Modeling Integrated Electricity and Natural Gas Systems Using Co-Simulation

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United States Association for Energy Economics
Session on Coordinated Modeling of Electricity and Gas Infrastructure
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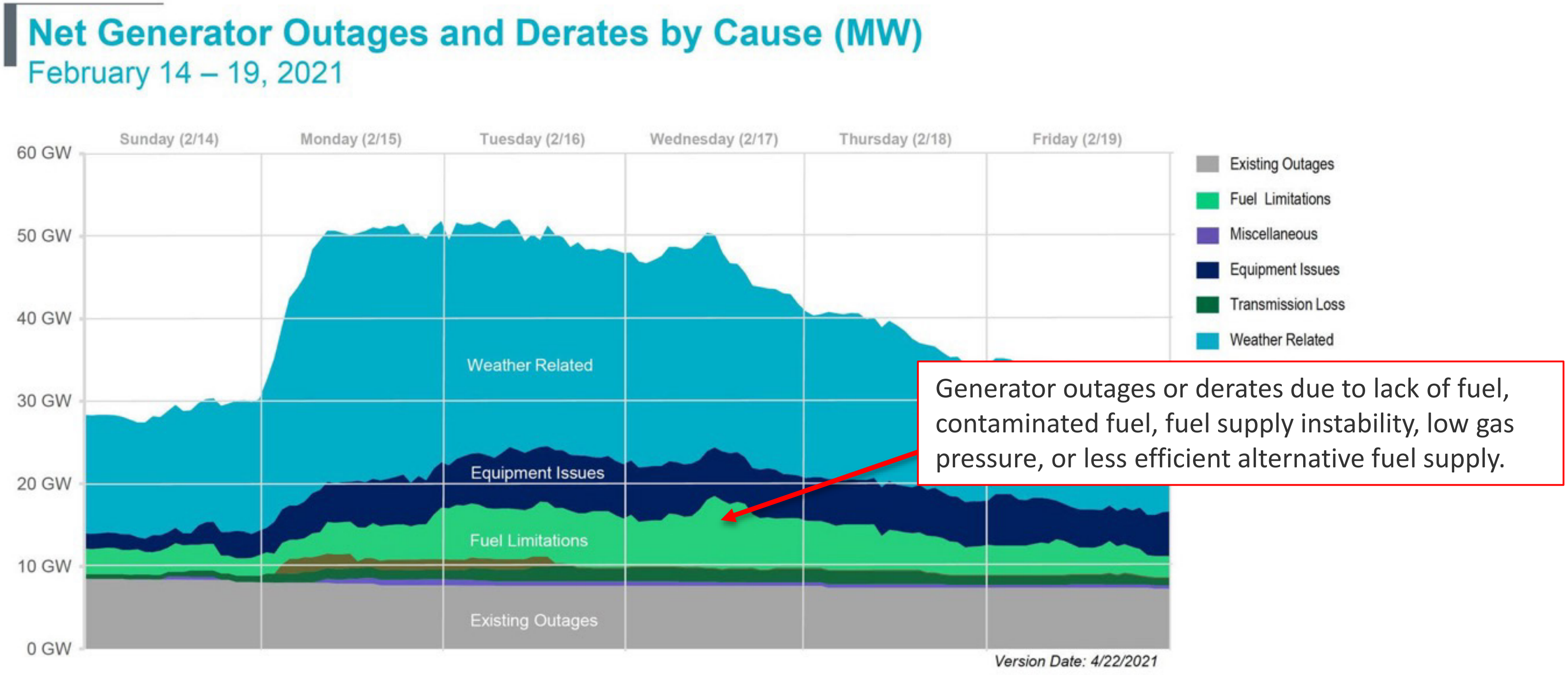
Photo from iStock-627281636

Winter Storm Uri



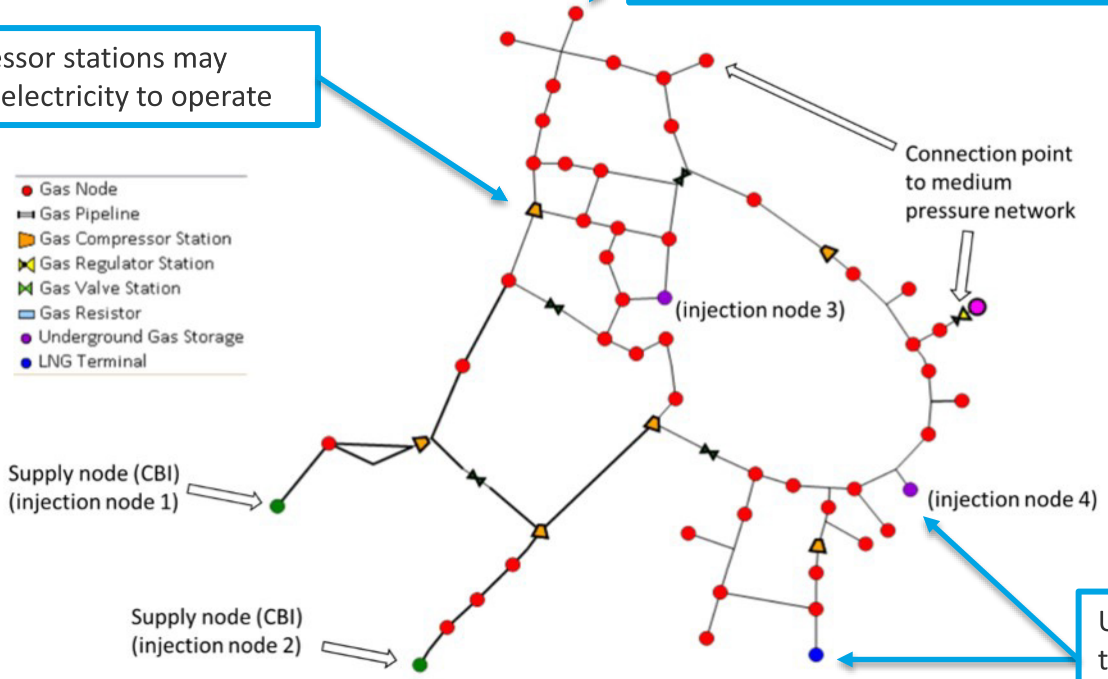
Net generator outages at the beginning of each hour on February 14-19, 2021, by cause category.

Source: ERCOT, "February 2021 Extreme Cold Weather Event: Preliminary Report on Causes of Generator Outages and Derates"
http://www.ercot.com/content/wcm/lists/226521/51878_ERCOT_Letter_re_Preliminary_Report_on_Outage_Causes.pdf

Coupling points of gas and grid systems

Gas fired power plants require natural gas delivered at sufficient pressure

Compressor stations may require electricity to operate

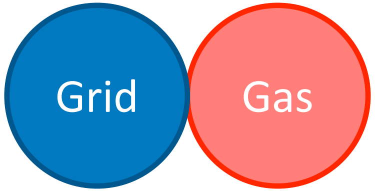


Electric systems can adapt in real-time, but gas network response time depends on topology and conditions

Underground storage or LNG terminals may require electricity to inject gas into the pipeline network

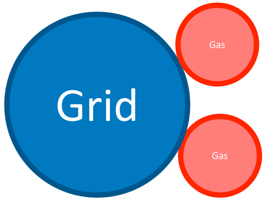
How do we capture these coupling points in modeling?

Integrated Model



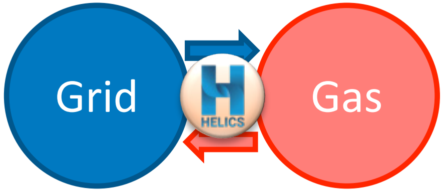
+ Preserve modeling details
- May be computationally intractable
- Often requires building (and supporting) new modeling capability

Simplified Model



+ Can potentially fit with existing tools
+ Easier to solve
- Loss of some modeling details

Co-simulation



+ Preserve modeling details
+ Utilize existing tools
+ Scalable into sub problems

Co-simulation can offer a means of capturing system interactions without the need to develop “one model to rule them all”

Hierarchical Engine for Large-scale Infrastructure Co-Simulation (HELICS)

HELICS is a flexible, open-source platform for modeling the co-simulation of cyber-physical-energy systems.

- Scalable from 2 simulators on laptop to 100k+ on high performance computing environments
- Supports Python, C, C++, C#, Java, Julia, MATLAB, FMI, etc.
- Cross-platform: Linux, Windows, OSX

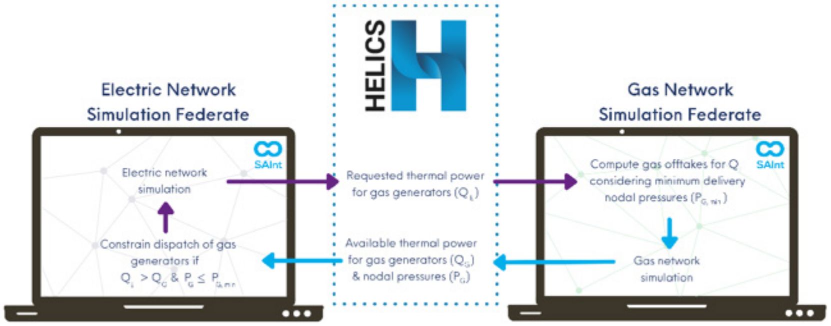
Information, demos, and docs at https://www.helics.org/

As part of DOE'S HELICS+ project, NREL is working with SAInt and other national lab and industry partners to advance co-simulation of gas and grid systems

Do we know co-simulation works?

Co-simulation validation

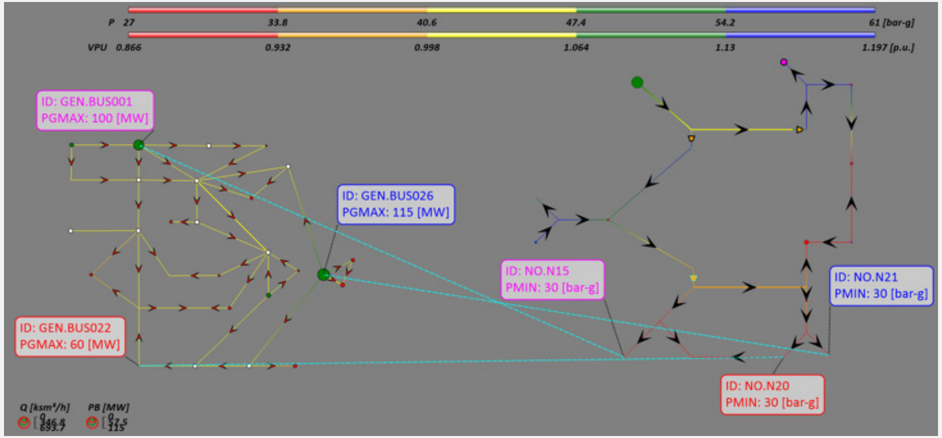
- NREL partnered with Encoord Inc., whose modeling tool SAInt allows for integrated gas-grid modeling
- We compare modeling results from SAInt with results from SAInt's grid and gas modules run separately and connected via co-simulation

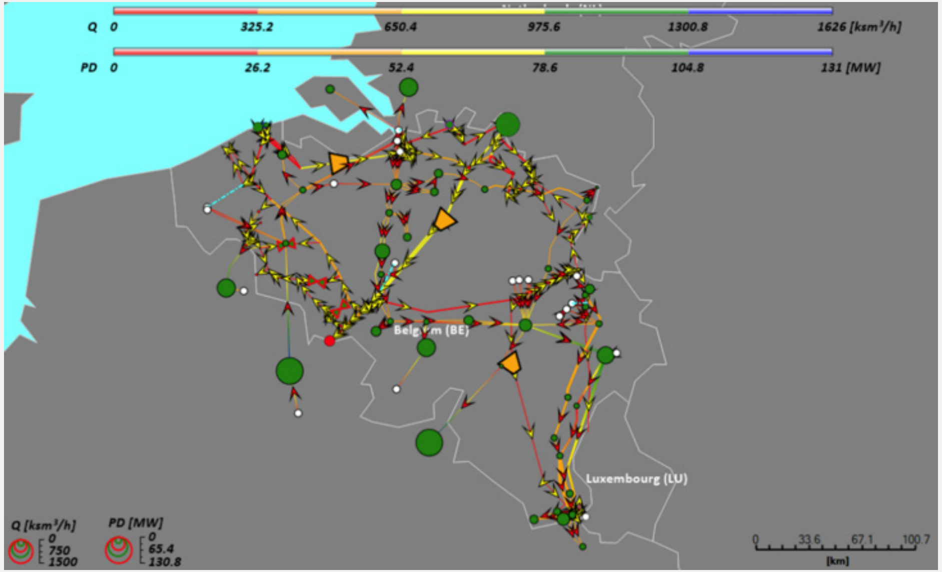


Source: Encoord Inc., "Case Study: HELICS+ Natural Gas and Grid Validation and Optimization"

Co-simulation tests

- 3 networks (2 test cases, 1 model the Belgian gas/power system)
- Each network tested under normal operating conditions and a stress-case with a compressor outage
- Each case has “coupled” nodes with gas generators that have min delivery pressures

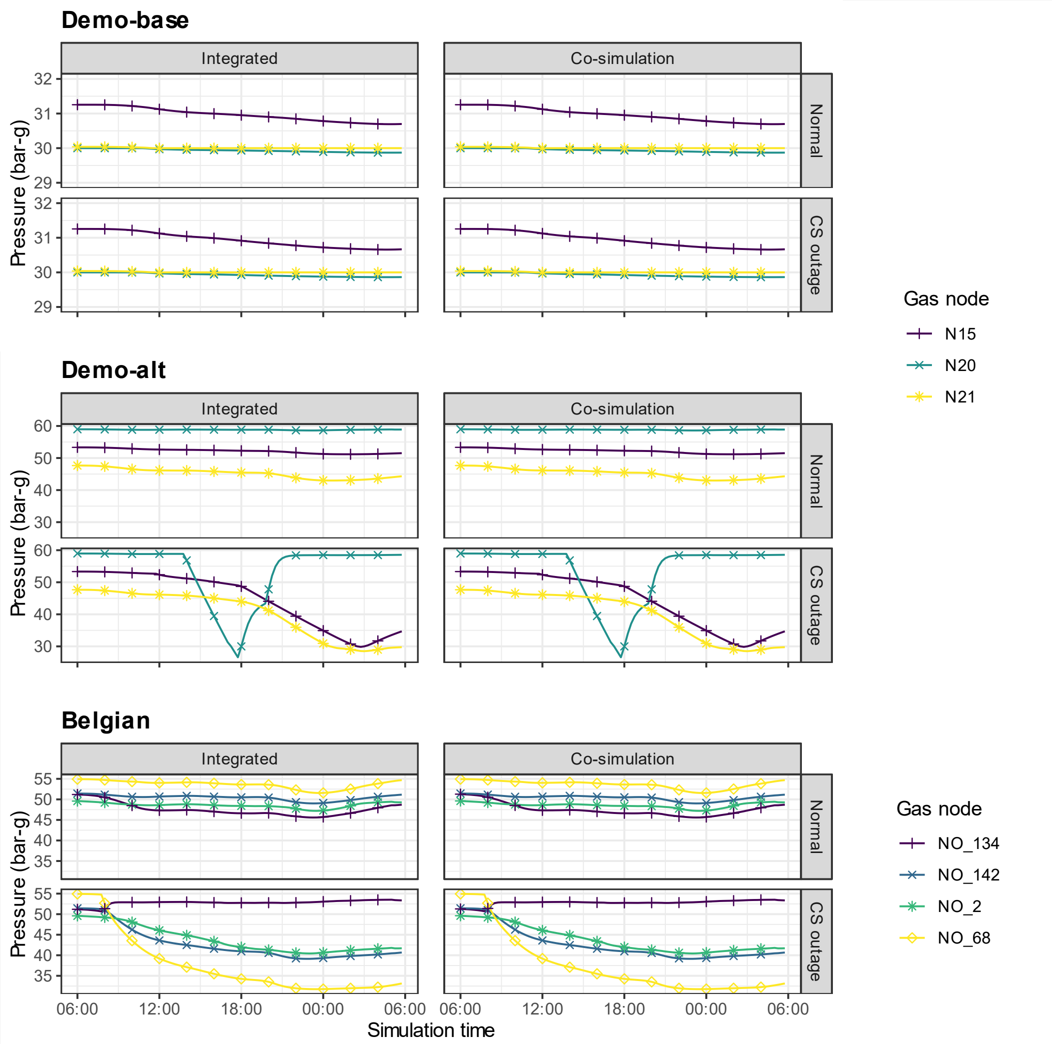




Source: Sergi and Pambour, 2022

Co-simulation validation:
gas pressure

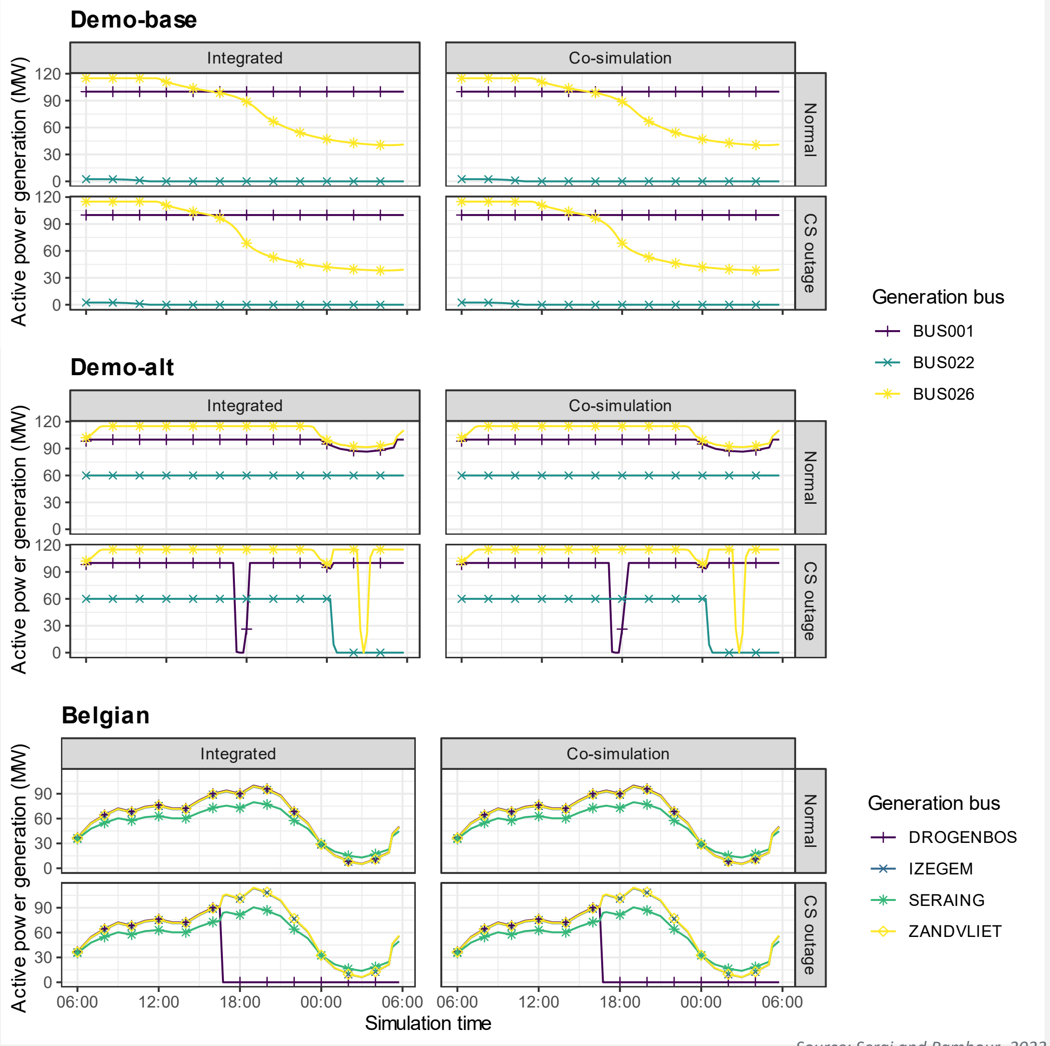
- No differences in pressures between the two modeling approaches
- Co-simulation captures the pressure drop that occurs when a compressor goes down



Source: Sergi and Pambour, 2022

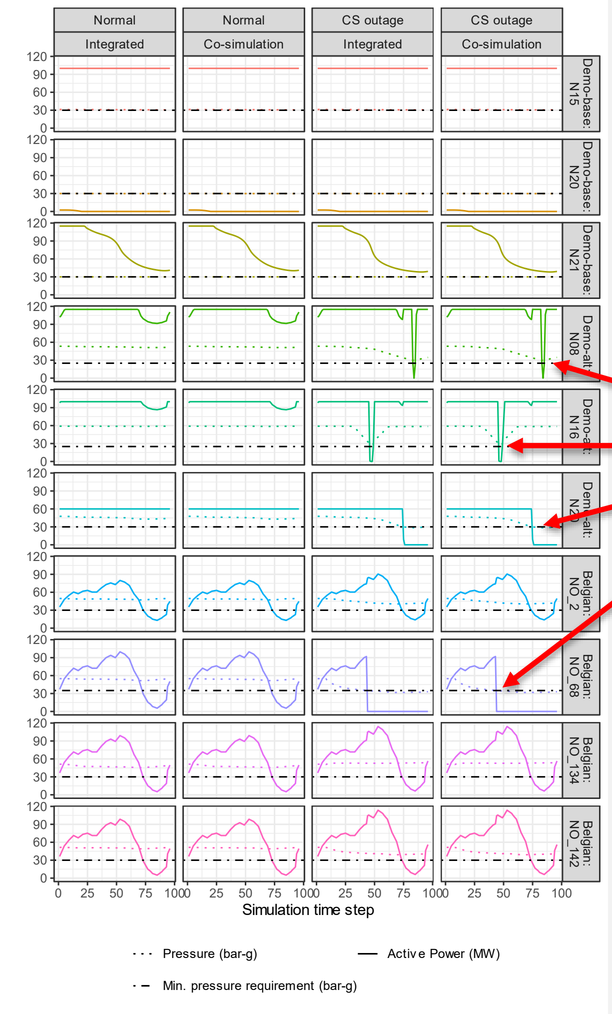
Co-simulation validation: power generation

- No differences in power generation
- Both approaches capture turning down generator in response to compressor station outage



Source: Sergi and Pambour, 2022

Co-simulation validation:
power generation

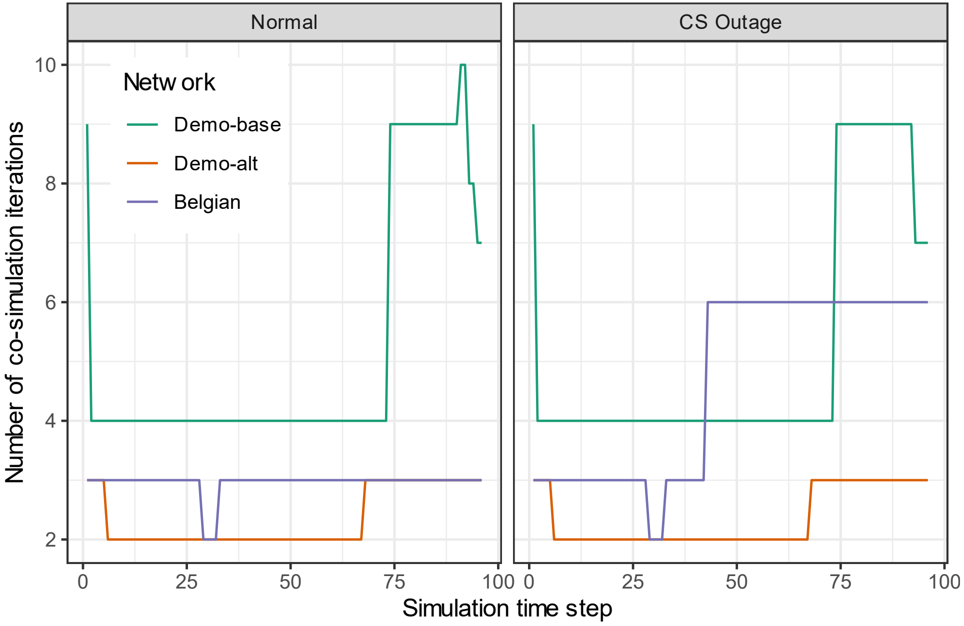


Pressure falls below min delivery pressure in gas model, results in generator turning off in the power model

Source: Sergi and Pambour, 2022

Co-simulation convergence

- Simulators converge relatively quickly
- Thus far we have only been modeling coupling in one direction (gas generator offtakes)
- Adding bi-directional coupling (e.g., electric drive compressors) would likely increase iterations

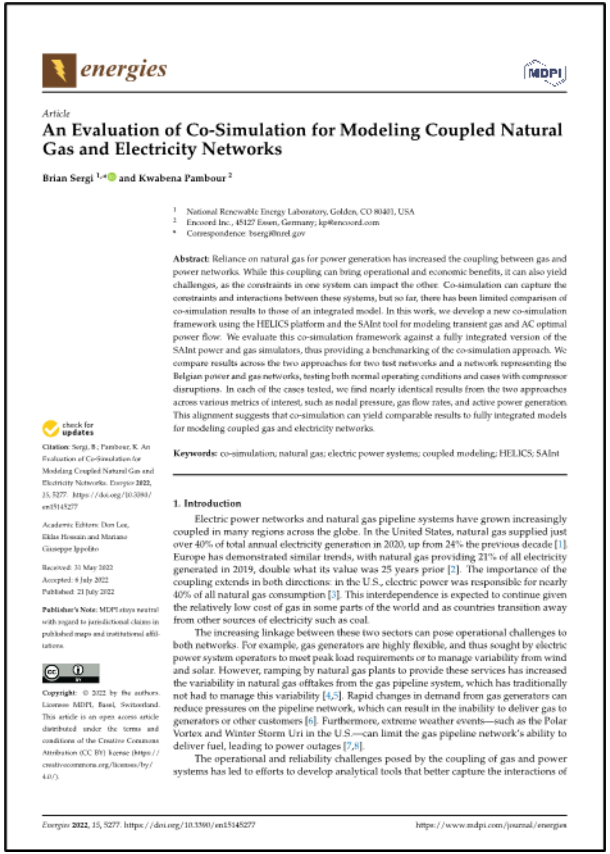


Source: Sergi and Pambour, 2022

Resources on co-simulation validation

Journal article published in *Energies* (Sergi and Pambour 2022): https://www.mdpi.com/1996-1073/15/14/5277

Encoord case study website: https://www.encoord.com/resources/case-studies/helics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Article

An Evaluation of Co-Simulation for Modeling Coupled Natural Gas and Electricity Networks

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Abstract: Reliance on natural gas for power generation has increased the coupling between gas and power networks. While this coupling can bring operational and economic benefits, it can also yield challenges, as the constraints in one system can impact the other. Co-simulation can capture the constraints and interactions between these systems, but so far, there has been limited comparison of co-simulation results to those of an integrated model. In this work, we develop a new co-simulation framework using the HELICS platform and the SAInt tool for modeling transient gas and AC optimal power flow. We evaluate this co-simulation framework against a fully integrated version of the SAInt power and gas simulators, thus providing a benchmarking of the co-simulation approach. We compare results across the two approaches for two test networks and a network representing the Belgian power and gas networks, testing both normal operating conditions and cases with compressor disruptions. In each of the cases tested, we find nearly identical results from the two approaches across various metrics of interest, such as nodal pressure, gas flow rates, and active power generation. This alignment suggests that co-simulation can yield comparable results to fully integrated models for modeling coupled gas and electricity networks.

Keywords: co-simulation; natural gas; electric power systems; coupled modeling; HELICS; SAInt

check for updates

Citation: Sergi, B.; Pambour, K. An Evaluation of Co-Simulation for Modeling Coupled Natural Gas and Electricity Networks. *Energies* **2022**, 15, 5277. https://doi.org/10.3390/en15145277

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1. Introduction

Electric power networks and natural gas pipeline systems have grown increasingly coupled in many regions across the globe. In the United States, natural gas supplied just over 40% of total annual electricity generation in 2020, up from 24% the previous decade [1]. Europe has demonstrated similar trends, with natural gas providing 21% of all electricity generated in 2019, double what its value was 25 years prior [2]. The importance of the coupling extends in both directions: in the U.S., electric power was responsible for nearly 40% of all natural gas consumption [3]. This interdependence is expected to continue given the relatively low cost of gas in some parts of the world and as countries transition away from other sources of electricity such as coal.

The increasing linkage between these two sectors can pose operational challenges to both networks. For example, gas generators are highly flexible, and thus sought by electric power system operators to meet peak load requirements or to manage variability from wind and solar. However, ramping by natural gas plants to provide these services has increased the variability in natural gas offtakes from the gas pipeline system, which has traditionally not had to manage this variability [4,5]. Rapid changes in demand from gas generators can reduce pressures on the pipeline network, which can result in the inability to deliver gas to generators or other customers [6]. Furthermore, extreme weather events—such as the Polar Vortex and Winter Storm Uri in the U.S.—can limit the gas pipeline network's ability to deliver fuel, leading to power outages [7,8].

The operational and reliability challenges posed by the coupling of gas and power systems has led to efforts to develop analytical tools that better capture the interactions of

Energies **2022**, 15, 5277. https://doi.org/10.3390/en15145277 https://www.mdpi.com/journal/energies

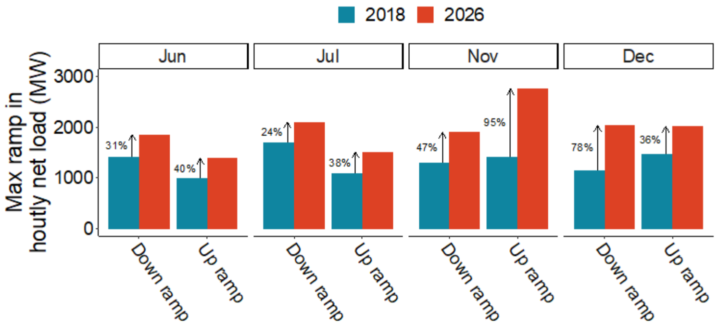
What types of problems can we study with co-simulation?

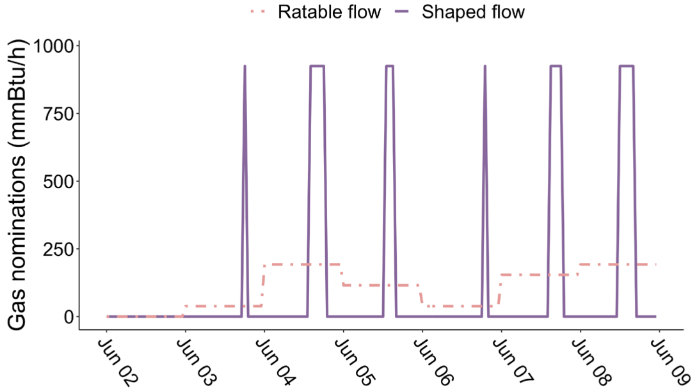
Co-simulation research questions

How does coordination between gas and electric sectors in forward markets (day-ahead, intra-day) help reduce constraints?

Does the importance of coordination change as systems incorporate more renewable energy sources?

How does the timing of natural gas requests from gas generator affect operations?





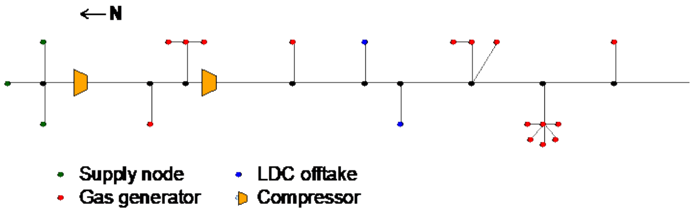
Source: Guerra et al., 2020

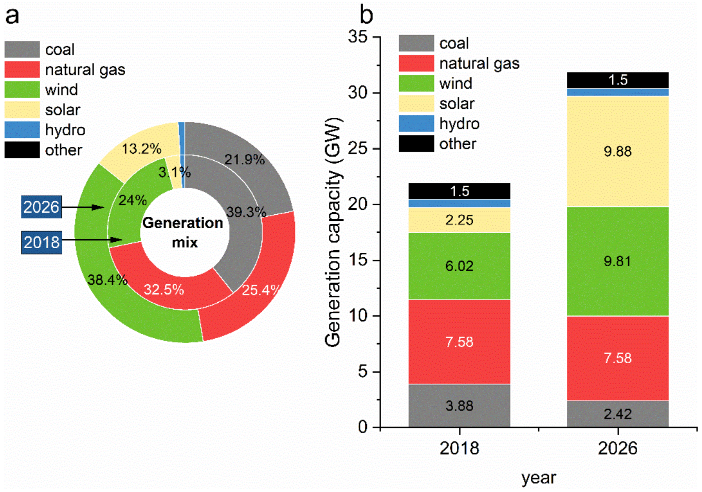
A case of study in Colorado

We explore these questions on a subset of the Colorado gas and power networks

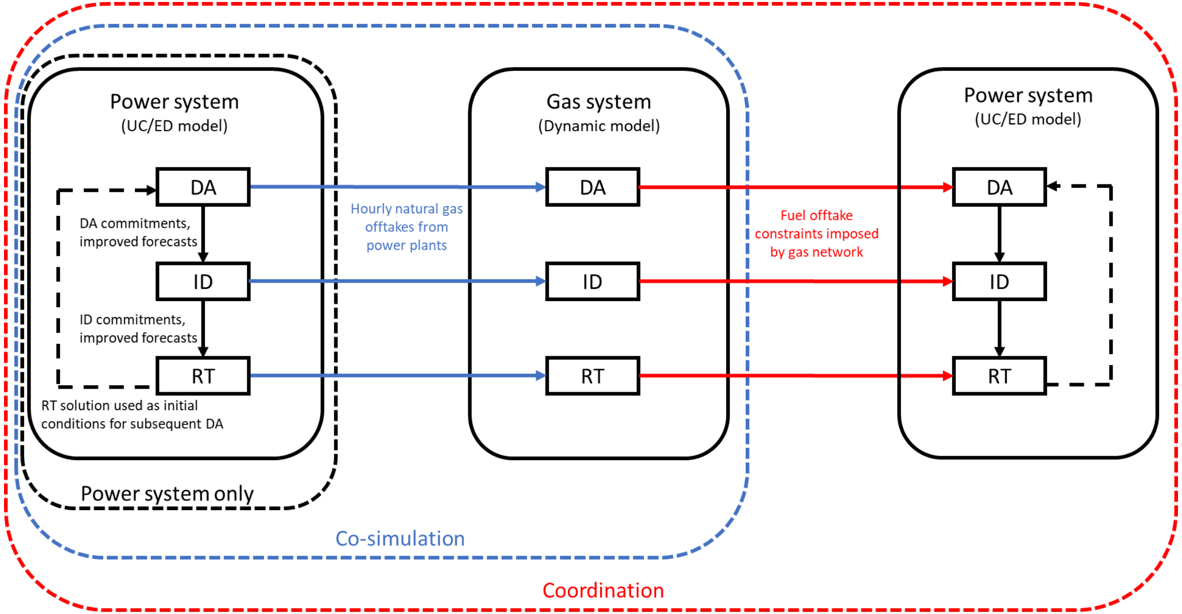
- Gas network data provided by Kinder Morgan, includes topology, non-power sector uses, and offtake pressure constraints
- Power system data based on networks develop in previous NREL work, with a high wind/solar cased based on projections from Western Resource Advocates (Overturf and Fansworth, 2020)

System modeled for four weeks in each season





Source: Guerra et al., 2020



Gas/grid co-simulation employed at multiple market levels (day-ahead, intra-day, and real-time)

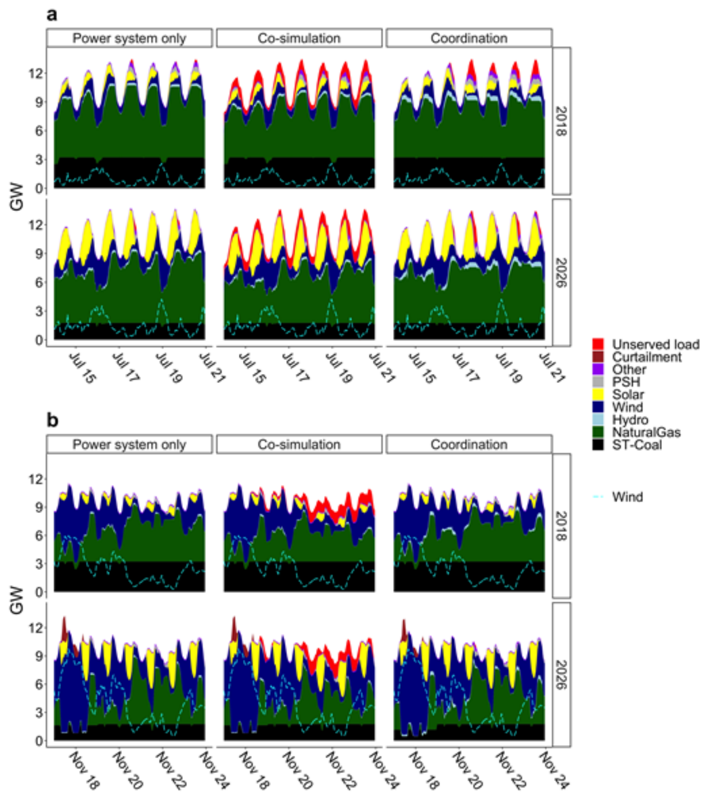
Source: Guerra et al., 2020

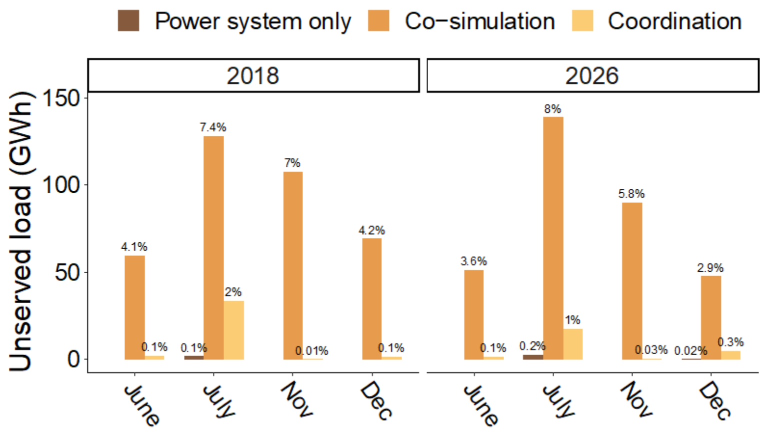
Power system only: results from the first iteration of the power system model, before any communication with the gas network.

Co-simulation: results after simulating gas offtakes from the power system model in the gas network; reflects curtailed gas but has not yet reoptimized the power system in response to gas constraints.

Coordination: results after re-optimizing the power system with constraints from the gas simulation.

Coordination helps reduce unmet gas demand





Coordination avoids dropped load or potentially costly operator intervention

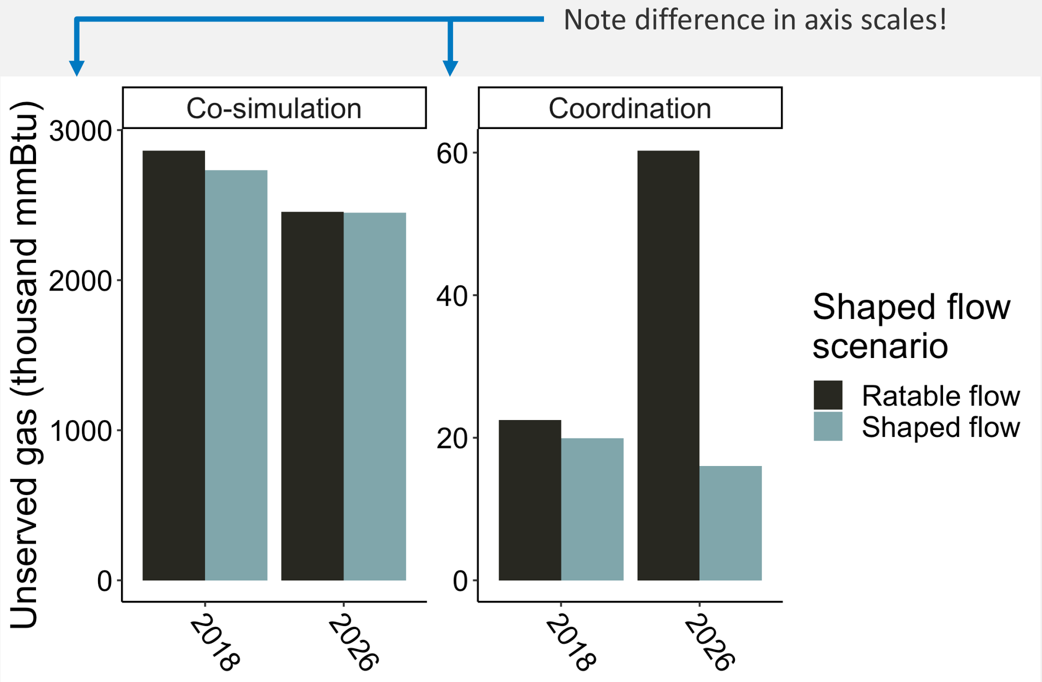
Reasons for dropped load are different seasonally:

- **Summer**: High gas demand from generators, system is maxed out
- **Winter**: High gas demand from other consumers + high wind variability, system takes time to respond

Source: Guerra et al., 2020

Co-simulation → coordination dramatically reduces the amount of gas that is requested but not delivered

After coordination, moving to “shaped” hourly flows reduces unmet gas



Source: Guerra et al., 2020

Links to studies

Journal article published in *Journal of Cleaner Production* (Guerra et al., 2020): https://www.sciencedirect.com/science/article/pii/S0959652620348034

More detailed NREL report: https://www.nrel.gov/docs/fy20osti/77096.pdf

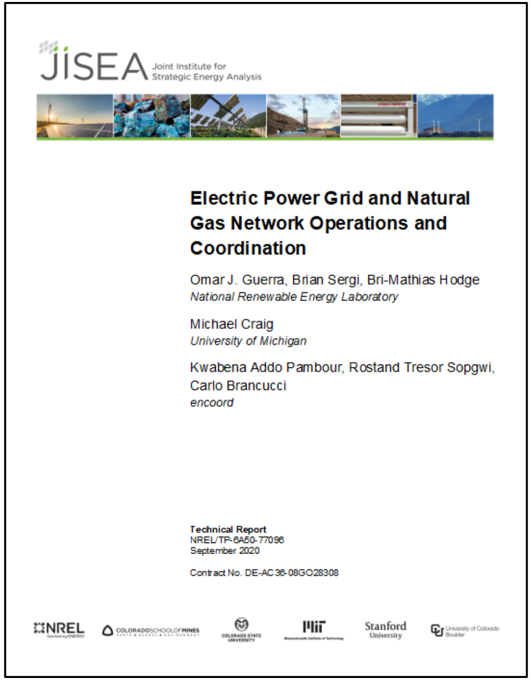

Journal of Cleaner Production

Coordinated operation of electricity and natural gas systems from day-ahead to real-time markets

Omar J. Guerra, Brian Sergi, Michael Craig, Kwabena Addo Pambour, Carlo Brancucci, Bri-Mathias Hodge

ARTICLE INFO

ABSTRACT


JISEA Joint Institute for Strategic Energy Analysis

Electric Power Grid and Natural Gas Network Operations and Coordination

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NREL/TP-6A50-77096
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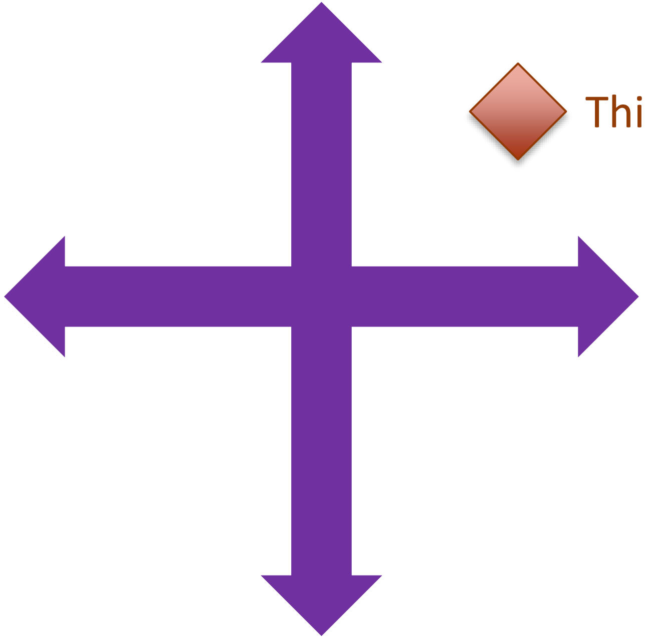
Summary and ongoing work

- Co-simulation offers a promising way to leverage existing tools to capture gas-grid interactions

- Ongoing efforts:
  - Expand co-simulation exchange to include more coupling points (e.g., compressors)
  - Use coupled modeling to understand system behavior during times of stress

Levels of co-simulation



Thanks!

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