CLIMATE CHANGE EFFECTS ON SUPPLY AND DEMAND

Summary

- City Light used projected increases in temperature and changes in streamflow from three climate change scenarios to model the effect on demand and hydropower generation.
- Results of the climate change scenarios were compared to the expected base case and "do nothing" portfolio of the Integrated Resource Plan (IRP), not the candidate portfolios in the portfolio analysis, in order to isolate the effects of climate change.
- The inclusion of warmer temperatures in the 20-year demand forecasted lowered the 0.41 projected annual load growth by 0.01 to 0.04 percentage points because of the importance of winter temperatures on City Light's demand forecast.
- Total annual hydropower generation decreases for climate change scenarios that project decreases in annual streamflow and increases for scenarios that project increases in streamflow with a range from a 2.6 percent decrease to a 2.3 percent increase in generation for the three scenarios.
- City Light will continue to evaluate potential effects of climate change on supply and demand as additional information becomes available from the forthcoming climate change study of the Columbia River System.

Introduction

This Appendix summarizes City Light's analysis of the potential effects of climate change on the utility's load-resource balance for the 20-year period of the IRP, 2016 to 2035. City Light used projected increases in temperature and changes in streamflow provided by regional academic institutions to model load and hydropower generation under climate change scenarios and compared results to the expected base case for the IRP. The expected base case and "do nothing" portfolio was used for this climate change assessment because the objective was to isolate the effect of climate change on the load-resource balance and not confound this effect with the differences among multiple portfolios. However, the climate change scenarios used for this analysis are not the base assumptions used to compare resource portfolios in the IRP; the expected base case used to evaluate portfolios in the IRP remains based on historical climate data. Climate data used in this analysis are projections of potential trends due to climate change over time, and not forecasts of the weather, generation, or load in any one year. This appendix describes the climate change scenarios selected for the analysis, methods used to project changes in generation and load, and results of both analyses.

Climate Change Scenarios and Global Climate Model Selection

University of Idaho (UI) provided City Light with downscaled climate data from 20 global climate models of the Coupled Model Intercomparison Project phase 5 (CMIP5)[1]. These climate models use input scenarios of global emissions of greenhouse gases to simulate changes in temperature and precipitation. Global emissions scenarios are essentially storylines of the potential rate and amount of greenhouse gases emitted to the atmosphere over the next century for the entire world. The amount of emissions (and associated warming) diverges among these scenarios later in the 21st century, but for the 20-year time period of the IRP they are very similar, so City Light used the higher emissions scenario (RCP 8.5). Climate models project future climate at a spatial scale that is too coarse for analyzing hydropower generation or demand in a particular location, so the data must be "down-scaled" to a scale appropriate for local analysis. UI used a statistical downscaling method called Multivariate Adaptive Constructed Analogs to downscale data to weather stations of interest to City Light. This method captures the scale necessary for evaluating local impacts of climate trends but preserves the spatial patterns of meteorological data as simulated by the more coarse-scale climate models.

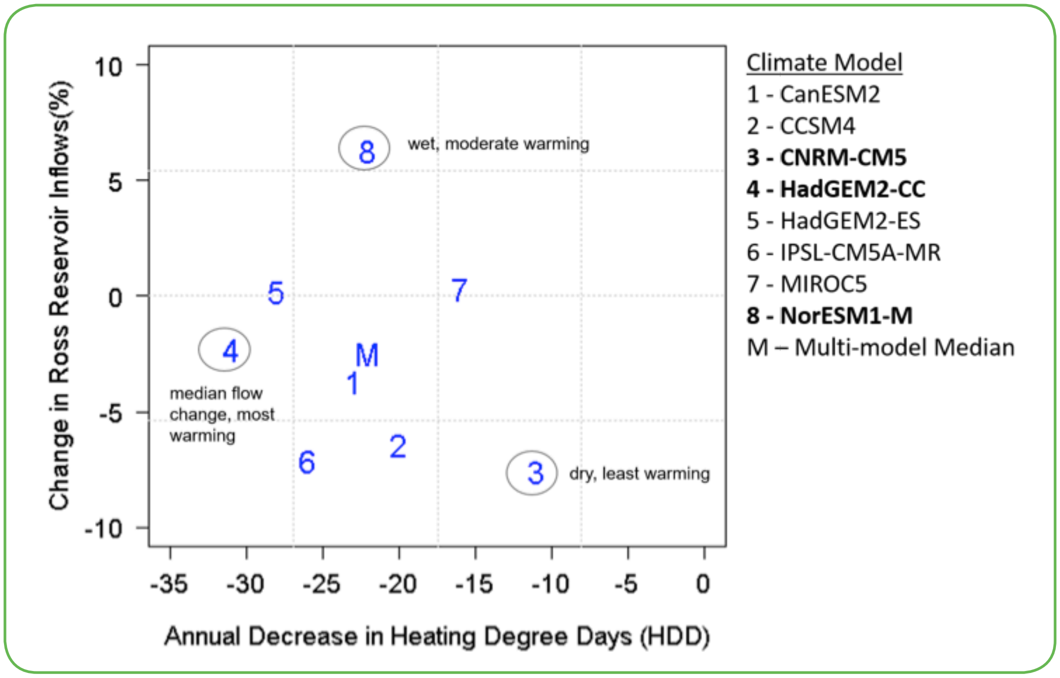
The down-scaled climate data must be used in a hydrologic model to project changes in streamflow at particular locations in order to simulate the effects of climate change on available streamflow for hydropower generation. Researchers at the University of Washington used the Distributed Hydrology Soil Vegetation Model (DHSVM) to simulate changes to inflows at City Light's Skagit hydropower project based on projected future climate from eight of the 20 climate models[2]. The hydrologic modeling includes the effects of changes in precipitation, snowpack, and runoff from glaciers, which all contribute to inflows available for hydropower generation.

City Light selected temperature and streamflow projections from three of the eight climate models (HadGEM2-CC, NorESM1-M, and CNRM-CM5) to cover the range of potential future warming and changes in streamflow (Figure 1) for use in the analysis of effects on the load-resource balance. The criteria for model selection were to capture a high, median, and low change in both temperature for the service area and annual streamflow at the hydropower projects. An additional constraint on model selection was that the same three models be used for the analyses of demand and supply. Each of the three models is considered to be an equally likely scenario of the future climate.

To select the models for load forecasting, temperature projections for each of the eight models were ranked by their respective rates of decrease in heating degree days (HDD) per year. It is because City Light is a "winter peaking" utility (energy use is higher in winter than summer) that HDD projections were used to select the climate models for this analysis. The three models cover the range of decreases in HDD projected for the eight models with annual decreases of 31 HDD (HadGEM2-CC), 22 HDD (NorESM1-M), and 11 HDD (CNRM-CM5).

Streamflow projections for Ross Reservoir show a similar pattern for changes in seasonal inflows for all eight climate models used in the hydrologic modeling but vary in changes in total annual inflows as shown in Figure 1. For the 2011 to 2040 period, the median change in annual inflow at Ross Reservoir is a decrease of 2.5 percent with a range from an increase of 6.3 percent to a decrease of 7.6 percent. The three models selected for assessing effects on hydropower generation cover this range of changes in annual inflows: a 7.6 percent decrease (CNRM-CM5), a 2.3 percent decrease (HadGEM2-CC), and 6.3 percent increase (NorESM1-M). These models were the same as the three selected for the demand analysis.

Figure 1. Annual Change: Current vs 2011 - 2040



Climate Change Effects on Energy Demand

Demand Methods

To provide a demand forecast under conditions of "normal" weather, City Light's Load Forecast Model uses weather data from the SeaTac airport weather station to account for the effect of temperature on energy demand. When determining the IRP's load-resource balance, forecasted load in the IRP base case uses 30-year climate normals at SeaTac as defined by the National Oceanic and Atmospheric Administration (NOAA) for the period of 1981 to 2010. More specifically, and consistent with common practice in the industry, degree days are used to account for the nonlinear relationship between energy and temperature.

City Light's Load Forecast Model was executed to create three new and separate load scenarios with each iteration using the projected change in quarterly temperature data for each of the three climate scenarios, rather than the current normal used in determining the IRP base case. Table 1 shows the change from current (1981-2010) to projected future (2011-2040) HDD climate normals for each of the three climate models.

TABLE 1. Heating degree days at SeaTac weather station for current conditions (1981- 2010) and three climate change models for the period 2011-2040.

Quarter	Current normal	HadGEM2-CC	NorESM1-M	CNRM-CM5
	1899	1798	1848	1868
	869	770	806	832
	217	164	168	197
	1721	1600	1620	1674

Demand Results

The expected load forecast used in the 2016 IRP Base Load Model to assess the utility's expected load-resource balance assumed an average annual growth rate of roughly 0.41 percent for the 20-year period of the IRP. As expected, the inclusion of warmer temperature data from projected future climate scenarios did result in forecasted lower growth of system load. This was expected given that the utility's service area uses more energy in winter, in part, because of the relatively mild summers experienced in the service area. Thus, because the utility experiences greater load demand in winter (fairly consistent 28 percent of annual load over the past fifteen years) relative to any other season, the inclusion of warmer temperatures in forecasting 20-year demand did result in lower load growth for each of the three climate models used. Also as expected, the magnitude of change in load growth varied with each model's respective temperature projections. Of the three models, CNRM-CM5 with the mildest amount of warming resulted in a decrease of forecasted average annual load growth of about .01 percentage points when compared to the IRP Base Load Model. The model (NorESM1-M) with temperature projections closest to the 8-model ensemble resulted in load growth .03 percentage points lower than the IRP Base Load Model. The HadGEM2-CC model with the warmest projection resulted in load growth .04 percentage points lower than the IRP Base Load Model. This model resulted in a decrease of approximately 9 aMW in 2035, the final year of the IRP, when compared to the IRP Base Load Model. For context, 9 aMW is equal to roughly 0.8 percent of City Light's 2015 system load and 0.7 percent of 2035's forecasted load from the IRP Base Load Model.

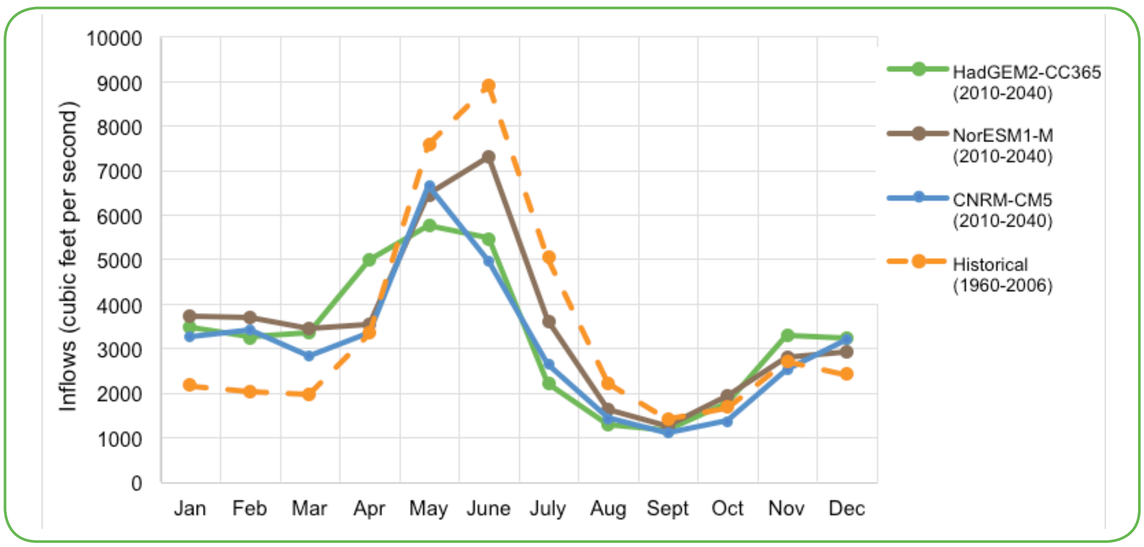
As mentioned previously, City Light has higher load in winter due to relatively mild summers. This differs from warmer regions of the nation where, due to abundant of air-conditioning use, electricity consumption is highest during summer months. Air-conditioning use is currently low in City Light's residential sector, at only about 5 percent according to the most recent Residential Building Stock Assessment[3]. Temperature projections indicate warming in all seasons, but it remains unknown if summers will warm sufficiently to cause an increase in air-conditioning use or a significant increase in summer energy consumption in City Light's service area. Currently, the 30-year normal for cooling degree days in Seattle is 190. For comparison, cooling degree days in cities in eastern Washington are three to five times greater (710 in Pasco, 850 in Wenatchee, and 950 in Kennewick). For the 2010 to 2040 period, cooling degree days in Seattle are projected to increase to about 325 (+/- 50). Studies suggest this warming could correspond to an increase in air-conditioning use to about 25 percent, which is roughly equivalent to the current residential air-conditioning use in San Francisco, CA and Buffalo, NY.[4]

Climate Change Effects on Hydropower Supply

Hydropower Supply Methods

City Light used the three climate model scenarios for inflows to estimate hydropower projections for the utility's total generation relative to the expected case based on historical inflows. All three models show a similar shift in the seasonal pattern of inflows toward greater inflows in December through March and lower inflows in May through September (Figure 2)[5] . This seasonal change is the result of more winter precipitation falling as rain, a decline in snowpack, and an earlier snowmelt and runoff period.

FIGURE 2. Mean Monthly Inflows to Ross Resevoir for Historical Conditions (1960-2006) and Three Climate Change Scenarios



Total generation for the analysis included generation from all hydropower projects owned by the utility, as well generation for the sections of the Columbia River system from which City Light purchases power through contracts with Bonneville Power Administration (BPA). For each of the three climate models, City Light applied changes for monthly inflows to estimate changes for monthly hydropower generation, assuming that current dam capacity and operating constraints for flood control, fish protection, and reservoir levels remain the same in the future as they are today. Therefore, future monthly changes in generation were constrained to the current operating conditions imposed by existing capacity, operating licenses, and the current biological opinion, so that generation could not increase or decrease below the lowest or highest value in the historical range.

Changes in inflows at Ross Reservoir were used to estimate changes in generation at the other dams, subject to the capacity and operating constraints of those dams, because of limited data in those locations. Although there are likely to be some variations by location, this method assumes that climate change affects water availability at the other locations in a similar way. This assumption is reasonable given that 99 percent of utility-owned hydropower generation and contract purchases are from snow-dominated systems in Washington for which seasonal water availability is expected to respond similarly to climate change. The River Management Joint Operating Committee (RMJOC, composed of BPA, Bureau of Reclamation, and Army Corps of Engineers) is collaborating with the University of Washington (UW) to project changes in streamflow and hydropower generation for the Columbia River system. The results of the RMJOC research are expected to be available in late 2016.

Generation for the climate change models were compared with the base case generation for the IRP "do nothing" portfolio. The "do nothing" portfolio assumes that the current BPA contracts are extended, but no new resources or contracts are added as others expire, therefore relying on wholesale market purchases to meet additional power supply needs.

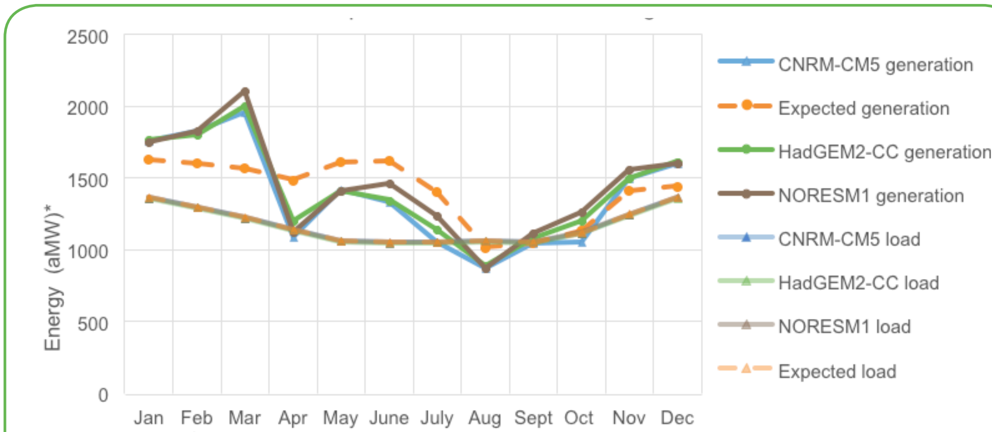
Hydropower Supply Results

Projected seasonal and annual changes in energy generation reflect the seasonal and annual changes in streamflow (Figure 3). All three climate change models show decreases in energy generation in April through August and increases in November through March. The largest decreases in generation are projected for April and the largest increases are projected for March as a result of the snowpack runoff shifting early in the year.

For the expected base case, average monthly generation exceeds average monthly load in all months except August and September. However, as noted above, total generation in Figure 3 does not include new programmatic energy efficiency, wholesale market purchases, or any new resources added after existing contracts expire (except BPA which remains in place). These resources are regularly used to fill gaps between supply and demand. For all three climate change scenarios, the deficit between average generation and demand increases in August, but the difference is within the range of what the utility has experienced in the past. Differences between supply and demand in other months vary depending on the model, but generally show less of a deficit in September and less of a surplus (or deficit for two models) in April.

Total annual generation increases (decreases) consistent with the models that show increases (decreases) in annual inflows, but the relationship is not one-to-one. The NORESM1 model, which shows a 6.3 percent increase in annual inflows, results in a 2.3 percent increase in annual generation. The CNRN-CM5 scenario, which shows a 7.6 percent decrease in annual inflows, shows a 2.6 percent decrease in generation. This suggests a "rule of thumb": for every 1 percent change in annual inflows, the system has about a 0.35 percent change in generation, assuming capacity and operating constraints for flood control, reservoir levels, and fisheries remain the same.

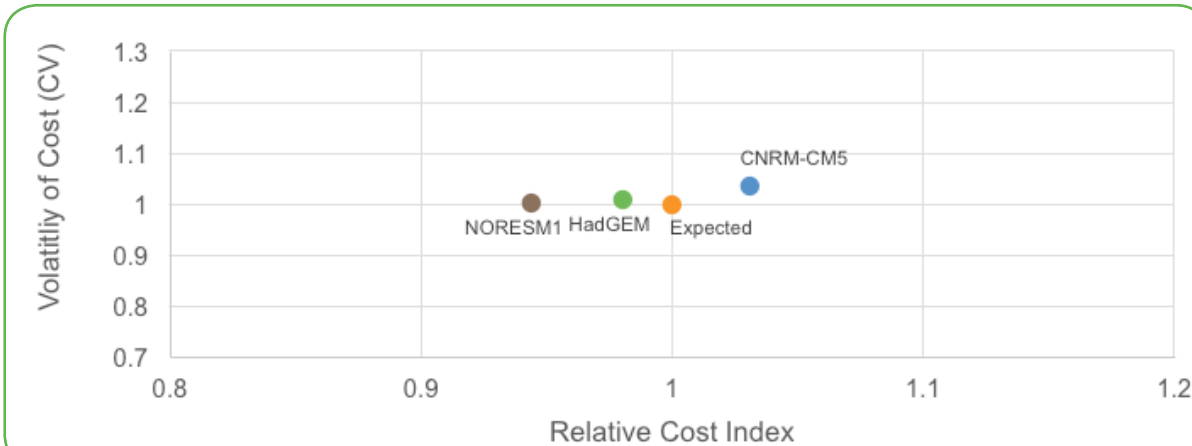
FIGURE 3. Energy Generation and Load (2016 - 2036): Expected Base Case Compared to Three Climate Change Scenarios



*Note: Energy excludes new programattic conservation, wholesale market purchases, and replacement contracts for resources other than BPA for the 20-year period.

City Light compared generation from the three climate change models with the expected base case generation in terms of relative cost and volatility of cost (Figure 4). All three models generally show little change in cost or volatility of cost. The CNRN-CM5 model (lower inflows) results in higher cost and relative to the expected condition, whereas the NORESM1 model (higher inflows) results in lower cost. The HadGEM-CC model, which had little change in annual inflow and is most similar to the eight climate model median, showed little change in cost or volatility.

FIGURE 4. Relative Cost and Volatility of Cost: Expected Base Case compared to Three Climate Change Models



Future Climate Change Research and Analysis

In addition to this assessment, City Light evaluated other risks associated with climate change through the development of a Climate Change *Vulnerability Assessment and Adaptation Plan*, available online at http://www.seattle.gov/light/enviro/climatechg.htm. This report assesses potential impacts to utility operations and infrastructure caused by sea level rise, warming temperatures, changes in extreme weather patterns, more frequent natural hazards, and changes in snowpack and streamflow. City Light will continue to evaluate climate change effects on demand and supply, as well as other potential impacts through the utility's climate change research program. Future research on demand may include potential changes in air-conditioning use associated with warming and the indirect effect that population growth and climate migration could have on residential air-conditioning use. City Light will continue to collaborate with UW and the RMJOC to evaluate potential effects of climate change on water availability and hydropower generation for the Columbia River system. The results of the RMJOC study will increase City Light's understanding of potential changes in generation and operations of the Boundary Project and Columbia River dams from which City Light receives power. City Light's assessment of climate change effects on supply and demand will be updated as necessary based on the results of the forthcoming RMJOC climate change research project and other new research on climate change effects in the region.

[1]MACA Climate Downscaling. Prepared by Katherine Hegewisch & John Abatzoglou Department of Geography, University of Idaho Pacific Northwest Climate Impacts Research Consortium for Ron Tressler, Crystal Raymond, and Seattle City Light research team.

[2] Hydrologic Impacts of Climate Change in the Skagit River Basin. Prepared by Christina Bandaragoda, Chris Frans, Erkan Istanbulluoglu Crystal Raymond and Larry Wasserman. Final report prepared for: Skagit Climate Science Consortium, Mt Vernon, WA and Seattle City Light, Seattle, WA 12/31/2015

[3] Seattle City Light Residential Building Stock Assessment: single-family characteristics and energy use. Prepared by Ecotope Inc. 2014.

[4] Sailor, D.J. and A.A. Pavlova. 2003. Air conditioning market saturation and long-term response of residential cooling energy demand to climate change. Energy 28: 941-951.

[5] Hydrologic Impacts of Climate Change in the Skagit River Basin. Prepared by Christina Bandaragoda, Chris Frans, Erkan Istanbulluoglu, Crystal Raymond and Larry Wasserman Final report prepared for: Skagit Climate Science Consortium, Mt Vernon, WA and Seattle City Light, Seattle, WA 12/31/2015.