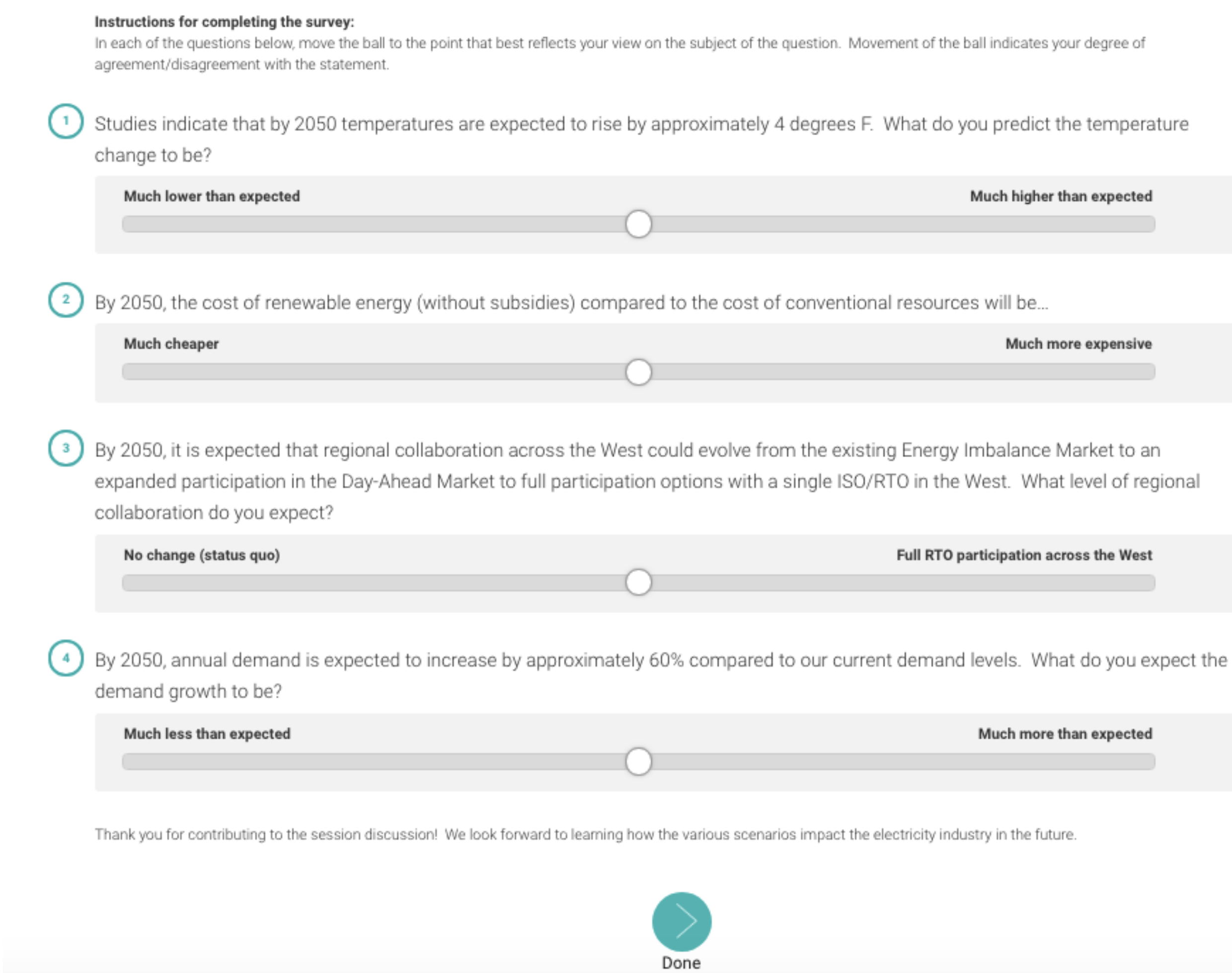
7. CONCLUSIONS

In order to properly model the risk of a climate event such as a 2^0 world, we need to model the forward distributions and scenarios for all the climate related factors that affect the organization we are measuring. This paper develops an algorithm for doing so. It also shows how the input data, that is required, may be generated by using the collective wisdom of “the crowds”.

Most powerful of all is the fact that this algorithmic framework will apply to almost all institutions/organizations and is executed in the same manner for all. In TCFD terms it applies to Transition Risk and Physical Risk in a consistent manner.

The method presented here is in the context of climate change risk. The framework, however, applies more broadly and may be applied wherever strategic decisions need to be evaluated in the face of uncertainty. In particular, we feel that it becomes especially relevant in situations where there is insufficient historical data to be able to generate forward looking scenarios adequately.

APPENDIX 1: CAISO example poll



Instructions for completing the survey:
In each of the questions below, move the ball to the point that best reflects your view on the subject of the question. Movement of the ball indicates your degree of agreement/disagreement with the statement.

1. Studies indicate that by 2050 temperatures are expected to rise by approximately 4 degrees F. What do you predict the temperature change to be?

   Much lower than expected — **Much higher than expected**

2. By 2050, the cost of renewable energy (without subsidies) compared to the cost of conventional resources will be...

   Much cheaper — **Much more expensive**

3. By 2050, it is expected that regional collaboration across the West could evolve from the existing Energy Imbalance Market to an expanded participation in the Day-Ahead Market to full participation options with a single ISO/RTO in the West. What level of regional collaboration do you expect?

   No change (status quo) — **Full RTO participation across the West**

4. By 2050, annual demand is expected to increase by approximately 60% compared to our current demand levels. What do you expect the demand growth to be?

   Much less than expected — **Much more than expected**

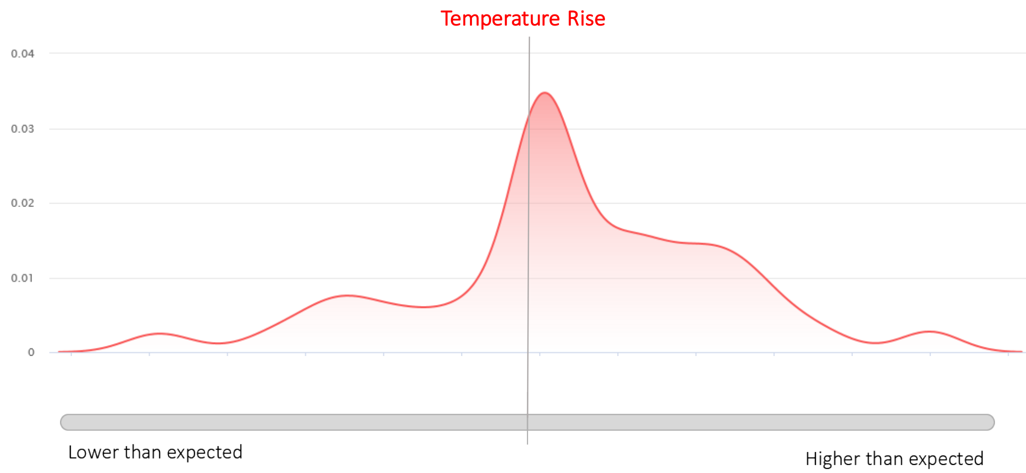
Thank you for contributing to the session discussion! We look forward to learning how the various scenarios impact the electricity industry in the future.

Done

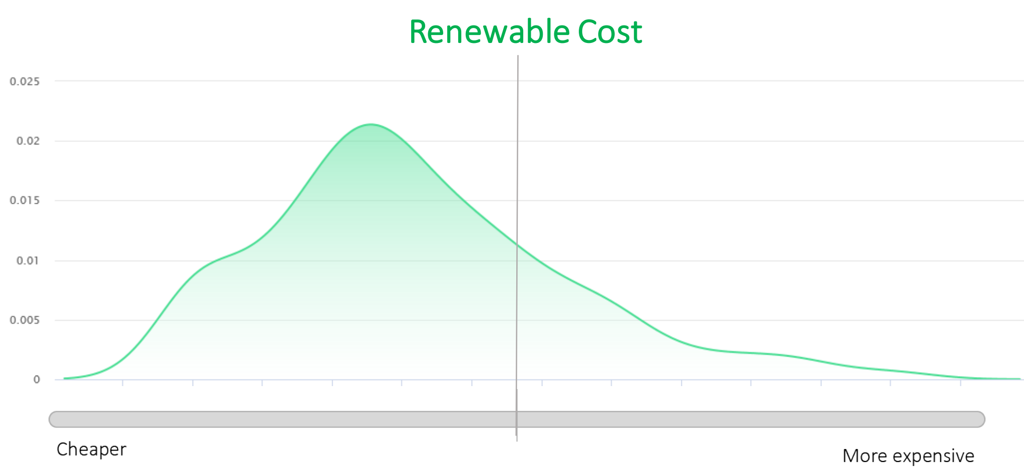
This survey is not meant to be a definitive analysis of CAISO's future risk. Its purpose is to demonstrate the method on a simplified problem.

APPENDIX 2: Results of the CALISO Poll[13]

Studies indicate that by 2050 temperatures are expected to rise by approximately 4 degrees F.
What do you predict the temperature change to be?



By 2050, the cost of renewable energy (without subsidies) compared to the cost of conventional resources will be…



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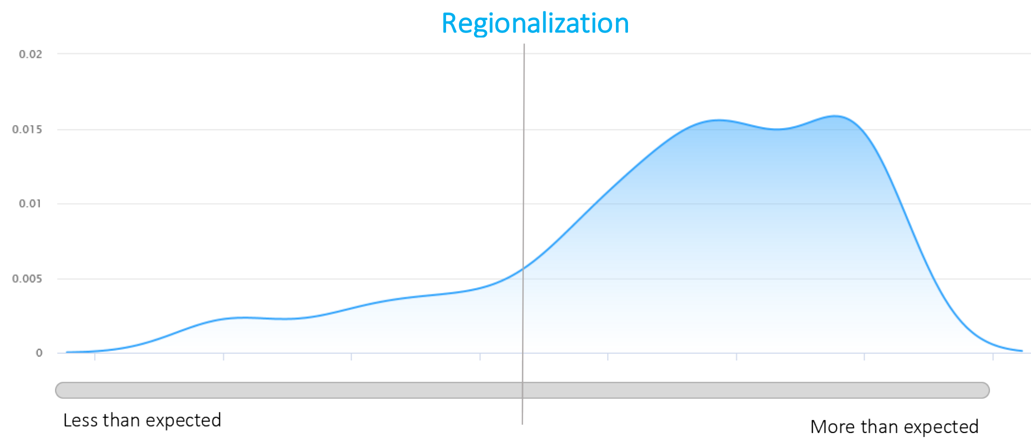
[13] We would like to thank the organizers of the CALISO 2018 Stakeholder Symposium, especially Joanne Serina and Mark Rothleder, for their cooperation in this exercise and for conducting this poll with CALISO's stakeholders. Approximately 25% of the 1000 attendees responded to the poll.

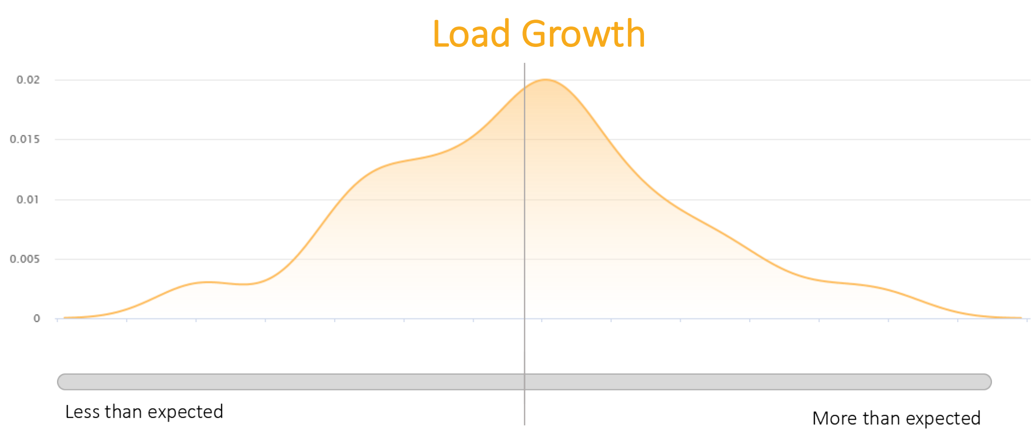
By 2050, it is expected that regional collaboration across the West could evolve from the existing Energy Imbalance Market to an expanded participation in the Day-Ahead Market to full participation options with a single ISO/RTO in the West.

What level of regional collaboration do you expect?



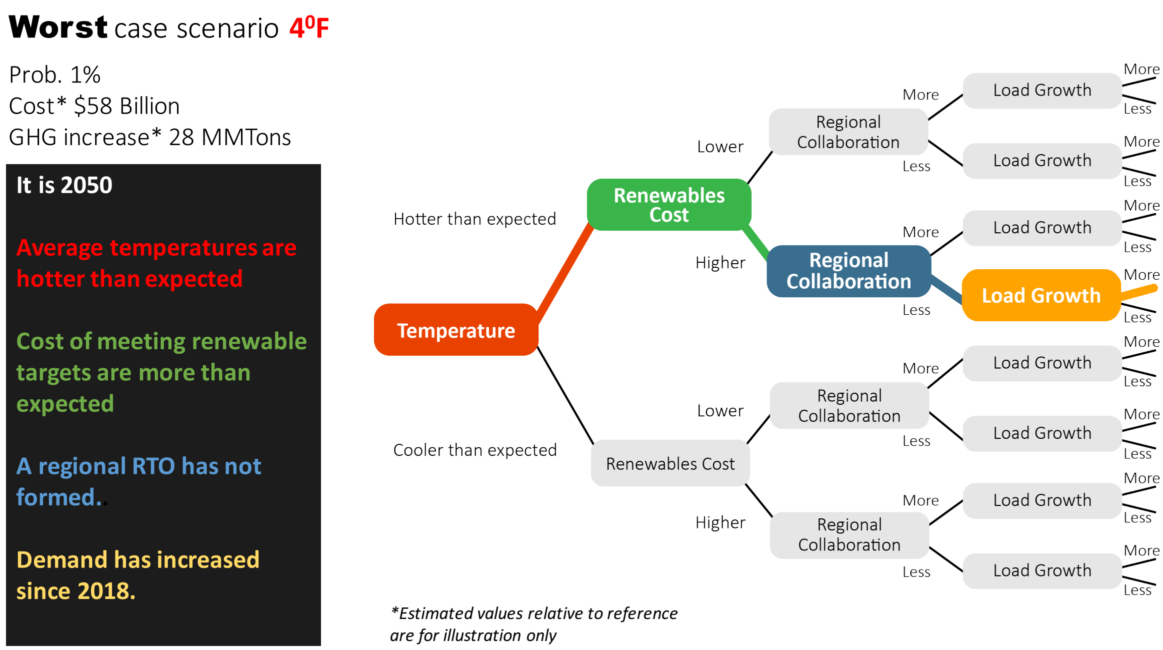
By 2050, annual demand is expected to increase by approximately 60% compared to our current demand levels.

What do you expect the load growth to be?



These results are not meant to be a definitive analysis of CALISO's future risk. They are meant to demonstrate the method on a simplified problem.

APPENDIX 3: The CALISO representative scenario tree (worst case scenario)



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