Comparison of GHG Emissions Between CAISO 2017 and RESOLVE 2018

August 10, 2018

Introduction

- 2018 GHG emissions (a RESOLVE model output) for the CAISO footprint in the IRP Reference System Plan are lower than 2017 GHG emissions reported by CAISO
  - CAISO 2017: 52.9 MMTCO$_2$
  - RESOLVE 2018: 41.3 MMTCO$_2$
- Stakeholders have asked for a benchmarking analysis of RESOLVE 2018 results as compared to actual 2017 emissions reported by CAISO to understand key drivers of the differences
- Goals of the comparison:
  - Explain sources and magnitude of emissions discrepancy
  - Suggest possible improvements to RESOLVE modeling
- This analysis focuses on high-level conclusions – additional detail would be required to increase precision

Production Simulation vs. Actual Dispatch

- CAISO day-to-day operations include a full nodal unit commitment and dispatch algorithm. Dispatch decisions are made every five minutes on a plant-by-plant basis.
- Production simulations differ from reality in many ways:
  - Market participant behavior – bids not always priced at opportunity cost
  - Self scheduling
  - Perfect foresight
  - Generator and transmission outages
  - Contingencies
  - Weather-driven heat rate differences and de-rate factors
  - Weather-driven demand, hydro, and variable resource production
- Output from any production simulation model will differ from actual dispatch in many ways, even if the loads are identical

RESOLVE vs. Other Production Simulation Models

- The RESOLVE model focuses on long-run capacity investment decisions
- To internalize the economics of unit commitment and dispatch within the investment framework, RESOLVE includes a simplified production simulation:
  - Dispatch is simplified to aggregated plant types
  - Unit commitment constraints are partially linearized
  - 37 representative days per year are simulated (as opposed to 365)
  - Dispatch decisions are made on an hourly level, with some representation of sub-hourly flexibility needs via reserve constraints
  - Transmission constraints within CAISO are not included
- RESOLVE is formulated to capture the major drivers of GHG emissions
  - One major benefit of this benchmarking analysis is to improve the RESOLVE formulation

Comparison Methodology

- GHG emissions and generation from technology classes are aggregated for:
  - CAISO 2017 historical ("CAISO 2017")
  - RESOLVE Reference System Plan in 2018 ("RESOLVE 2018")
- CAISO 2017 data was provided by CAISO
- E3 performed additional analysis on CAISO 2017 natural gas generation to break out emissions and generation by technology (CCGT, peaker, and CHP)
  - Additional data used: monthly generation data and generator heat rate curves
- Differences in emissions rate (tCO_2/MWh) and annual generation (MWh) quantified
- Attribution of emission and generation differences between datasets is not precise and requires assumption of a counterfactual
  - Some differences may have multiple contributing factors

Technology Classes:

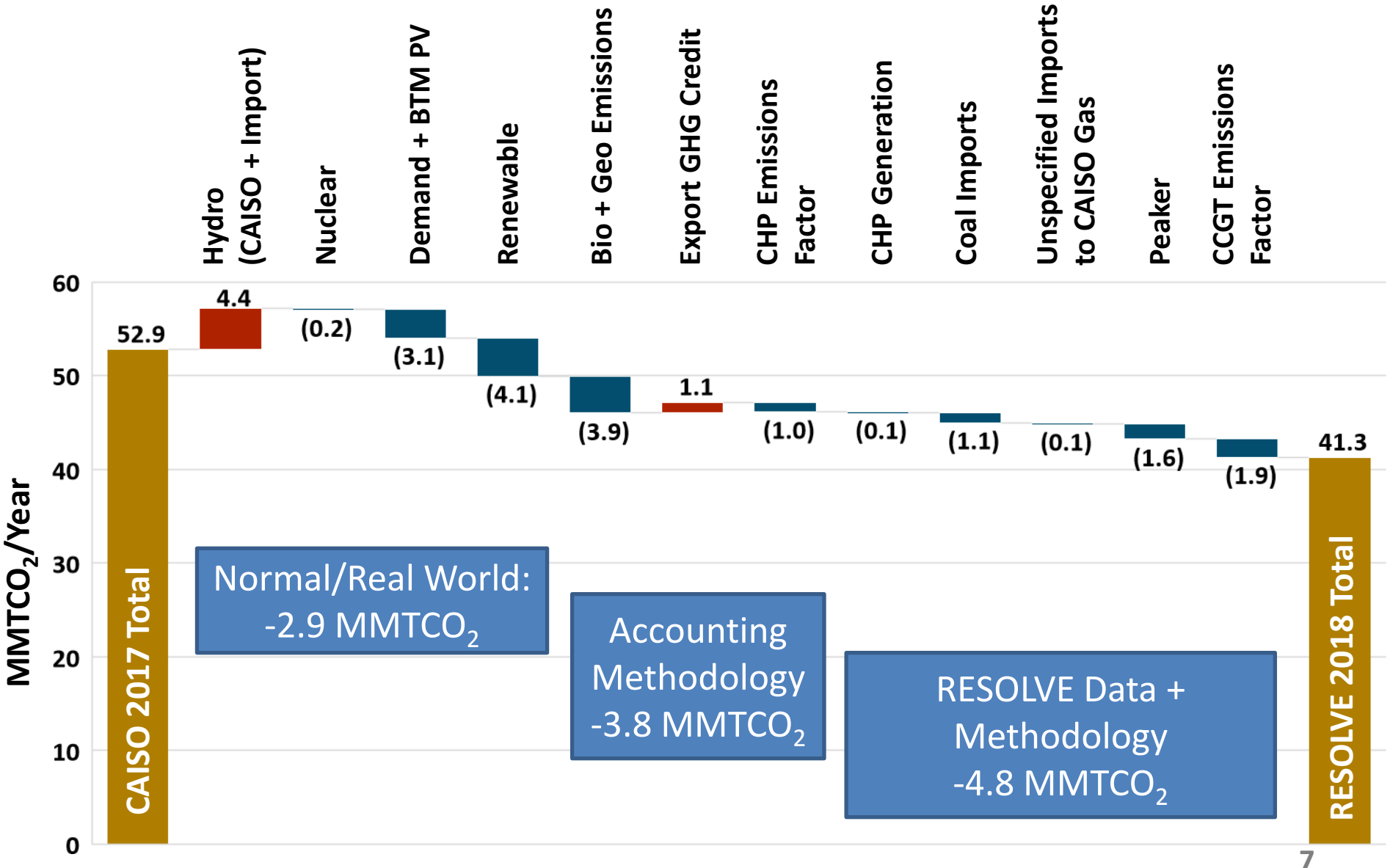
- Renewables
- Nuclear
- Hydro (in CAISO)
- Hydro (imports)
- Coal imports
- Unspecified imports
- Exports
- CCGT
- Peaker (gas turbines, steam turbines, reciprocating engines)
- Combined Heat and Power (CHP)

Categories of Differences

Differences between CAISO 2017 and RESOLVE 2018 are placed into three categories to aid in formulating next steps:

1. **Real World** – differences in weather, load, renewable & hydro production, etc.
2. **GHG Accounting Methodology**– accounting convention applied in CAISO reporting that differs from RESOLVE accounting, which mirrors CARB cap-and-trade accounting
3. **RESOLVE Data + Methodology** – issues in the RESOLVE simulation methodology and data inputs that are potential candidates for improvement

Emissions Comparison Waterfall



Note: Methodology used to quantify emissions differences is directional but not precise.

Waterfall Calculation Example: Difference in Renewable Generation

1. **Identify difference in datasets**

RESOLVE 2018 has ~10 TWh more renewable generation than CAISO 2017

2. **Identify counterfactual**

Counterfactual: renewables displace CAISO dispatchable gas (CCGT + peaker)

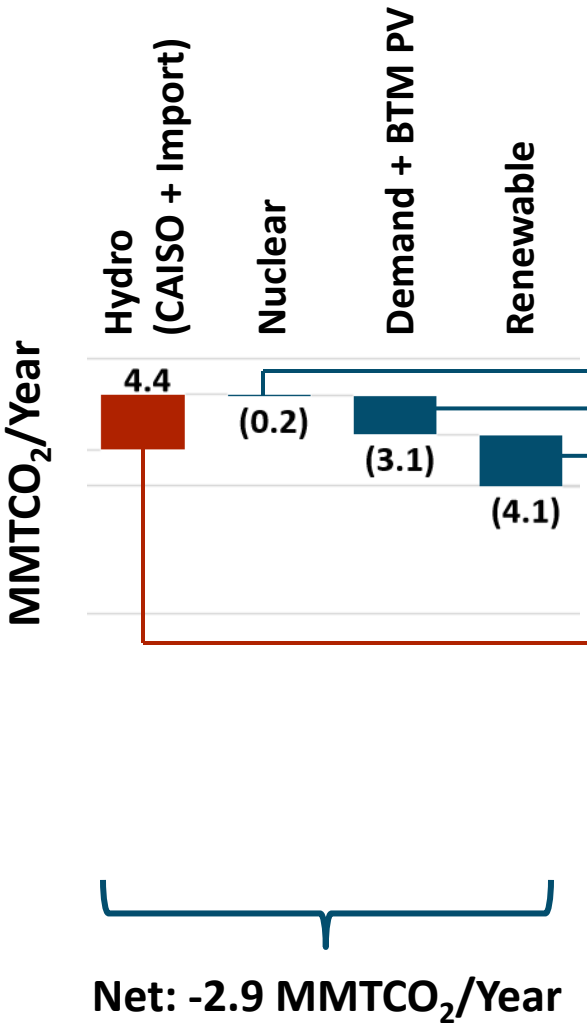
Result: dispatchable gas generation increased by ~10 TWh

3. **Calculate difference in emissions**

Calculation:
Δ TWh
*** dispatchable gas tCO_2/MWh**

Result: ~10 TWh
*** ~0.4 tCO_2/MWh**
= 4.1 $MMTCO_2$

Normal Deviations of Real World from Modeled Assumptions: -2.9 MMT



RESOLVE 2018 includes slightly more **nuclear** generation than CAISO 2017.

Assumed **demand** in RESOLVE 2018 was lower than actual demand in 2017. Growth in behind the meter PV between 2017 and 2018 could account for a portion of the difference.

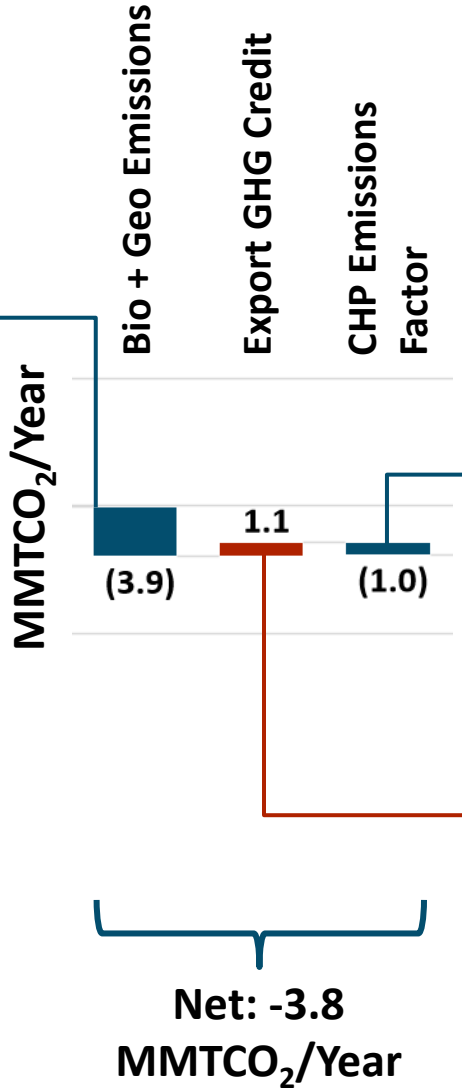
- **Renewables** were brought online throughout 2017.
- Additional wind was added by RESOLVE in 2018.
- Potential differences in renewable capacity factor and specified renewable imports.

Assumed **hydro** in RESOLVE 2018 was lower than actual hydro in 2017 due to higher than average hydro conditions in 2017.

Deviations Due to Accounting Methodology: -3.8 MMT

Biomass, biogas, and geothermal emissions are included in CAISO's emissions inventory. CARB requires reporting of bio + geo emissions, but emissions are exempt from the cap and trade program.

Reflecting cap and trade compliance obligations, RESOLVE does not include emissions from bio + geo.



CAISO emissions rates for **CHP** appear to be higher than RESOLVE (~0.5 vs. 0.4 tCO_2/MWh respectively), suggesting that there may be a difference in accounting for emissions from the heat and electric portions of CHP.

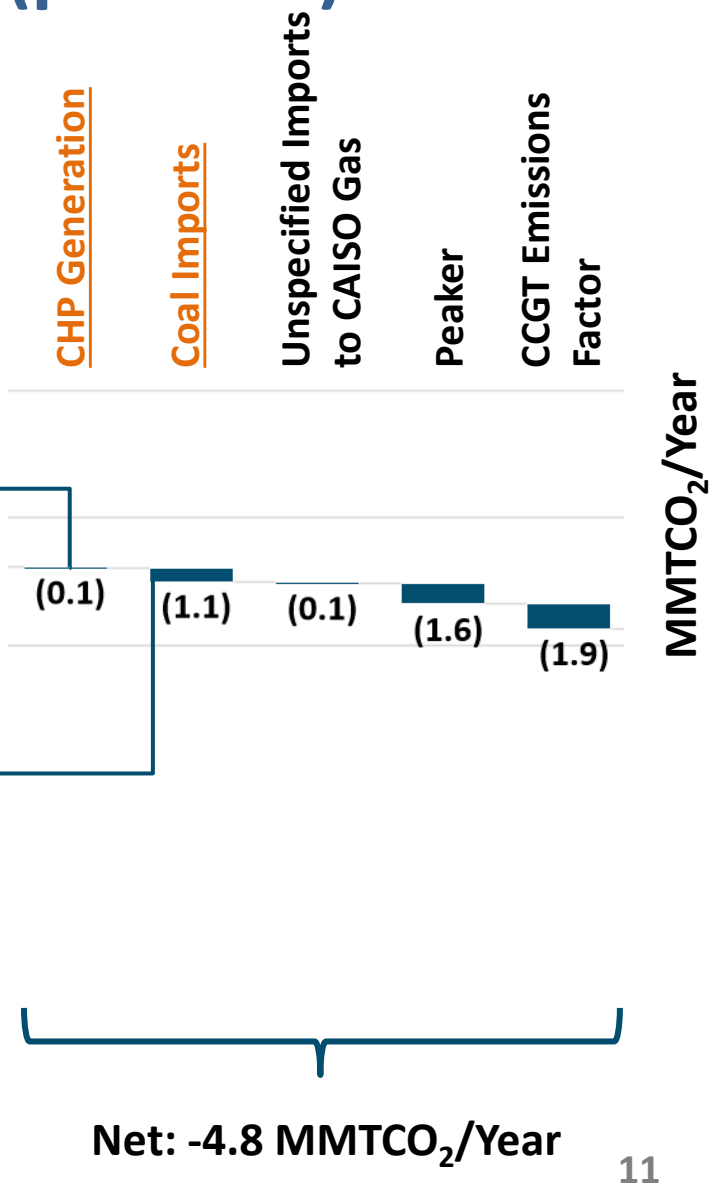
CAISO gives credit for GHG emission reductions from **exports** at the unspecified import rate.
RESOLVE does not give credit for exports.

Deviations Meriting Investigation for RESOLVE: -4.8 MMT (p. 1 of 2)

Data Inputs

RESOLVE includes ~50% more **CHP** generation than was observed in 2017. Dispatchable gas and CHP emissions factors are similar, leading to a small (0.1 MMT) difference in emissions.

RESOLVE does not include specified **coal imports** into CAISO, but some specified coal imports may remain in the near-term.



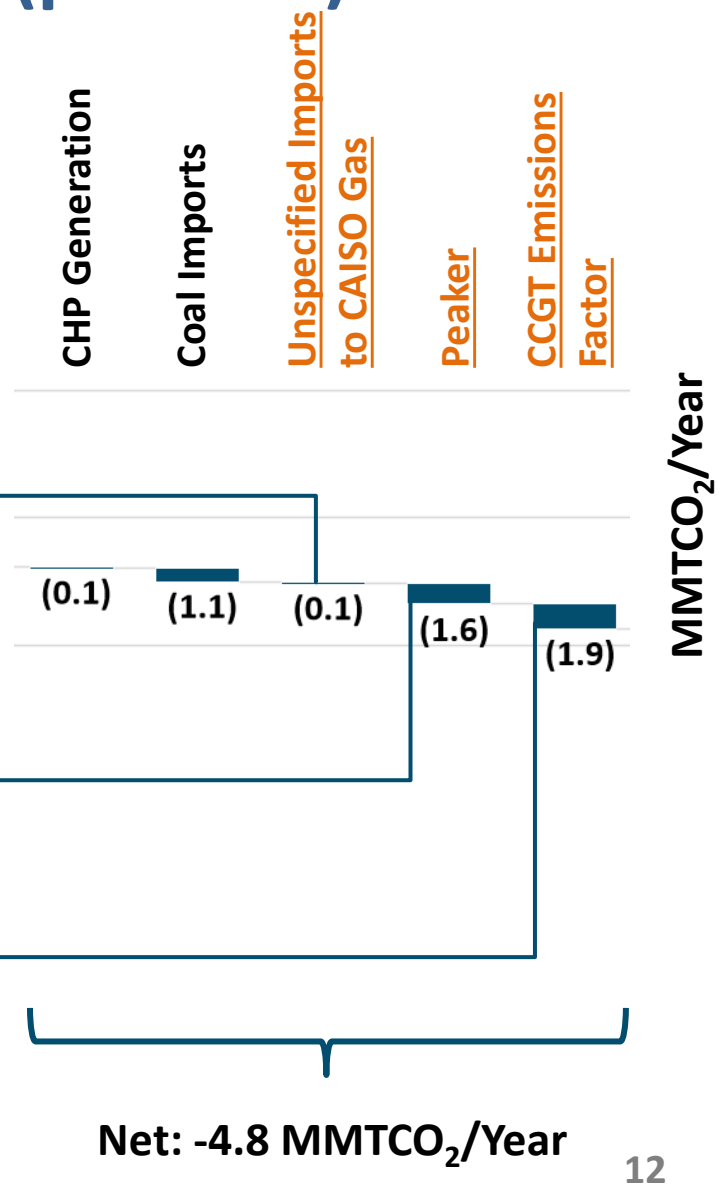
Deviations Meriting Investigation for RESOLVE: -4.8 MMT (p. 2 of 2)

Methodology

CAISO 2017 includes almost double the level of **unspecified imports** relative to RESOLVE 2018. RESOLVE 2018 includes more in-CAISO gas generation, predominantly CCGT generation. Dispatchable gas and unspecified import emissions factors are similar, leading to a small (0.1 MMT) difference in emissions.

Peakers were dispatched much more frequently in 2017 than were dispatched in RESOLVE in 2018

RESOLVE dispatches **CCGTs** with a slightly lower average emissions rate.
*Methodology used to quantify emissions rate differences is directional but not precise.



Potential Directions for RESOLVE Improvement

- Include fuel consumption when starting CCGTs and peakers, potentially resulting in dispatch patterns that are more consistent with CAISO operations
  - RESOLVE currently includes start costs for CCGTs and peakers, but does not include start fuel
- Impose additional operational constraints on resources providing reserves, potentially resulting in increased peaker utilization due to more stringent operational constraints
  - Restrict range for pumped hydro reserves to reflect forbidden operational range
  - Restrict reserves from (non-pumped) hydro resources based on historical data
- Add specified coal imports (only in near-term)
- Model part of the CHP fleet as dispatchable and update installed capacity
- Update demand forecast
- Compare historical and modeled renewable capacity factors

Questions for Stakeholders

- Which of the identified potential methodological improvements in RESOLVE should staff pursue in the upcoming IRP 2019-20 cycle?
  - Include fuel consumption when starting CCGTs and peakers
  - Impose additional operational constraints on resources providing reserves, potentially resulting in increased peaker utilization
  - Add specified coal imports in near-term
  - Model part of the CHP fleet as dispatchable and update installed capacity
  - Compare historical and modeled renewable capacity factors
- Are there any other steps IRP staff should take, working together with the CAISO, to help close the gap in GHG emissions accounting between RESOLVE modeling and CAISO reporting?