

**ISO New England’s Economic Studies Reference Guide:**

**Documentation Describing Software Tools and Study Metrics**

**March 31, 2021**

**ISO-NE internal USE**

Preface

The ISO New England Inc. (ISO-NE or the ISO) System Planning Department is charged with simulating future system conditions and providing analysis to internal and external stakeholders. This effort is targeted toward supporting regional system planning. As part of the regional system planning effort, the ISO may conduct economic planning studies each year[[1]](#footnote-2) as specified in Attachment K of its [Open-Access Transmission Tariff (OATT](https://www.iso-ne.com/participate/rules-procedures/tariff/oatt)).

Using scenario analysis, the economic planning studies provide information on system performance, such as estimated production costs, load-serving entity (LSE) energy expenses, transmission congestion, and environmental emission levels. Scenario analysis is a process of analyzing future events by considering alternative assumptions about the future, which then produce differences outcomes. Each scenario normally combines optimistic, pessimistic, and/or more and less probable developments. However, most aspects of the scenarios should be plausible, even if they are conceptual and are not fully-developed plans. Scenario analyses inform stakeholders about alternative future systems. These hypothetical systems should not be regarded as physically realizable interconnection plans or the ISO’s vision of future development, projections, and preferences. Economic studies can be an exploration of new and non-traditional ways to economically serve anticipated future New England load.

Economic studies conducted under the authorities granted in Attachment K are performed under the auspices of the Planning Advisory Committee (PAC). The role of the PAC in the economic study process is to discuss, identify, and otherwise assist the ISO by advising on the studies. For studies requested by specific study proponents and agreed to by the ISO, they are afforded an opportunity to propose an initial set of assumptions to describe the scope and purpose of the study.

In accordance with ISO New England’s Information Policy, economic studies cannot assess the performance of an individual resource or asset, or individual resource or asset owners.

A key premise underlying these economic simulation studies is that the simulation be predicated on cost-based assumptions that specially excludes bidding behavior as a driver in study results.

The purpose of this document is to provide a guide to interested stakeholders how economic studies are performed, which software tools are used and a typical set of metrics an economic study will develop for the evaluation of results. Also included in this document is a list of key assumptions that should be defined when an economic study request is being submitted in accordance with Attachment K of the OATT.

ISO-NE maintains a list and description of all economic studies it has performed since 2011, along with all associated documents and support materials. This is located on the ISO-NE web site at <https://www.iso-ne.com/system-planning/system-plans-studies/economic-studies>.

# Contents

[Preface 2](#_Toc62826380)

[Contents 2](#_Toc62826381)

[Section 1 Modeling Tools 2](#_Toc62826382)

[1.1 GridView Unit-Commitment and Economic-Dispatch Program 2](#_Toc62826383)

[1.2 Electric Power Enterprise Control System (EPECS) 2](#_Toc62826384)

[1.3 Limitations of GridView and EPECS 2](#_Toc62826385)

[Section 2 Typical High Level Modeling Assumptions 2](#_Toc62826386)

[2.1 Load Models 2](#_Toc62826387)

[2.1.1 Load Forecast 2](#_Toc62826388)

[2.1.2 Load Profile 2](#_Toc62826389)

[2.1.3 Behind-the-Meter Photovoltaic (BTM-PV) 2](#_Toc62826390)

[2.1.4 Energy Efficiency (EE) 2](#_Toc62826391)

[2.2 Transmission Network Model 2](#_Toc62826392)

[2.2.1 Electrical Grid / Network Model 2](#_Toc62826393)

[2.2.2 Interface Ratings 2](#_Toc62826394)

[2.3 Resources 2](#_Toc62826395)

[2.3.1 Thermal Resources 2](#_Toc62826396)

[2.3.2 Fuel Prices 2](#_Toc62826397)

[2.3.3 Environmental Emission Allowances 2](#_Toc62826398)

[2.3.4 Variable Operation & Maintenance (O&M) 2](#_Toc62826399)

[2.3.5 Threshold Prices 2](#_Toc62826400)

[2.3.6 Interchange 2](#_Toc62826401)

[2.3.7 Renewable Energy Profiles 2](#_Toc62826402)

[2.3.8 Hydroelectric Energy Production 2](#_Toc62826403)

[2.3.9 Energy Storage 2](#_Toc62826404)

[2.3.10 Price Responsive Demand 2](#_Toc62826405)

[2.4 Reserve Requirements 2](#_Toc62826406)

[Section 3 Economic Economic and System Performance Metrics 2](#_Toc62826407)

[Section 4 Discussion of Key Metrics 2](#_Toc62826408)

[4.1 Economic Metrics 2](#_Toc62826409)

[4.1.1 Production Cost 2](#_Toc62826410)

[4.1.2 Load Serving Entity (LSE) Energy Expense 2](#_Toc62826411)

[4.1.3 Uplift (Adjustment to LSE Energy Expense) 2](#_Toc62826412)

[4.1.4 FTR/ARR (Adjustment to LSE Energy Expense) 2](#_Toc62826413)

[4.1.5 Locational Marginal Prices 2](#_Toc62826414)

[4.2 Investment Metrics 2](#_Toc62826415)

[4.2.1 Gross Revenues to Resources from LMPs 2](#_Toc62826416)

[4.2.2 Net Revenues to Resources from LMPs 2](#_Toc62826417)

[4.2.3 Net Revenues / Contributions to Fixed Costs (CTFC) by Fuel Type and Technology 2](#_Toc62826418)

[4.2.4 Relative Annual Resource Cost (RARC) 2](#_Toc62826419)

[4.3 Transmission Metrics 2](#_Toc62826420)

[4.3.1 Transmission Interface – Flow Duration Curves 2](#_Toc62826421)

[4.3.2 Transmission Interface – Percent of Time at the Limit 2](#_Toc62826422)

[4.3.3 Congestion 2](#_Toc62826423)

[4.3.4 Bottled-In Energy Due to Transmission Constraints 2](#_Toc62826424)

[4.4 Operational Metrics 2](#_Toc62826425)

[4.4.1 Energy Production by Technology Type/Fuel 2](#_Toc62826426)

[4.4.2 Capacity Factor by Unit Type 2](#_Toc62826427)

[4.4.3 Hours a Fuel is Setting the Locational Marginal Price 2](#_Toc62826428)

[4.4.4 Net Load Ramp 2](#_Toc62826429)

[4.4.5 Reserves 2](#_Toc62826430)

[4.5 Air Emission Metrics 2](#_Toc62826431)

[4.5.1 CO2 Emissions 2](#_Toc62826432)

[4.5.2 CO2 Emissions vs. State and/or Regional Emission Targets 2](#_Toc62826433)

[4.6 Renewable Resource Energy Production vs. Renewable Portfolio Standards (RPS) Targets or Goals 2](#_Toc62826434)

[4.6.1 Renewable Resource Production vs. RPS Targets or Goals 2](#_Toc62826435)

[4.6.2 Spillage by Resource Type 2](#_Toc62826436)

# Modeling Tools

When performing economic studies, two primary simulation tools are used by ISO-NE’s System Planning Department for the power system production-cost simulations that may include representations of transmission constraints. These tools are designed to consider conditions occurring throughout the study period requested by the study proponent.

With input from the economic study proponent and PAC members, the ISO develops the scenarios and assumptions based on the goals of the proposed study. To date in economic studies, the ISO generally studies relatively “normal” conditions (e.g., not contingency states) that explicitly incorporate a chronological analysis of a specific time period. The tools used for economic studies are not designed to analyze Loss-of-Load Expectation (LOLE) or Forward Capacity Market (FCM) expected outcomes.[[2]](#footnote-3) LOLE can be assessed but is usually not the focus of an economic study. The two simulation tools used in recent years for economic studies are GridView and Electric Power Enterprise Control System (EPECS). The following sub-sections describe the simulation tools and how ISO-NE uses them for economic studies.

## GridView Unit-Commitment and Economic-Dispatch Program

**Overview**

GridView is a software application developed by Hitachi ABB Power Grids Inc. to simulate the market operation of an electric power system considering the effect of constraints in the transmission system. GridView can be used to study the operational and planning issues facing entities participating in electricity markets. The link to the Hitachi-ABB web site is located at <https://www.hitachiabb-powergrids.com/offering/product-and-system/energy-portfolio-management/market-analysis/gridview>.[[3]](#footnote-4)

GridView was designed to study the numerous issues related to the restructuring of an evolving electric industry. The use of GridView can be helpful in investigating the changing types and quantities of energy transactions over the transmission system, in ways that may be different from the originally designed intent or ways that may stress the transmission system.

**Capabilities**

GridView integrates a detailed supply model, demand model, and transmission system model for a large-scale transmission grid. GridView performs transmission and security-constrained optimization of the system resources against spatially distributed loads to produce a realistic forecast of the utilization of power system components and flow patterns in the transmission grid. The Locational Marginal Pricing (LMP) provides investment signals to the energy provider as to the locations of import and export constraints. The congestion conditions and the shadow prices for constrained transmission lines or interfaces provide very valuable insight into the stressed pathways in the system, and the potential economic impact of expansion options that could alleviate those stresses.

The solution algorithm for the simulation centers on minimizing production costs for a given set of demand and supply-side resources given the transmission system that links them together. The program explicitly models a full network with New England modeled as a constrained single area for unit commitment.

**Timeframe of Applicability**

GridView simulates the economic operation of power system in hourly intervals for periods ranging from one day to many years. This hourly time-step provides sufficient granularity for comparing different visions of the future through scenario analysis.

**Typical Studies**

GridView has been the primary tool used to perform economic and environmental emission analysis of the evolving New England power system since the Economic Studies performed in 2011. These studies have included evaluations of the economic effects of transmission upgrades, increased penetration of onshore wind, offshore wind and the other changes to supply-side and demand-side resources. Metrics have been developed for comparing production costs to produce energy, costs to load-serving entities to obtain the energy and congestion across specific transmission paths.

While GridView incorporates a full network model and can respect limitations posed by individual transmission lines/transformers ratings and/or transmission contingencies (and resulting monitored elements), typical studies include only interface level constraints. Because GridView must accommodate all constraints that are input, the effect of small constraints that had not been ameliorated can be amplified and produce vastly disproportionate impacts on economic metrics.

GridView analyses are frequently simulated and analyzed under both unconstrained and constrained conditions. Under unconstrained transmission conditions, the New England transmission system is effectively modeled as a single-bus system. Under constrained transmission scenarios, the system is typically modeled using the “pipe and bubble” configuration.[[4]](#footnote-5)

The effect of transfer limitations across internal and external transmission interfaces are typically investigated based on values established for the latest FCM and/or regional planning studies. Resources are economically dispatched in the simulations to respect the assumed “normal” transmission system transfer limits.

**Limitations**

While GridView can use either cost-based inputs based on physical quantities or resource owner-determined bids, only cost-based inputs have been used for past economic studies. This cost-based assumption results in the absolutely lowest LMPs that could be achieved. While this tendency to estimate the lower range of LMPs may result low generator revenues, it does provide the basis for a consistent comparison between simulation cases. Performing simulations that use bids, which exceed costs, have been avoided because competition in markets may vary in ways that cannot be anticipated in the future year being studied.

Analyses of time frames shorter than an hour are not currently available in commercial versions of the GridView simulation tool. Consequently, GridView can only represent these quantities at an hourly time scale, which is sufficient to provide valuable insights.

## Electric Power Enterprise Control System (EPECS)

**Overview**

The Electric Power Enterprise Control System (EPECS) simulation software developed by Engineering Systems Analytics, LLC[[5]](#footnote-6) simulates the technology-economic behavior of an electric power system with the associated electric power markets that links these aspects of the enterprise together. EPECS specifically includes all types of conventional dispatchable resources as well as variable renewable energy, energy storage, and demand-side resources. It explicitly addresses the intermittency of renewable resources (i.e., lack of dispatchability) as well as the uncertainty (i.e., forecast errors) of the power grid’s distributed net load and simulates various types of operating reserves/ancillary services accordingly under uncertainty. The enterprise market includes multiple look-ahead time frames that are intended to represent time scales from forecast to real-time dispatch:

* Security-constrained unit commitment
* Real-time unit commitment
* Security-constrained economic dispatch
* Regulation service
* Physical model of the electric power grid

EPECS has the capabilities to solve using either an AC or a DC network model.

**Capabilities**

While many conventional production-cost modeling software tools are available, EPECS distinguishes itself in several respects.

First, EPECS integrates advanced modeling for renewable energy, energy storage, and demand-side resource integration. Technical literature[[6]](#footnote-7) states that renewable energy, energy storage, and demand-side resource integration studies must be holistic in nature and explicitly integrate market functionality along with physical grid models. Consequently, EPECS has been tailored specifically to not just the ISO New England physical grid (at a high level), but also ISO New England markets to provide analytical insight that are specific to the ISO New England region. Recently published IEEE papers have shown that small changes in market models can have dramatic impacts on simulation results and analytical insights.

EPECS leaves open the General Algebraic Modeling System (GAMS)[[7]](#footnote-8) source-code for the market optimization models so that ISO New England staff can edit the source code and investigate new market models and rules.

**Time Frame of Applicability**

EPECS provides a highly granular, one-minute, time-step analysis in the planning realm to analyze the use of regulation, ramping, and reserves capability needed to maintain the supply/demand balance of the New England markets.

EPECS simulator consists of four simulation layers addressing different user-defined time scales. The four layers and time scales currently used are:

1. Day-ahead resource scheduling as a security-constrained unit commitment (SCUC)
2. Four-hour-ahead real-time security-constrained resource scheduling as a real-time unit commitment (RTUC)
3. Fifteen-minute-ahead real-time balancing as a security-constrained economic dispatch (SCED)
4. Real-time physical power flow with integrated regulation service using one-minute time-steps

EPECS model provides an integrated platform for assessing simulated operating reserves, interface flows, tie-line performance, and regulation performance.

**Typical Studies**

EPECS can facilitate analysis of the consequences of forecast error in the “day-ahead” commitment and other dispatch steps that occur before real time. Forecast error is expected to have an increasing impact as the amount of renewable resource penetration increases.[[8]](#footnote-9)

Ramping reserve is a physical quantity that measures the ability of current on-line supply resources to ramp their output up or down from current levels, in response to anticipated system needs (in addition to whatever increase or decrease the resource may be scheduled for). Load-following reserve is the amount of upward or downward change in output that a resource could accomplish from its current output. Ramping reserve and load-following reserves are not ISO requirements, but physical quantities that EPECS can track and quantify. In other words, ramping reserve is how quickly system resources can move their output up or down in a given period, generally 10 minutes. Load-following reserve is the total amount the committed units can move up or down.

Notably, the current configuration of the EPECS tool and ISO system operations rely primarily on thermal resources to provide most reserves (the exception being Load Following Reserves down, which can be provided via curtailment). Within the EPECS model, ISO has the ability to revise the GAMS open-source code to including storage or renewables as part of reserves like TMSR and TMOR as desired. Additionally, other reserve products may be modeled in the GAMS code. EPECS can evaluate a future where renewables are able to provide reserves via inverter control and flexible curtailment.[[9]](#footnote-10)

In late 2020, the EPECS model was updated. In particular, alternative reserve acquisition methods were added to augment current-day, thirty-minute operating reserve (TMOR) and ten-minute spinning reserve (TMSR) acquiring of reserves, which have a nonlinear relationship between increasing quantity of reserves and decreasing reserve exhaustion. The new method has a monotonic relationship with decreasing reserve exhaustion. The update provides enhanced regulation modeling, more detailed renewables modeling, and a more realistic storage dispatch.

**Limitations**

The random nature of supply and demand that create minute-to-minute mismatches are not well understood from a forecasting perspective. This lack of understanding of the root causes of the randomness can result in the use of approximations that may or may not capture the characteristics of the factors underlying the resulting mismatches. Additionally, forecast error is one area where improvements could be made to better link random supply with random demand at the smaller time scales. Furthermore, the interpretation and meaning of the metrics that can be produced by the four-layer EPECS simulator represent a new field of research that may not be easily translated into actionable changes to markets.

## Limitations of GridView and EPECS

Currently, both the GridView and EPECS software cannot model the following functional areas or attributes:

**Distribution Level Modeling**

Costs and characteristics such as distribution level costs, upgrade costs and interconnection costs, along with distribution level headroom for utility and residential, commercial, and industrial (RCI) Distributed Energy Resources (DER), are currently unavailable.

**Custom Constraints Modeling**

Modeling features such as user-defined custom constraints, and the associated optimization around such constraints, are currently available using nomograms incorporating a limited number of parameters.

**De-Carbonization Modeling & Attributes**

The modeling and attributes associated with enforcement of, or compliance with, individual state or regional portfolio standards (RPS) is currently unavailable. Carbon pricing mechanisms/modeling such as carbon emissions dispatch, modeling of “cap & trade” markets, renewable energy credits (RECs), zero-emission credits (ZECs), and costs to load would be needed.

**Reliability Metrics and Resource Adequacy Modeling**

ISO-NE currently uses the GE MARS model for its resource adequacy assessments. Reliability planning and analysis that require standardized metrics such as Loss-of-Load Expectation (LOLE), Loss-of-Load Hours (LOLH), Annual Loss-of-Load Probability (ALOLP), Expected Unserved Energy (EUE), Effective Load Carrying Capability (ELCC), and Target Planning Reserve Margin (TPRM) are currently unavailable in these production-costing models and currently require the stand-alone MARS program. Not all economic study requests require the review of resource adequacy metrics, but the ISO has the capability to do such analyses as part of an economic study.

**Capacity Addition/Retirement Modeling**

Capacity addition/retirement pricing and optimization are also correspondingly unavailable.

# Typical High Level Modeling Assumptions

In performing Economic Studies, many assumptions are needed. This section provides a high-level overview of key assumptions. For brevity, only the most important assumptions will be discussed in detail in this section.

## Load Models

### Load Forecast

Annual and monthly peak loads and monthly energies for load are obtained from the most recent annual forecast cycle as published in the Forecast Report of Capacity, Energy, Loads, and Transmission (CELT report). Demand adjustments for electrification technologies such as heat pumps and electric vehicles are made based on the study proponent’s discretion.

### Load Profile

An hourly load profile from a historical year is used to represent the hourly variations in demand within each month (profiles within a month are typically scaled to the forecast monthly peak). The use of a historical profile from a specific year or years implies associated temperatures and climatic conditions that would result in monthly and annual energies, which would be different from the “weather-normal” conditions in a typical forecast. The amounts of behind-the-meter photovoltaic (BTM-PV) that reduced hourly loads (e.g., loads not seen by the ISO New England control room, but which are present) is added back[[10]](#footnote-11) to the net profile to obtain a profile representative of all the customer loads that needs to be satisfied.

### Behind-the-Meter Photovoltaic (BTM-PV)

BTM-PV is treated as a supply resource so that it can be tracked and reported.

### Energy Efficiency (EE)

An Energy-Efficiency profile is developed to be consistent with the selected historical hourly load profile.

## Transmission Network Model

### Electrical Grid/Network Model

A network model is selected to represent an appropriate future study year and includes all required buses, transmission lines, transformers and generator interconnection points.

### Interface Ratings

While much more granular constraints can be defined, interface ratings between RSP subareas are typically the only constraints imposed on the network model for long-term studies.

## Resources

Unless otherwise requested, all resources participating in the New England markets are included in an economic study regardless of whether they are capacity resources or energy only resources. New resources (generation and/or an elective transmission upgrade (ETU)) may be added, but resource characteristics and location(s) for the new resources are needed. Resource retirements may also be studied.

### Thermal Resources

Thermal generating resources and their characteristics are obtained from ISO New England public and confidential information to represent, among other data, capacity ratings and operating limits, fuel used, heat rates, emission rates, as well as maintenance and forced outages.

### Fuel Prices

EIA Annual Energy Outlook (AEO) is typically used as the basis for fuel prices.

### Environmental Emission Allowances

The value of environmental emission allowances prices for carbon dioxide (CO2) nitrous oxide (NOx), and sulfur dioxide (SO2) are reflected for fossil-burning generation units. The values for these allowances in future years have been obtained from various sources such as auctions and, in recent years, they have been sourced from the NYISO Congestion Resource and Integration Study (CARIS).

### Variable Operation & Maintenance (O&M)

Assumptions for variable O&M are typically not included in the simulations. This is because when compared to fuel and environmental emission allowances, the variable O&M is generally a small amount and the complexity of determining an appropriate variable O&M in a market environment is problematic. For example, a significant component for the variable O&M of a gas turbine can be established from the number of hours of operation and number of starts before a major inspection is required. Such an inspection could be a trigger for potentially significant renewal and replacement expenses. These operating hours and number of starts are traditional metrics suggesting wear and tear on the equipment, which could be converted into a $/MWh variable O&M charge. Past modeling practices have avoided representing non-cash expenses, and established a preference for representing only the identifiable fuel and environmental allowances expenses associated with producing a MWh of electricity.

As battery storage is added to the New England system, battery degradation may be a more significant characteristic as it is linked to cycling. If requested, it can be reflected using a variable O&M expense.

### Threshold Prices

For resources that are defined by input shape, and which are allowed to be curtailed in the event their energy cannot be consumed within New England, a “threshold price” can be specified that will allow the profiled energy to be reduced based on price. These threshold prices are allowed to set the locational Market Price (LMP) at the location where they are marginal. Threshold prices can be either positive or negative. Typically, threshold prices are applied to wind, solar and import profiles.

For resources that are modeled as must-take, non-dispatchable profiles such as “Energy Efficiency,” threshold prices do not need to be specified because they are outside of ISO dispatch and cannot be curtailed.

### Interchange

Interchange with each neighboring systems is typically represented as daily diurnal profiles based on a three-year historical window. A threshold price is used to determine the LMP at which the energy from a specific interconnection with a specific neighbor should be curtailed.

### Renewable Energy Profiles

Historical profiles for wind and PV are obtained that are consistent with the climatic conditions in the historical hourly load profile. A threshold price is used to determine the LMP at which a renewable resource should be curtailed.

### Hydroelectric Energy Production

Historical statistics for each hydroelectric generating station are developed to describe the monthly maximum output, the monthly minimum output and the monthly energy.

### Energy Storage

Energy storage capability is defined using a charging rate, a discharge rate, a quantity of energy to be stored and an overall cycle efficiency.[[11]](#footnote-12) If requested to do so, variable O&M costs can be included because “wear and tear” or degradation may be a significant identifiable cost.

### Price Responsive Demand

The ability of consumers to respond to market price signals is represented by the injection of emission-free energy at specific threshold or dispatch prices. These injections are equivalent to either customer-load curtailment, customer emission-free self-generation or withdrawal of energy from local customer-based storage devices.

## Reserve Requirements

Reserve requirements are based on the Northeast Power Coordinating Council, Inc. (NPCC) criteria, which requires 120% of the first contingency to be activated in ten minutes. This amount is assumed to be split equally between Ten-Minute Spinning Reserve (TMSR) and Ten-Minute Non-Spinning Reserve (TMNSR). To satisfy the first half of the spinning reserve requirement, additional generation is committed for reserves, but not for producing energy. The other half of the reserve requirement is satisfied by off-line, quick-start resources.

Activation of reserves due to forecast uncertainty associated with either load or output from variable energy resources is not typically represented in GridView. EPECS, however, is designed to explicitly consider and respond to forecast uncertainty.

Additionally, sudden generator forced outages are not typically modeled in economic studies. Consequently, the effect of activating off-line resources to provide reserves is not modeled and these off-line resources do not have an effect.

# Economic Economic and System Performance Metrics

Results of economic studies can be compiled to produce various metrics depicting different aspects of system-expansion scenarios. These metrics can then be used by stakeholders to describe the pros and cons associated with the selected scenarios. Such metrics could assess simulated system performance for scenarios investigating futures that could include changes, such as possible additional imports from Canada, offshore wind, resource retirements and additions.

Key metrics that are typically developed include estimates of production costs, transmission congestion, electric-energy costs for New England consumers, environmental emissions and a number of others aspects of system operations. These metrics may suggest beneficial economic locations for resource development, as well as the least economical locations for resource additions or retirements. These studies provide a common framework for NEPOOL participants, regional electricity market stakeholders, policymakers, and consumers to identify and discuss reliability, economic, and environmental issues along with possible solutions.

The following is a list of the commonly reported metrics:

* Economic Metrics
  + Production Cost
  + Load-Serving Entity Energy Expense (LSEEE or LSE Energy Expense)
  + Uplift
  + Congestion Costs
    - Congestion
    - Congestion with FTR/ARR adjustments by Financial Transmission Rights (FTR)/Auction Revenue Rights (ARR)
  + Locational Marginal Prices (LMP)
  + Gross Revenues
  + Net Revenue/Contributions to Fixed Costs (CTFC) by Fuel Type and Technology
* Investment Metrics
  + Relative Annual Resource Cost (RARC) given an assumption such as Annual Carrying Charges (e.g., assuming 16% to 18% of capital cost per year)
* Transmission Metrics
  + Interface Flow
    - MW Flows
    - Percent of Interface Transfer Limit
  + Hours at Interface Transfer Limit
  + Congestion
  + Bottled-In Energy Behind Transmission Transfer Limits
* Operational Metrics
  + Energy Production by Resource Type (GWh)
  + Energy Production by Fuel Type
  + Fuel Setting the Marginal Price
  + Net Load Ramp
  + Reserves
  + Capacity Factor by Unit Class
  + Annual spillage by resource
* Emission Metrics
  + System Emission Targets
    - Carbon dioxide (CO2)
    - Nitrous oxides (NOX)
    - Sulfur dioxide (SO2)
  + Renewable Resource Production vs. RPS Targets

# Discussion of Key Metrics

The following metrics have been used in past economic studies. Each metric has its own purpose, range of applicability and limitations. The GridView software is used for the following metrics.

## Economic Metrics

In an organized ISO/RTO market, fixed costs associated with either capital investment or fixed operating costs are assumed to be borne by the investor and are not a concern for ISO/RTO markets that administer the energy and ancillary service markets.

### Production Cost

Production cost is the variable cost of producing the energy to serve customer loads.

#### Purpose

The theory underlying the primacy of the production-cost metric in economic studies is that the actual dollars spent in the region are the best indicator of the cost to the customers. Therefore, changes to production cost due to a project or improvement provides an indicator of the change in cost to be borne by the customers in the region. All changes that improve the “efficiency” of the system operation or markets will reduce production costs.

The production-cost concept does not distinguish between costs that provide benefits to the local economy versus costs that provide benefits to an external economy. For example, it may be cheaper to spend $10 million on fuel from Saudi Arabia than spend $11 million on locally-harvested biomass using labor whose paychecks are spent locally, as the economic activity recirculates throughout the regional economy. This is because of the different ramifications of money spent inside the region versus outside the region on the state and local economies.

This aspect is particularly important when studying future changes in infrastructure. With future changes, differences in capital spending versus operational expense becomes important. For example, part of the economic benefits for wind and PV is that those technologies provide “green jobs,” which frequently means “local” jobs during the construction phase as opposed to the ongoing purchase of fuel. This benefits the economy of other gas-producing regions. While economy-wide regional economic modeling is sometimes requested to better understand the downstream impacts of inside-the-region costs versus outside-the-region costs, and benefits this aspect, it is not part of the economic studies performed by ISO New England.

The magnitude of the production-cost metric is affected by what is included in the production cost. Generators may have variable revenue streams from renewable energy credits, production tax credits, solar energy credits, as well as variable costs such as emission allowances. The most appropriate fuel prices to use are challenging because fuel prices may include scarcity premiums, which make the local fuel appear expensive even though its intrinsic value is lower, excluding the locally extracted economic rent.

#### Calculation

Summation of the cost of all fuel, environmental emission allowances and variable Operations and Maintenance (O&M) costs to produce the energy demanded by the customers.

#### Units of Measure

Typically, this metric is expressed in Millions of Dollars per year.

#### Limitation

Accounting for the production cost of external interchange is challenging because the actual costs are unknown and subject to supply and demand in a larger interregional marketplace. In economic studies, assumed interchange profiles are developed that represent the flows into New England and, in some cases, out of New England. Past practices have been to assign a relatively low price that ensures the energy has a high priority and all the energy could be imported. This allows the assumed price to cancel out when comparing cases because the same amount of energy would be imported at the same price. However, if transmission constrains impede the import of the assumed interchange, then unequal amounts of imported energy result in the simulations, and the cost of imported energy does not cancel out completely. This leaves undefined the proper adjustment to the production-cost metric for this unequal imported energy.

### Load-Serving Entity (LSE) Energy Expense

LSE Energy Expense is thought to be a superior metric for evaluating economic alternatives because it has a customer focus – and “this is what customers pay.”

#### Purpose

LSE Energy Expense is a metric that intends to represent the cost of energy to customers. This metric excludes non-energy charges such as capacity, transmission and distribution network demand charges, user fees and other legislated or tariff charges.

#### Calculation

LSE Energy Expense is calculated by summing, at each location, the load multiplied by the corresponding LMP in each hour.

In the current framework, energy efficiency and energy served by BTM-PV are included in the MWh of load within the RSP subareas and, therefore, included in the aggregate LSE Energy Expense.

#### Units of Measure

Typically, this metric is expressed in Millions of Dollars per year.

#### Limitations

LSE Energy Expense can be a challenging metric for use in economic analysis because:

1. Transmission constraints may create pockets of high or low LMPs that distort the LSE Energy Expense metric.
2. Depending on the relative size of the areas affected by the high and low LMPs, an improvement that increases efficiency can either increase or decrease the LSE Energy Expense metric.
3. Production-cost simulation models develop a simulated dispatch based on a production-cost minimization algorithm, and create a dispatch that would be different from the results of a simulation based on an LSE Energy Expense minimization algorithm.

In a production-cost model, a small change in assumptions may result in a change in optimization to minimize production costs. For example, hypothetically, not dispatching a base-load unit with high start-up costs, but rather dispatching a high-variable, cost-peaking unit instead, may lower production costs while simultaneously increasing LSE Energy Expense. Because an annual analysis consists of 8,760 dispatch periods, it can be “supposed” that the different optimizations will settle out into a “reasonable” and explainable pattern – but this is not guaranteed.

Transmission constraints that create a “pocket” with bottled-in, low-cost (possibly price taking) generation may result in model-estimated LMPs in the “pocket” that are set so low that any change to the assumptions about the pocket may dominate the LSE Energy Expense metric. Past studies have shown that relieving an export constraint reduced production cost, but increased total New England LSE Energy Expense. This was because the LMPs associated with the small amount of load in bottled-in areas increased significantly from their depressed levels, while the change in the rest of New England’s prevailing LMPs were very small. Therefore, total New England LSE Energy expense increased.

Explicitly modeled load, such as electrification technologies for heat pumps and electric vehicles, is represented as negative resource profiles and are not considered load within GridView. They would require an adjustment to aggregate these “explicitly-modeled loads” with the general loads.

Complexities also arise about whether EE and BTM-PV should be included in the amount (MWh) of load within the RSP subareas, and subsequently included in the LSE Energy Expense.

### Uplift (Adjustment to LSE Energy Expense)

Uplift is a revenue stream paid to a generator when the generator is dispatched by the simulation model, but does not recover all of its start-up and production costs from energy revenues within a 24-hour period.

#### Purpose

The purpose of this metric is to provide additional information that provides a more complete estimate of costs to customers for energy than just the LSE Energy Expense alone. Because the incremental costs of energy production from the marginal resource is what sets the LMP (and the incremental costs of energy from the marginal unit is lower than the average cost to produce the power from that resource), the marginal generator will not recover its operating costs from the LMP-based revenue stream.

The difference between cost and the earned revenue is uplift.

#### Calculation

Uplift is an account that is tracked for each resource in each hour. If the account shows that the revenues from the LMP-based energy is insufficient to cover the start-up and no-load cost of a generator in a 24-hour calendar day, the shortfall is recorded and accumulated as uplift. Uplift is assumed to be settled on a daily basis. This represents a revenue stream to generators and a cost to the customer that may need to be included when looking at total profitability of resources or a more complete estimate of the total LSE Energy Expense.

#### Units of Measure

Typically, this metric is expressed in Millions of Dollars per year.

#### Limitations

Uplift in actual ISO-NE markets is a relatively small component and typically results from out-of-market dispatch. In ISO New England energy markets, the bidding and LMP price formation is intended to cover most, if not all, of the energy costs without an out-of-market revenue stream (e.g., uplift). Because only costs, without bidding strategies, are currently included within the production-cost simulations, uplift becomes larger than historical charges.

### FTR/ARR (Adjustment to LSE Energy Expense)

This metric can be considered to be an adjustment to LSE Energy Expense, and is based on the distribution of Auction Revenue Rights (ARRs) received from the sale of Financial Transmission Rights (FTRs) in an ISO/RTO administered market. These FTRs have a value because LSEs have a right to a portion of any lower-cost energy produced in export-constrained areas.

#### Purpose

The economics of energy brought into an import-constrained area, or alternatively delivered from an export-constrained area, can be accounted for using a mechanism that, effectively, allows the imported energy to be valued at the producing area’s LMP. This mechanism is based on the concept of FTRs, where LSEs have a right to a portion of any lower-cost energy produced in other areas. The value of these FTRs is monetized in an FTR auction and the proceeds of the auction flow back to the LSEs as their share of the ARRs. Thus, this adjustment to the LSE Energy Expense economic metric is referred to as “FTR/ARR” congestion.

#### Calculation

FTR/ARR congestion values are equal to the product of the constrained interface flow and the price differential across the constrained interface. The effect of compensating LSEs indirectly via ARRsfor energy produced within a constrained area is a reduction in the net LSE Energy Expense metric. With this reallocation, the LSE Energy Expense will equal the sum of the supplier/generator revenues.

#### Units of Measure

Typically, this metric is expressed in Millions of Dollars per year.

#### Limitations

This FTR/ARR process assumes that 100 percent of the ultimate value of the FTRs is returned to the LSEs via their share of ARRs. However, this is not necessarily the case under New England’s current market structure because the FTRs are sold via auctions, where participants value them based on their estimates of future on- and off-peak transmission constraints.

### Locational Marginal Prices

Locational Marginal Prices (LMPs) can be used as a comparative metric representing costs to customers in various locations.

#### Purpose

The purpose of this metric is to provide a yardstick for the cost of energy at various locations throughout the network. LMPs are comprised of three components – energy cost, congestion costs, and losses. The latter two would be zero within a lossless, unconstrained system.

#### Calculation

The LMP is calculated from the incremental cost of energy production from the most expensive marginal cost resource that is needed to serve customer loads within a constrained area (if constraints exist). Whenever a transmission constraint is reached, there will be a marginal resource on either side of the constraint.

#### Units of Measure

Typically, this metric is expressed in $/MWh.

#### Limitations

There are nuances with definitions of exactly how the GridView LMPs are calculated and reported for an aggregate area that create subtle LMP differences. GridView LMP metrics are based on one of the following three formulas:

1. A simple average of all LMPs at each bus in a year (LMPavg)
2. An LMP weighted based on the load at each load bus (LMPload)
3. An LMP weighted based on the generated MWh at each generator (LMPgen)

For economic studies, ISO New England uses a fourth metric based on the RSP subarea’s LSE Energy Expense divided by RSP subarea’s load MWh to calculate a load weighted LMP that would be consistent with LSE Energy Expense. The average GridView calculated LMPload is slightly different and, therefore, creates slight inconsistencies.

## Investment Metrics

While some of these metrics were used in the 2016 Economic Studies, they contain many embedded assumptions and caveats that impairs their value as a standard metric.

### Gross Revenues to Resources from LMPs

The sum of Gross Revenues earned by all resources (internal and external) should equal the cost paid by load as measured by LSE Energy Expense. If there is a difference, it will be the effect of congestion as calculated by the FTR/ARR metric. In addition, uplift represents an additional revenue stream that is outside of the LMP-based energy market.

#### Purpose

The purpose of this metric is to show the magnitude of the revenues that resources will receive.

#### Calculation

The gross revenues are the sum of each MWh of energy produced by a resource in an hour times the LMP applicable to the resource’s location in that hour.

#### Units of Measure

Typically, this metric is expressed in $/kW-year or Millions of Dollars per year for a specific resource that is intended to be representative of a type of resource.

#### Limitations

This metric does not explicitly take into account uplift revenue, which may be an important revenue stream for some resources.

### Net Revenues to Resources from LMPs

The Net Revenues to Resources should equal the Gross Revenues to Resources minus fuel, variable O&M and emission-allowance costs. As noted earlier, uplift represents an additional revenue stream that is outside of the LMP-based energy market.

#### Purpose

The purpose of this metric is to show the magnitude of the net revenues that resources will receive from operations. Ideally, this net revenue would be applied to recover the fixed costs of the resources. This metric helps provide another aspect to assess the efficient operation of the wholesale electric market.

#### Calculation

The net revenues are the sum of each MWh of energy produced by a resource in an hour times the LMP applicable to that location minus the fuel, variable O&M and emission allowance costs.

#### Units of Measure

Typically, this metric is expressed in $/kW-year or Millions of Dollars per year for a specific resource.

#### Limitations

This metric does not explicitly take into account uplift revenue, which may be an important revenue stream for some resources. Additionally, a limitation for the application of this metric is that there are many fixed costs that are borne by an owner that are not included in the production-cost simulations.

### Net Revenues/Contributions to Fixed Costs (CTFC) by Fuel Type and Technology

Net Revenues are Gross Revenues minus the cost of fuel, environmental allowances and variable O&M costs. This is the amount of profit a generator earns from operations by selling into the system at their hourly LMP, and is compared to the costs of ownership.

#### Purpose

The purpose is to provide a metric, on a normalized basis, that shows the profitability of a resource from operations which can be compared to the fixed costs of owning and maintaining a resource.

#### Calculation

These net profits from operations (energy production and sale at the LMP) are also described as Contributions to Fixed Costs (CTFCs). This is typically calculated for a single “representative” resource for each technology/fuel type.

#### Units of Measure

Typically, this metric is expressed in $/kW-year and compared to an estimated levelized fixed cost of owning and maintaining a resource.

#### Limitations

This metric can be negative if the energy production sold at the LMPs is not sufficient to cover start-up and no load costs of operations. This can happen because the incremental heat rate that determined LMPs is lower than average cost for the marginal unit. In GridView, “uplift” accounts for these revenue shortages and prevents a negative CTFC. A negative CTFC would mean that the there is no money for fixed O&M, property tax, depreciation expense, return on capital investment, etc.

### Relative Annual Resource Cost (RARC)

The Relative Annual Resource Cost (RARC) metric is a means of comparing the total costs of representative scenarios to see the various tradeoffs in terms of the cost of all scenarios for a given year.

#### Purpose

This metric is used to compare different visions of the future, using a snapshot showing the key cost components in a single metric. The RARC accounts for the annual system-wide production costs (which can be thought of as operating costs), plus the annual costs of capital additions by including the annualized carrying costs for new resources and high-order-of-magnitude, transmission-development costs. RARC is thus a measure of the relative total costs for a scenario. It does not include all consumer costs that would ultimately be determined by distribution rates, which may include a variety of factors outside the scope of this metric, but should be equal in the other scenarios that are compared using this metric.

#### Calculation

Capital costs for new resources and/or transmission upgrades need to be converted to a levelized annual-cost perspective using an assumption such as Annual Carrying Charges (e.g., assuming 12% to 15% of capital cost per year) that can be used in the comparison.

* Levelized annual cost of transmission upgrades/additions
* Levelized annual capital cost of new resources (which can be presented by new scenario-based technology types)

These capital costs are typically uncertain, and ISO/RTOs have developed markets and procedures to allow participants to compete based on their expertise and familiarity with these costs. Participants can compete to provide supply resources in the Forward Capacity Market and develop transmission solutions through competitive solicitations.

#### Units of Measure

Typically, this metric is expressed in Billions of Dollars per year or cents per kilowatt-hour (kWh).

#### Limitations

This allows very high-level comparison that includes many of the associated component costs (e.g., transmission costs, capital costs for new capacity additions, annualized carrying costs, etc.), which are estimated because they are not precisely known.



Figure 1: Typical Transmission Interfaces Used in Economic Studies

## Transmission Metrics

Interface limits can vary depending on system conditions. In the pipe-and-bubble-based production simulation model, interface limits between RSP subareas are fixed, and the simulation model can dispatch around these constraints. Simulation models have a mathematical formulation that will utilize the interface up to its limit. This allows a summary statistic, “hours at the interface limit” to be developed. See Figure 1, above, for an example of pipe-and-bubble-modeled transfer limits.[[12]](#footnote-13)

### Transmission Interface – Flow Duration Curves

Interface flow duration curves provide graphical metrics that can be used to quantify how close the system is to being constrained, and help assess the risk of the transmission system being inadequate for the demands placed on it.

#### Purpose

To provide a graphical illustration showing how close transmission flows are to the assumed interface limits for the constrained system. From an unconstrained perspective, how often – and by how much – the unconstrained system would exceed the interface limit. Under unconstrained transmission scenarios, the New England transmission system is modeled as a single-bus system. Under constrained transmission scenarios, the system is typically modeled using only broad interfaces that may be limited (e.g., pipe-and-bubble configuration)[[13]](#footnote-14) although any transmission element may be constrained if their limits are represented.

#### Calculation

Hourly flows are sorted from highest to lowest to create a continuous distribution over the study period. This is then compared to the nominal interface limit.

#### Units of Measure

Distributions are presented in MW flows or percent of the (preferably stable) interface rating. (Note: Some interface limits can be affected by unit dispatch/topology and the percent of rating becomes less meaningful because the denominator is varying).

#### Limitations

The economic consequences of interface flows at the limit are not apparent in the resulting distributions. For example, if a maximum flow is reached, there could be a large economic penalty or the difference could be negligible. If the metric is expressed as a percent of limit, to be informative, the “defining limit” should be stable/static.

### Transmission Interface – Percent of Time at the Limit

The Percent of Time at the Interface Limit metrics can provide a single numerical value to quantify how often an interface, or transmission element, is constrained. This metric can be applied to either an internal or external interface or transmission element.

#### Purpose

To provide a single value showing the number of hours that an interface, or transmission element, is constrained. This metric can also be converted to show the percent of time the interface is at a specified fraction of the limit, such as at 85 or 90 percent of the hours.

#### Calculation

The number of hours at which the interface flows is at the limit, or a specified percentage of the limit, divided by the length of time.

#### Units of Measure

Distributions are presented in hours or percent of time.

#### Limitations

In isolation, this metric provides only a small piece of information about the performance of the network.

### Congestion

Congestion is a monetized value that represents the economic consequence of any transmission constraint being reached causing a resultant increase in production costs. This metric can be applied to an interface or specific transmission element that is internal or external to New England.

#### Purpose

The purpose of a congestion metric is to identify the transmission elements on the system where congestion is observed. Congestion can be associated with either granular constraints or broad interface-based constraints.

#### Calculation

One way of observing the total congestion metric is to sum the difference between the cost of the energy paid by LSEs for energy (LSE Energy Expense) and the revenue paid to generators (excluding uplift). This is the dollar difference that would need to be allocated to FTR holders, so that all of the congestion dollars are accounted for.

For example, if there are 1,000 MWh of energy from “bottled-in” generation (i.e., they are located in an export constrained location), they will receive a lower LMP for the energy they produce than the load would pay for it in the outside unconstrained area. This creates a difference generically called “congestion” and can be assumed to be captured by the FTR/ARR revenue reallocation as described above.

GridView calculates congestion as a sum of the shadow-prices from the optimization algorithm for flows from all energy injections. A dollar amount can be associated with each binding transmission constraint.

#### Units of Measure

Typically, this metric is expressed in Millions of Dollars per year.

#### Limitations

Congestion can be defined in many ways. This is partly because there is no universal definition of congestion and there is no universal reference point against which congestion is calculated.

### Bottled-In Energy Due to Transmission Constraints

One metric associated with a study of an export-constrained area is the amount of bottled-in energy (e.g., “curtailed” or “spilled”) that is associated with the export constraint. Bottled-in energy is energy that cannot be produced and exported because of transmission constraints. Recent analyses have shown energy from renewable resources being curtailed due to transmission constraints.[[14]](#footnote-15)

#### Purpose

The bottled-in energy metric is important for explaining results developed during an analysis, and provides a measure of the adequacy of a transmission system to accommodate specific types of resources in specific locations. For example, available wind energy profiles define the maximum amount of wind energy that resources in an export-constrained area could produce if unconstrained. In this case, the differences in wind energy produced in the simulation can then be compared with the input profiles to determine the amount of bottled-in energy.

#### Calculation

This is calculated as the difference between the maximum amount of available GWh of energy from specific types and the amount actually generated in the simulations. For example, bottled-in energy for renewable resources is calculated as the difference between the maximum amount of available GWh of renewable energy profiles and the amount actually generated in the simulations.

#### Units of Measure

Typically, this metric is expressed in GWh per year or TWh per year.

#### Limitations

Energy curtailed inside an export-constrained area may be from either transmission constraints, or when the system could not absorb the energy from resources physically located within the transmission-constrained area.

## Operational Metrics

Many of the metrics extracted from the simulation describe physical quantities related to operations. Some of the most frequently used metrics for describing physical quantities are described below.

### Energy Production by Technology Type/Fuel

Energy Production by Technology Type or Fuel Type is useful because it allows quantification of energy production into broad or distinct categories that are useful in understanding the results.

#### Purpose

To allow a comparison of various scenarios using a characterization of the sources of energy. For example, in a scenario that has coal units operating and another scenario where they are retired, the difference in the source of energy can be seen. These metrics can be used to explain the behavior of other metrics such as production costs, emissions and LMPs.

#### Calculation

Summation of energy from each resource type and/or fuel type category.

#### Units of Measure

Typically, this metric is expressed in GWh per year or TWh per year. The metric can also be presented as percentage of total requirements.

#### Limitations

None

### Capacity Factor by Unit Type

The rate of utilization of specific resource types as characterized by capacity factor can be useful in understanding their contribution in the market operations. Capacity factor is defined as the amount of energy actually produced as a fraction of the energy that could have been produced, if the resource or group of resources had been dispatched at maximum rating for 100 percent of the time.

#### Purpose

To show the utilization of various unit types in future years.

#### Calculation

Amount of energy produced by the resource type divided by the total (maximum) capacity of the group of resources, and then divided by the number of hours within the study period.

#### Units of Measure

Typically, this metric is expressed in percent. If there is a wide range of capacity factors within a group of resources, then distributions of the capacity factors versus unit count (or cumulative MW) can be developed, which would then be informative to understand how various resource types perform as well as look for noticeable trends or distinctions among the resources based on the metric.

#### Limitations

This metric is useful for many classes of generators, but there are exceptions. For example, within a broad “unit class” for the gas turbine technology “GT,” the resources may utilize different fuels that range from “zero-cost” landfill gas (which would result in a high capacity factor), to high cost, intra-day natural gas (which may provide a low capacity factor) or distillate oil (which would result in a very low capacity factor). To be informative, a unit class may need to be subdivided into smaller distinctive sub-classes. This could make the classes potentially small.

A large-unit class, such as the 10,000+ MW of combined cycle generators, may have a very wide continuous range that cannot be easily subdivided. Reasons for variations within the class could result from relatively small cost differences due to heat-rate, chiller-operations, or even different characteristics of no-load and start-up costs. Additionally, operation of a generator within either an import- or export-constrained area could affect capacity factors and provide outliers that would need supplemental information to explain.

### Identifying which Fuel is Setting the LMP

Knowing which fuel(s) set the marginal LMP in an economic study can be useful in understanding some of the potential simulation results.

#### Purpose

This metric is developed to help explain the resulting LMPs and which resource(s) contribute to setting the LMP.

#### Calculation

For each hour, an estimate of the marginal unit can be made. In the GridView simulation tool, this metric is not produced internally. To obtain this metric requires significant post-processing and application of rules.

#### Units of Measure

Typically, this metric is expressed in hours or fraction of total hours in the study period.

#### Limitations

This metric has limitations related to transmission constraints, energy-storage resources and hydro units.

For example, there are multiple “marginal” units whenever a transmission constraint is binding. When there is a binding transmission constraint, an incremental change in load on one side of the constraint cannot be compensated for by a change in generation (e.g., from the marginal resource) on the other side of the constraint. Consequently, multiple marginal units must accounted for on each side of a constraint.

Additionally, in actual operations, hydro generators and pumped storage resources are frequently setting the LMP due to their bidding behavior. However, in the GridView model, hydro generation and pumped storage are treated as load modifiers that are not be able to be “marginal” based on their bidding behavior. In studies with significant penetrations of wind, PV and batteries, those types of resources may also be marginal in actual operations, but GridView cannot reflect such behavior.

### Net Load Ramp

Net load ramp is defined as the change in load that the ISO/RTO operators need to match by adjustments from dispatchable resources, after taking into account output from renewable resources (most renewable resources are assumed to be “must take”). As the magnitude of changes in loads that dispatchable resources will need to follow increases, a corresponding increase in flexible dispatchable resources needs to be available. This flexibility will be increasingly important in futures reflective of high penetrations of renewable resources, because of the fewer dispatchable resources on-line to serve the lower net load. Net load ramp is typically calculated after subtracting BTM and market-facing wind and solar generation from customer loads.

#### Purpose

This metric provides a numerical or graphical comparison of the changes in net loads over a specific time-step (or interval), which helps identify the amount of load following reserves needed to keep supply from resources and demand from load in balance.

As the output of renewable resources used to serve load becomes a larger fraction of the dispatched resources, these net load ramps may become more difficult to forecast accurately and, yet, they must be accommodated to satisfy the laws of physics.

#### Calculation

The difference in net loads for a given time-step is calculated and sorted as a distribution over the study period. The time-step could be net-load ramps in one minute, five minutes, thirty minutes, one hour, two hours, four hours, or any other time-step desired.

#### Units of Measure

Typically, this metric is expressed in “Change in MW per time-step.”

#### Limitations

Typically, this metric assumes that the absorption of the renewable energy has a very high priority, and that renewable resources do not participate in automatic generation control (AGC) or load following because some amount of energy would be foregone (e.g., “spilled”). As the penetration of renewables increases, renewable resources may need to be “dispatchable” to accommodate the potential limitations or shortfalls of other dispatchable resources.

### Reserves

Ensuring that adequate reserves are available to manage deviations from expected conditions is an essential role for a NERC Balancing Authority, such as ISO New England. The number of hours in which reserves are deficient, or approaching a deficiency, are of great concern.

#### Purpose

The purpose of this metric is to quantify the amount and frequency of reserve deficiencies and/or the amount and frequency that reserves are approaching a deficient state.

#### Calculation

Compare the amount of reserves provided by the resource mix being modeled in the simulation with the target amount reserves desired for the simulation.

#### Units of Measure

Typically, this metric is expressed as a number of hours with deficient reserves.

#### Limitations

Using the typical one-hour time-step, no random forced outages and perfect foresight, the GridView model does not typically show reserve deficiencies. The GridView dispatch algorithm commits additional resources so that the required amounts of spinning reserve are available. In addition to committing additional dispatchable resources for spinning reserve, pumped storage resources are assumed to respond quick enough to count toward this operational requirement. Because of the “perfect foresight” assumption used in GridView’s unit commitment and dispatch, off-line available resources are never called on during the simulations.

For time frames shorter that one hour, the EPECS tool can be used to reflect real-time unit commitment economic dispatch decisions under uncertainty.

## Air Emission Metrics

Quantifying emissions at both a state and system-wide level is a desired metric. The primary emissions of concern in recent years is CO2. Interest in the emissions of NOx and SO2 has decreased, primarily due to the greatly decreased use of coal and oil, which was the primary source of these pollutants. Therefore, unless specifically requested, NOx and SO2 emission rates are not a focus for economic studies.

### CO2 Emissions

The amount of CO2 emissions are a primary concern in planning studies.

#### Purpose

To quantify the amount of CO2 emissions to facilitate comparisons between cases.

#### Calculation

Summation of tons of CO2 from each source and the emission by state.

#### Units of Measure

Typically, this metric is expressed in Short Tons per year (2,000 lb./ton-per-year), although many of the regulations express the requirements and goals in terms of Long Tons/Metric Tons per year (2,200 lb./ton-per-year).

#### Limitations

None

### CO2 Emissions vs. State and/or Regional Emission Targets

State and regional emission targets for CO2 have been established and this makes CO2 emissions an important metric. For example, Regional Greenhouse Gas Initiative (RGGI) sets CO2 emission targets for the New England states, but because of its cap and trade methodology, these are not state-specific limits. However, all the New England states have set individual CO2 emissions targets against which the simulated emissions can be compared.

#### Purpose

To quantify the amount of CO2 emissions to compare with a state or regional goal or target.

#### Calculation

Summation of tons of CO2 from each resource and a comparison with the state or regional goal or target. Care must be taken to know which resources are to be included and which resources are to be excluded. For example, in past economic studies, it was appropriate to ignore emissions from some stationary resources, such as units less than 25 MW, or those burning municipal solid waste or biomass.

#### Units of Measure

Typically, this metric is expressed in Short Tons per year (2,000 lb./ton-per-year), although many of the regulations express the requirements and goals in terms of Long Tons/Metric Tons per year (2,200 lb./ton-per-year).

#### Limitations

As described earlier, not all CO2 emissions are counted towards meeting the goals or requirements.

## Renewable Resource Energy Production vs. Renewable Portfolio Standards (RPS) Targets or Goals

The states have mandated Renewable Portfolio Standards (RPS), and set target levels of renewable resource energy production that must be obtained by LSEs, as the mechanism for verifying compliance with CO2 emissions reduction strategies that encourage the utilization of carbon-free or carbon-neutral energy sources.

### Renewable Resource Production vs. RPS Targets or Goals

#### Purpose

The purpose of this metric is to compare the amount of MWh generated from renewable resources to state or regional LSE portfolio requirements.

#### Calculation

Summation of tons of CO2 from each source and a comparison with RPS targets or goals.

#### Units of Measure

Typically, this metric is expressed as a comparison between the MWh of renewable energy generated and the MWh required to satisfy a state or regional mandate.

#### Limitations

Because of the complexities of the RPS standards, which place energy from similar resources in one “bucket” versus another bucket based on attributes like “new”versus. “existing as of a specified date,” the accounting has proven daunting and can only be addressed at a conceptual level.

### Spillage by Resource Type

“Spilled” or “curtailed” energy occurs when resource production exceeds the system’s ability to absorb or export (sell or “bank” the over-supplied power) due to transmission constraints. Spillage is most often studied when interconnecting large amounts of new renewable resources. State regulators have put a great deal of effort into encouraging renewable energy production and want to minimize events when available renewable energy is not absorbed into the system.

#### Purpose

Quantify the amounts of energy that could not be utilized due to either transmission constraints or insufficient load.

#### Calculation

Summation of the available MWhs from renewable-energy resources, by type, defined in the input data versus the amounts of renewable energy that could not be absorbed or exported by the system.

#### Units of Measure

Typically, this metric is expressed in GWh or TWh not absorbed/exported. It can also be expressed as a percentage of the available energy by resource type. Spillage is most often quantified at the annual or monthly level in economic studies.

#### Limitations

The amounts of spillage could change from hour-to-hour, day-to-day, month-to-month and year-to-year due to different climatic conditions.

1. The ISO’s stakeholders may request the ISO to initiate a Needs Assessment to examine situations where potential regulated transmission solutions or market responses or investments could result in (i) a net reduction in total production cost to supply system load based on the factors specified in Attachment N of this OATT, (ii) reduced congestion, or (iii) the integration of new resources and/or loads on an aggregate or regional basis (an “Economic Study”) [↑](#footnote-ref-2)
2. ISO New England Inc. uses the GE MARS software for LOLE assessments. This is the same software used for Installed Capacity Requirement (ICR) and Related Values development. The ISO has yet to develop a software tool to consider FCM pricing and has used outside consultants for these types of analyses. [↑](#footnote-ref-3)
3. In addition, a short brochure, provided by Hitachi-ABB, that highlights the main features of the GridView software is included at: <https://search.abb.com/library/Download.aspx?DocumentID=9AKK106930A8192&LanguageCode=en&DocumentPartId=A4-web&Action=Launch>. [↑](#footnote-ref-4)
4. The “pipe and bubble” configuration represents 13 sub-areas (or “bubbles”) of supply-side resources within the New England control area connected by simplified transmission models (or “pipes”). These “pipes” are a defined collection of specific transmission lines with assigned transfer limits. (Reference Figure 1 below) For additional information, see [https://www.iso-ne.com/about/key-stats/maps-and-diagrams#system-planning-subareas](https://www.iso-ne.com/about/key-stats/maps-and-diagrams%23system-planning-subareas). [↑](#footnote-ref-5)
5. Contact Information: Engineering Systems Analytics, LLC, 89 Washburn Hill Road, Lyme, NH 03768, Phone 646-724-0264 [↑](#footnote-ref-6)
6. <https://web.archive.org/web/20200202034529/http:/engineering.dartmouth.edu/liines/research/SPG/index.php> [↑](#footnote-ref-7)
7. The General Algebraic Modeling System, <https://www.gams.com/> [↑](#footnote-ref-8)
8. A. Muzhikyan, A. M. Farid, and K. Youcef-Toumi, “Variable Energy Resource Induced Power System Imbalances: A Generalized Assessment Approach,” in IEEE Conference on Technologies for Sustainability, (Portland, Oregon), pp. 1–8, 2013. <http://amfarid.scripts.mit.edu/resources/Conferences/SPG-C17.pdf>. [↑](#footnote-ref-9)
9. See “An Enterprise Control Assessment Method for Variable Energy Resource Induced Power System Imbalances. Part II; Parametric Sensitivity Analysis,” published 22 January 2015. <https://ieeexplore.ieee.org/document/7018074> [↑](#footnote-ref-10)
10. “Behind-the-Meter Photovoltaics Data Documentation,” <https://www.iso-ne.com/static-assets/documents/2020/07/btm_pv_data_documentation.pdf> [↑](#footnote-ref-11)
11. “Modeling of Battery Storage in Economic Studies,” <https://www.iso-ne.com/static-assets/documents/2020/12/a9_modeling_of_battery_storage_in_economic_studies.pdf> [↑](#footnote-ref-12)
12. Figure 1 is from the NESCOE 2019 Economic Study, which examined transmission system and wholesale market impacts associated with the increasing penetration of incremental offshore wind resources strategically placed in southern New England. See ISO New England, *2019 Economic Study: Offshore Wind Integration*, final report (June 30, 2020), <https://www.iso-ne.com/static-assets/documents/2020/06/2019_nescoe_economic_study_final.docx>. [↑](#footnote-ref-13)
13. For more information on RSP subareas, refer to the “System Planning Subareas” map at this ISO website link: https://www.iso-ne.com/about/key-stats/maps-and-diagrams/#system-planning-subareas. Also, refer to the ISO’s “Regional System Plan” webpage at <https://www.iso-ne.com/system-planning/system-plans-studies/rsp/>. [↑](#footnote-ref-14)
14. For example, see section 5.1 of the 2019 Anbaric Economic Study Report, <https://www.iso-ne.com/static-assets/documents/2020/10/2019-anbaric-economic-study-final.docx>. [↑](#footnote-ref-15)