

SEI Asia Centre

# Training on Low Emissions Analysis Platform

Day 3: 21 October 2021

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SWEDISH INTERNATIONAL  
DEVELOPMENT COOPERATION AGENCY

# Workshop registration

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**Please register your attendance daily**

Participants need to register for at least 3 days  
to be eligible for an attendance certificate

**Registration link day 3**

<https://tinyurl.com/SEIAsiaLEAPtraining-3408>

Password: Day03\$

# Workshop connection information

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## Web meetings

<https://tinyurl.com/SEIAsiaLEAPtraining>

Zoom meeting ID: 872 2041 5222

Zoom passcode: 353649

## Shared files

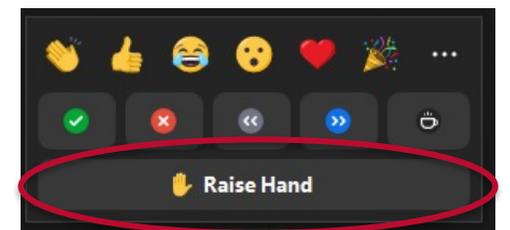
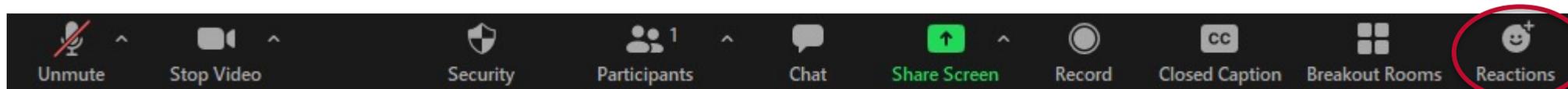
<https://tinyurl.com/SEIAsiaLEAPMaterials>

Password: seiasia1021

# Zoom etiquette

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- Please:
  - **Enter your name in Zoom** so meeting hosts can identify you in participant lists
  - **Mute yourself when not speaking**
  - Use your camera if possible
  - If you have a question, **raise your hand in Zoom**



# Workshop overview

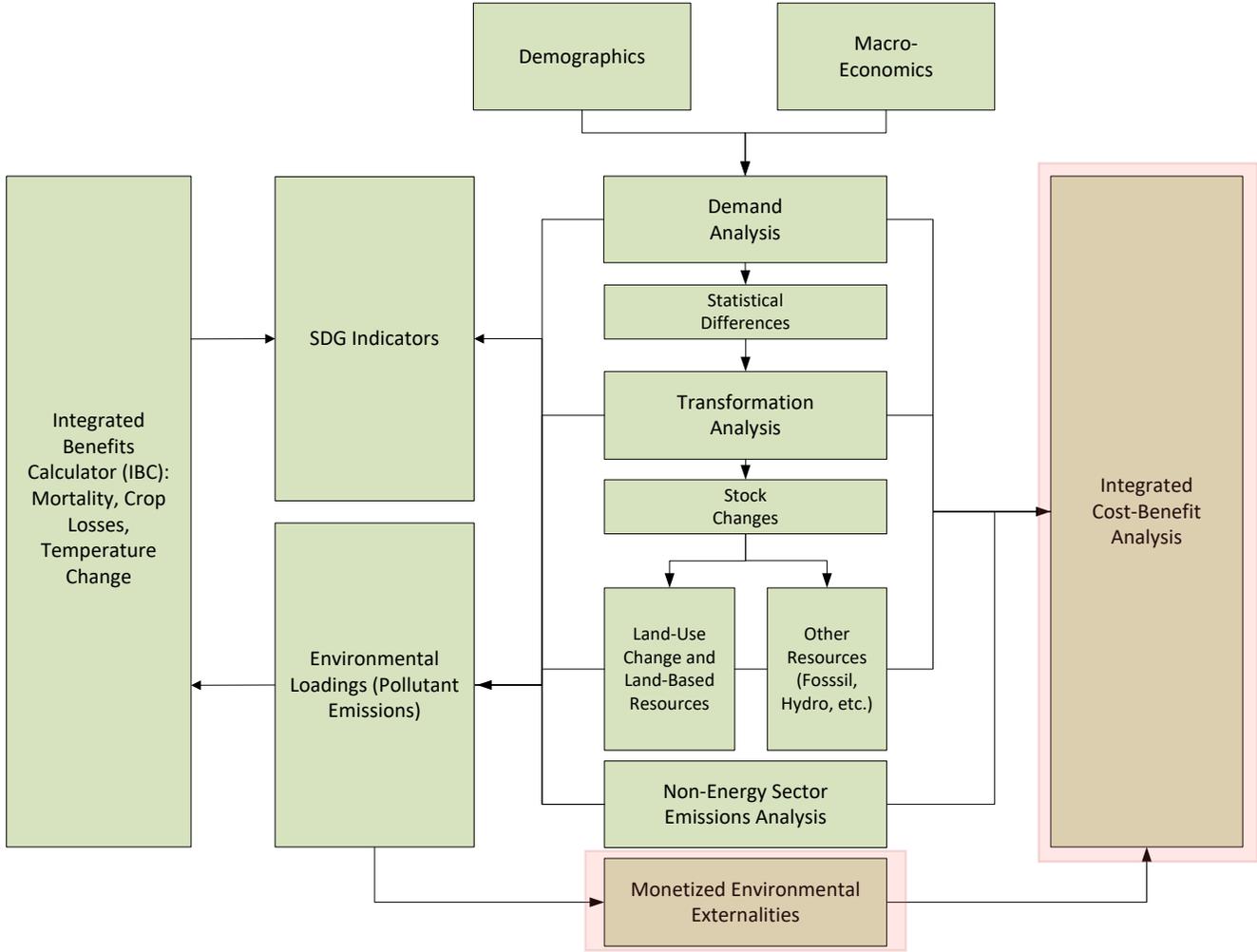
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- **Day 1:** Introduction to LEAP and energy demand modeling
- **Day 2:** Energy supply and emissions modeling
- **Day 3:** Cost-benefit analysis and optimization modeling
- **Day 4:** Linking LEAP and WEAP and other advanced topics

# Cost-benefit analysis with LEAP



# Structure of a representative LEAP analysis



# Cost-benefit analysis overview

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- **Costs** can be included in **energy and non-energy** modeling in LEAP
- Typically, **real social costs** are used
- Both **undiscounted** and **discounted** costs can be reported
- LEAP avoids double counting energy costs by drawing a consistent **boundary around costing analysis**



# Enabling cost modeling

Settings

Scope & Scale | Years | Costs | Calculations | Optimization | Internet | Folders | Scripts

Area:  
Name: Sample LEAP data set for fictional country "Freedonia". Use in conjunction with the LEAP Training Exercises.  
Freedonia

Scope:

- Demand
- Transformation & Resources
- Land-Use Change & Land-Based Resources
- Statistical Differences & Stock Changes
- Costs**
- Energy Effects
- Non-Energy Effects
- Complex Effects
- Health, Ecosystem & Climate Impacts (IBC)
- Extraction-Based Accounting of Effects
- Map Results to Grid
- Indicators

Results to Save:  
 All  Selected: [Choose](#)

Scale:

- Global
- Multinational
- National
- Sub-National
- Undefined

Country: [Fictitious or Example Data](#)  
*IBC not available.*

User Information: Not Available

Property	Value
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[Edit your user profile](#)

Close Help

Settings

Scope & Scale | Years | **Costs** | Calculations | Optimization | Internet | Mapping | Folders | Scripts

Cost-benefit calculation boundary: [Transmission and Distribution](#)

- Environmental externality costs
- Foreign exchange fraction of costs

Capital cost annualization method: [Capital Recovery Factor \(Default\)](#)

Discount rate: [5](#)

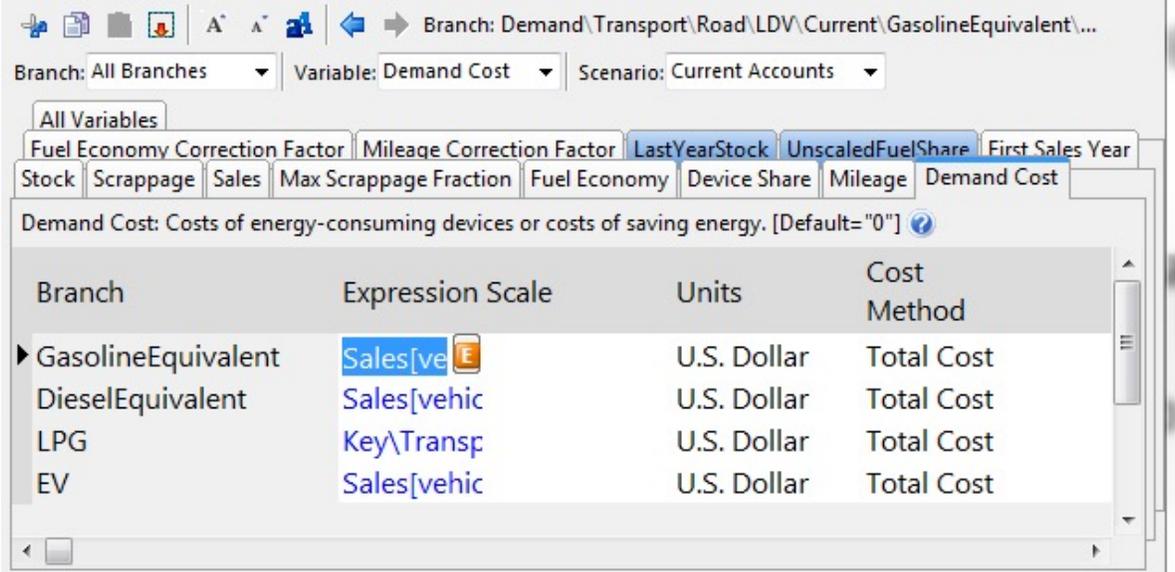
Inflation rate: [0](#)

Close Help

# Energy demand costs

## Several costing methods supported

- *Costs per activity*
  - E.g., cost per vehicle-km traveled
- *Total annual costs*
  - E.g., total annual costs of a driver education program
- *Cost of saved energy relative to a reference scenario*
  - E.g., incremental costs per unit energy saved due to efficiency retrofits of long-haul trucks



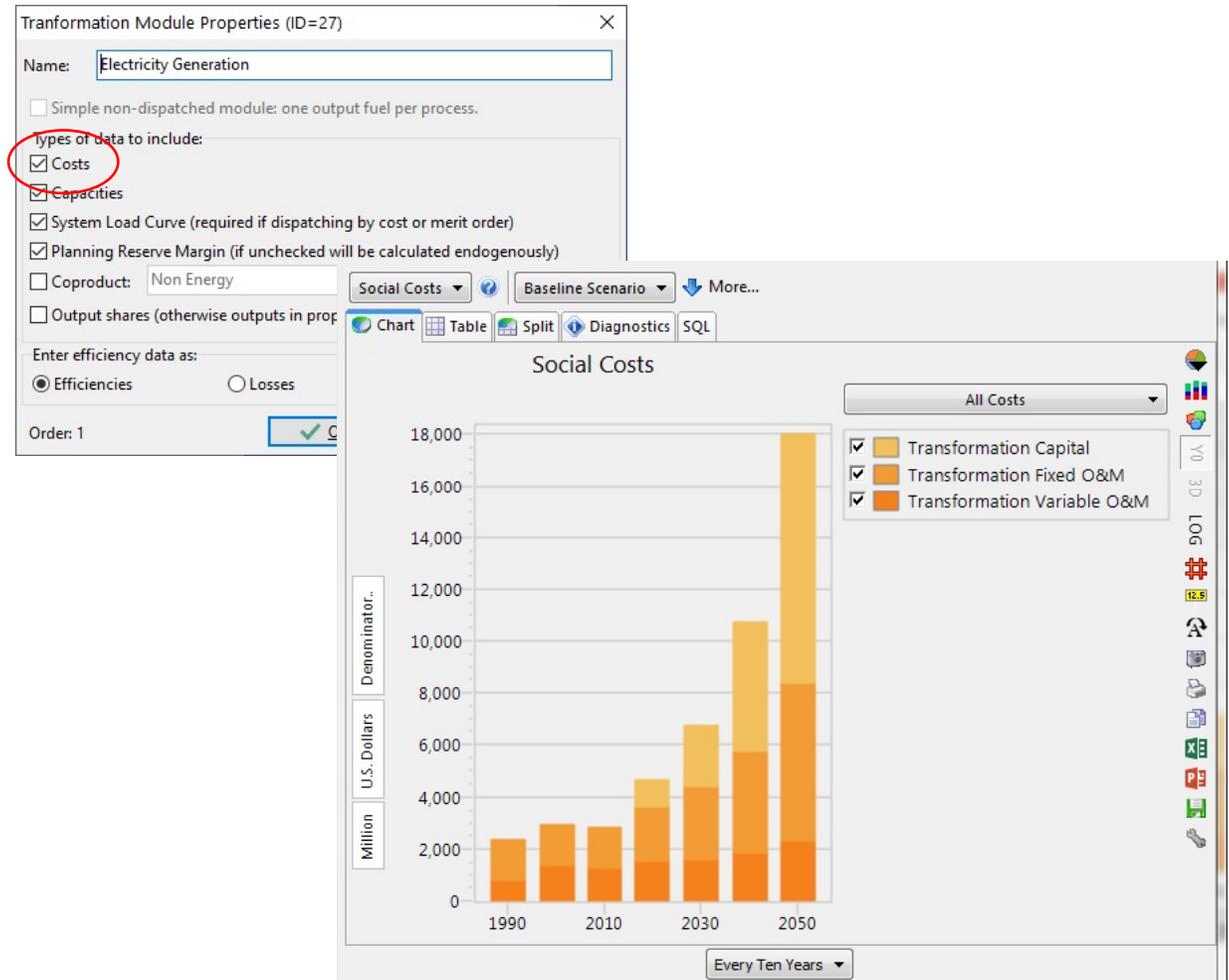
The screenshot shows a software interface for defining demand costs. At the top, there are navigation and filter options: Branch: Demand\Transport\Road\LDV\Current\GasolineEquivalent\..., Variable: Demand Cost, and Scenario: Current Accounts. Below this, there are tabs for various variables: All Variables, Fuel Economy Correction Factor, Mileage Correction Factor, LastYearStock, UnscaledFuelShare, First Sales Year, Stock, Scrappage, Sales, Max Scrappage Fraction, Fuel Economy, Device Share, Mileage, and Demand Cost. The 'Demand Cost' tab is active, showing a description: 'Demand Cost: Costs of energy-consuming devices or costs of saving energy. [Default="0"]'. Below the description is a table with four columns: Branch, Expression Scale, Units, and Cost Method.

Branch	Expression Scale	Units	Cost Method
GasolineEquivalent	Sales[ve	U.S. Dollar	Total Cost
DieselEquivalent	Sales[vehic	U.S. Dollar	Total Cost
LPG	Key\Transp	U.S. Dollar	Total Cost
EV	Sales[vehic	U.S. Dollar	Total Cost

Demand costs exclude fuel costs  
(these are calculated separately on  
supply side of model)

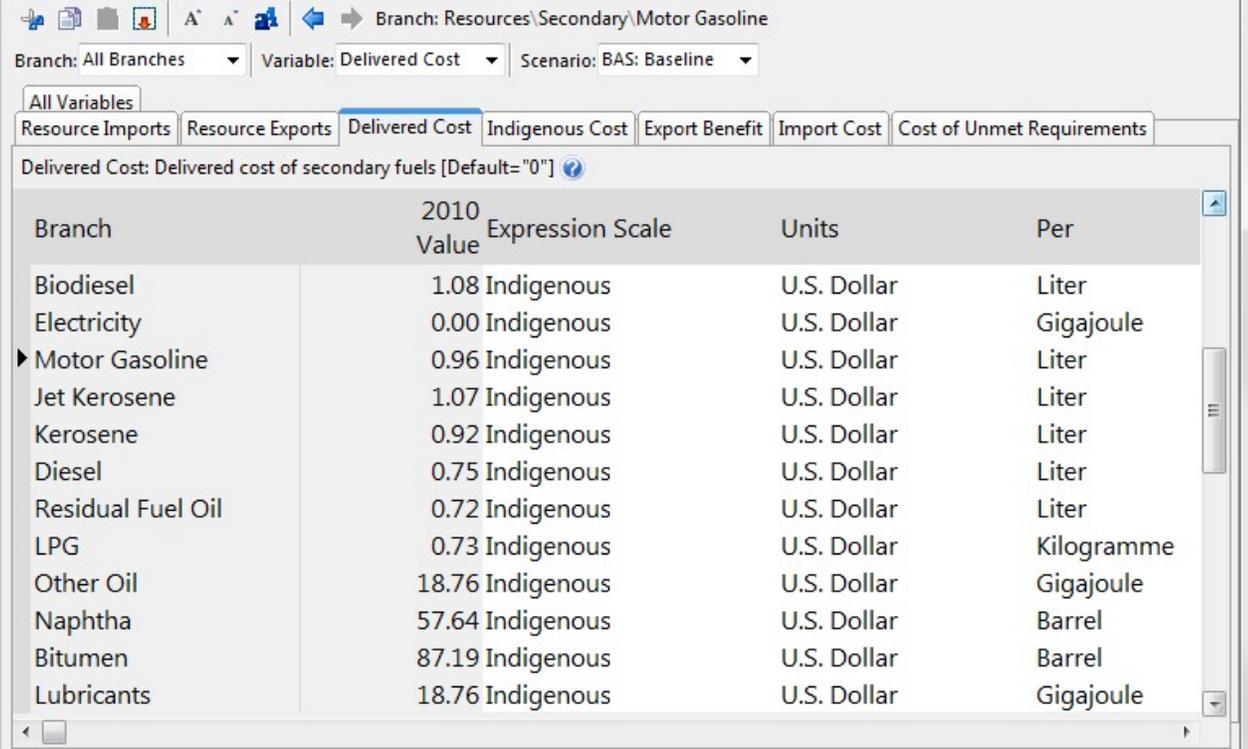
# Energy transformation costs

- Considered for transformation modules inside costing boundary and for which costing is activated
- Can include:
  - Capital costs (amortized using process-specific interest rates)
  - Fixed and variable O&M costs
  - Decommissioning costs
  - Other industry (module) costs
- Fuel input costs calculated separately based on costs of other modules and resource costs



# Resource costs

- Import costs and export benefits
- Depletion/extraction costs (indigenous costs)
- Social costs of unmet requirements for fuels (e.g., costs of brown-outs due to inadequate electricity supply)



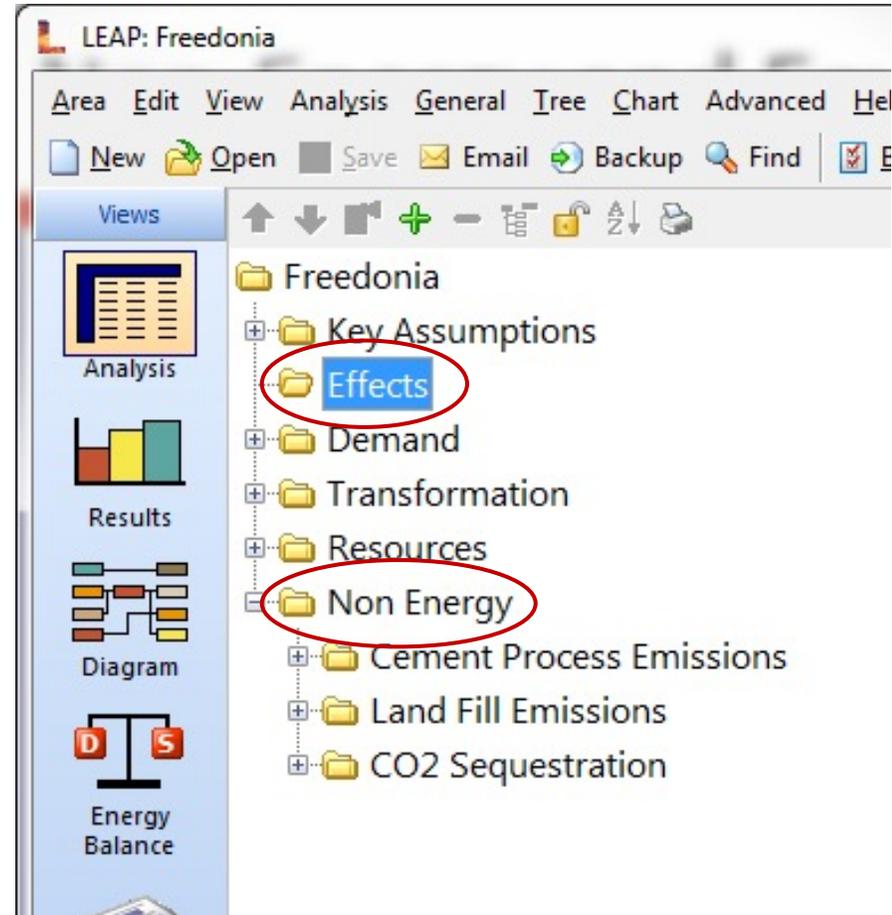
The screenshot shows a software interface with a toolbar at the top and a main data table. The toolbar includes icons for copy, paste, print, and zoom, along with a navigation arrow. The main area has a header with 'Branch: Resources\Secondary\Motor Gasoline', 'Branch: All Branches', 'Variable: Delivered Cost', and 'Scenario: BAS: Baseline'. Below this are tabs for 'All Variables', 'Resource Imports', 'Resource Exports', 'Delivered Cost', 'Indigenous Cost', 'Export Benefit', 'Import Cost', and 'Cost of Unmet Requirements'. The 'Delivered Cost' tab is active, showing a table of data for various fuel types.

Branch	2010 Value	Expression Scale	Units	Per
Biodiesel	1.08	Indigenous	U.S. Dollar	Liter
Electricity	0.00	Indigenous	U.S. Dollar	Gigajoule
▶ Motor Gasoline	0.96	Indigenous	U.S. Dollar	Liter
Jet Kerosene	1.07	Indigenous	U.S. Dollar	Liter
Kerosene	0.92	Indigenous	U.S. Dollar	Liter
Diesel	0.75	Indigenous	U.S. Dollar	Liter
Residual Fuel Oil	0.72	Indigenous	U.S. Dollar	Liter
LPG	0.73	Indigenous	U.S. Dollar	Kilogramme
Other Oil	18.76	Indigenous	U.S. Dollar	Gigajoule
Naphtha	57.64	Indigenous	U.S. Dollar	Barrel
Bitumen	87.19	Indigenous	U.S. Dollar	Barrel
Lubricants	18.76	Indigenous	U.S. Dollar	Gigajoule

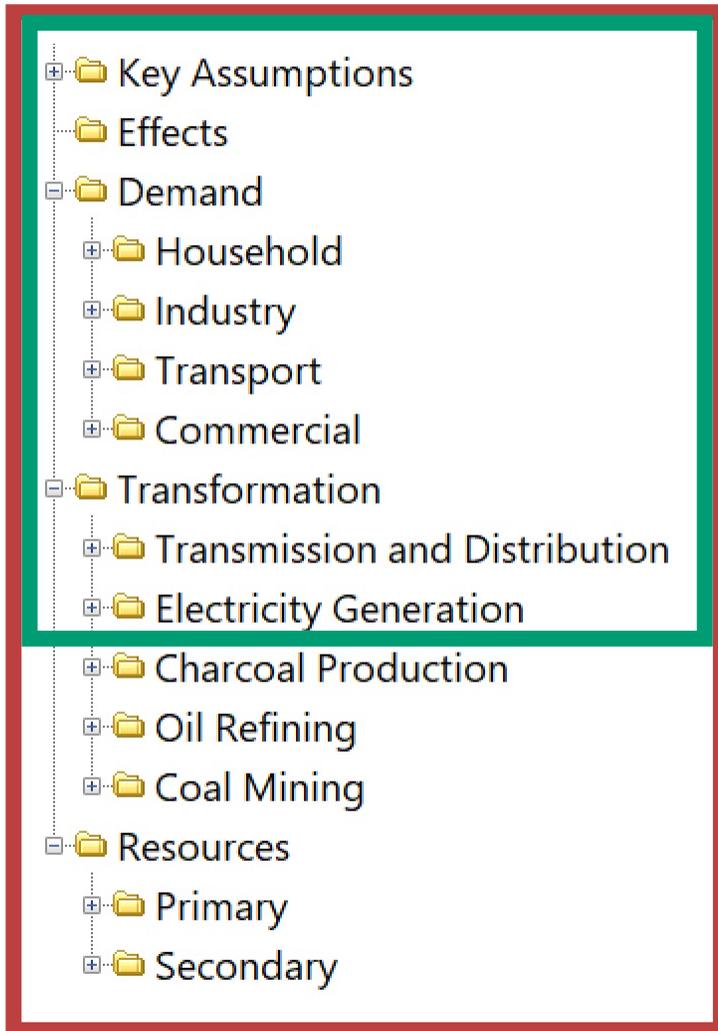
# Non-energy and pollutant costs

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- Non-energy – defined for non-energy emissions
  - Total costs of annual emissions of a pollutant from a source
- Environmental externalities – defined for selected pollutants
  - Costs per unit of emissions



# Costing boundary



## Red box: *complete energy system*

- Energy demand costs
- Bottom-up costing for all energy transformation modules
- Resource import, export, and extraction costs

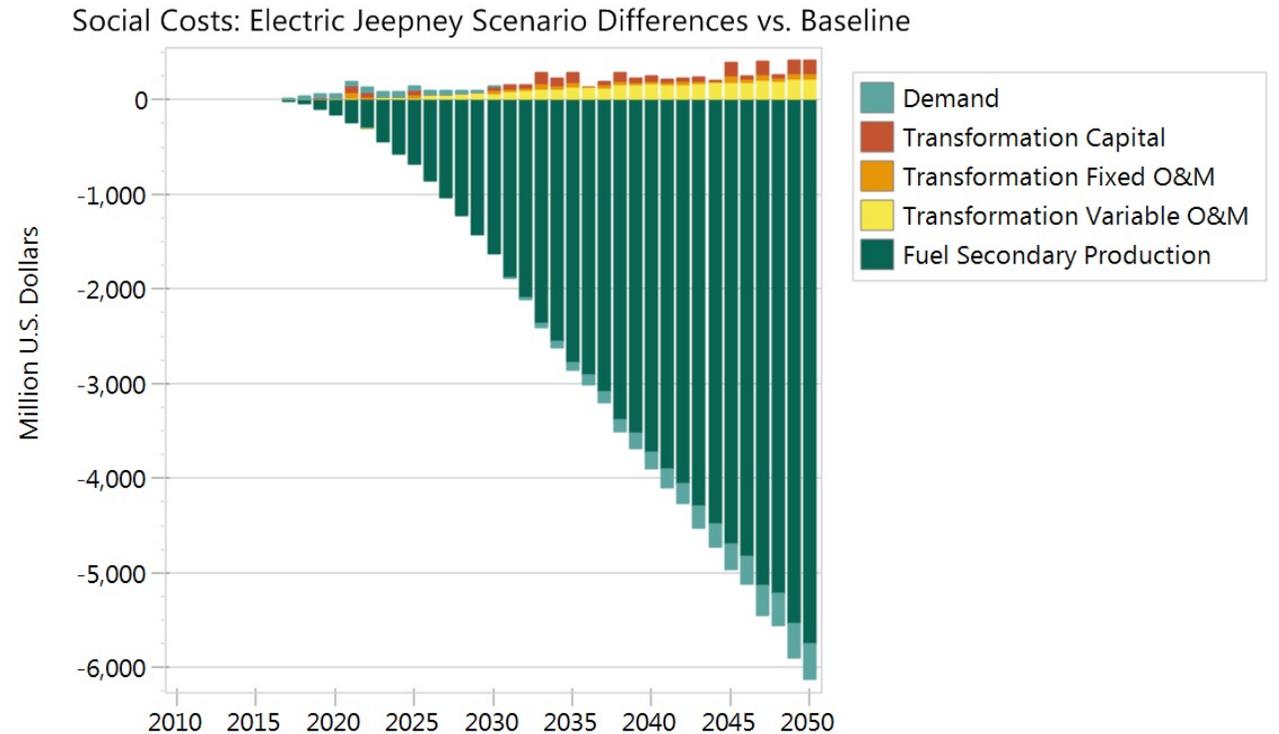
## Green box: *subset of energy system*

- Energy demand costs
- Bottom-up costing for transformation modules within boundary
- Bottom-up production costs in other modules and resource import, export, and extraction costs *not* used => instead, a **“delivered cost”** is used for fuels produced outside boundary

Non-energy and pollutant costs not affected by boundary

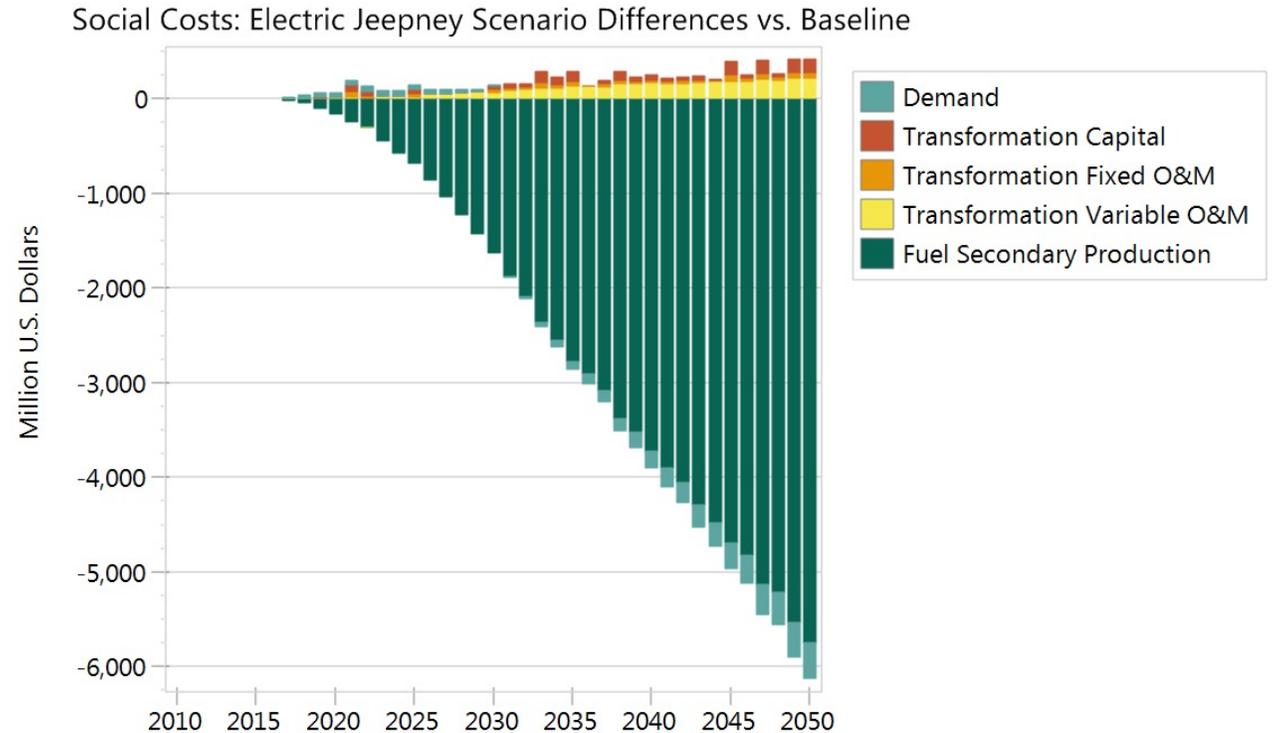
# Cost reporting in Results view

- Real or discounted costs
- Annual or cumulative costs
- All or selected cost types/categories (e.g., demand, fuel)
- Incremental costs of one scenario compared to another
- Currency conversions



# Cost reporting in Results view

- Real or **discounted** costs
- Annual or **cumulative** costs
- All or selected cost types/categories (e.g., demand, fuel)
- **Incremental** costs of one scenario compared to another
- Currency conversions



# Optimization modeling with LEAP and NEMO



# How to model energy systems?

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- Investment
- Operations
- Impacts
- Limits
- Vulnerabilities



# A common approach: least-cost optimization

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Meet energy requirements while minimizing discounted energy system costs

- Capital
- Operation & maintenance (O&M)
- Fuel imports and exports
- Salvage values
- Environmental externalities

*Real costs, typically  
quantified from a social  
perspective*

# Basic rationale

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- **Efficiency**
  - *Other things being equal, it makes sense to meet requirements in the least costly way*
- **Planner's perspective**
  - *It's what a planner would do*
- **Market dynamics**
  - *It's a reasonable approximation of how (some) energy markets operate*
- **Technical specificity**
  - *It accounts for important physical features of energy technologies*

*An idealization,  
but a potentially  
useful one*

# Mathematical formulation

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*minimize:*  $\sum$  *discounted energy system costs*

*subject to:*  $g_i(\mathbf{x}) \leq 0 \quad i = 1, \dots, m$

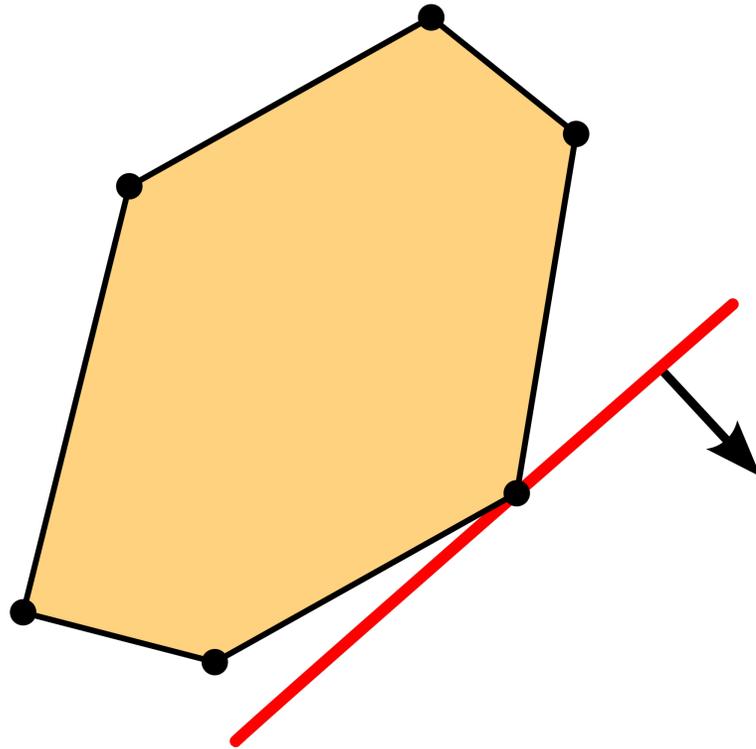
*and:*  $h_j(\mathbf{x}) = 0 \quad j = 1, \dots, n$

*and:*  $\mathbf{x}^L \leq \mathbf{x} \leq \mathbf{x}^U$

- Sum of discounted costs is **objective function**
- $\mathbf{x}$  is a vector of **model variables** (e.g., capacity built; values determined by model)
- $g(\mathbf{x})$  and  $h(\mathbf{x})$  are **constraints** (e.g., operating limits, accounting identities, demand requirements)
- $\mathbf{x}^L$  and  $\mathbf{x}^U$  are **lower and upper bounds** for variables
- Modeler can specify other (exogenous) values in constraints and objective function – these are **parameters** (e.g., power plant efficiencies)

# Graphical interpretation

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- A simple linear program with two variables
- The set of feasible solutions is the yellow polygon
- Each line on the polygon is a particular constraint
- The linear cost function is represented by the red line and the arrow: the arrow indicates the direction of optimization (cost minimization)

# Full vs. partial energy system optimization

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- Some tools allow for **full energy system optimization**
  - Starting with useful energy requirements (e.g., for transport or heating), they identify least cost configuration of entire energy system subject to constraints
  - Examples include NEMO, TIMES/MARKAL, MESSAGE, HOMER, and OSeMOSYS
- Others support **partial energy system optimization**
  - Only selected sectors can be modeled – typically, electricity production
  - Examples include LEAP, WASP, and PLEXOS
- In practice, **most optimization analyses focus on energy supply**

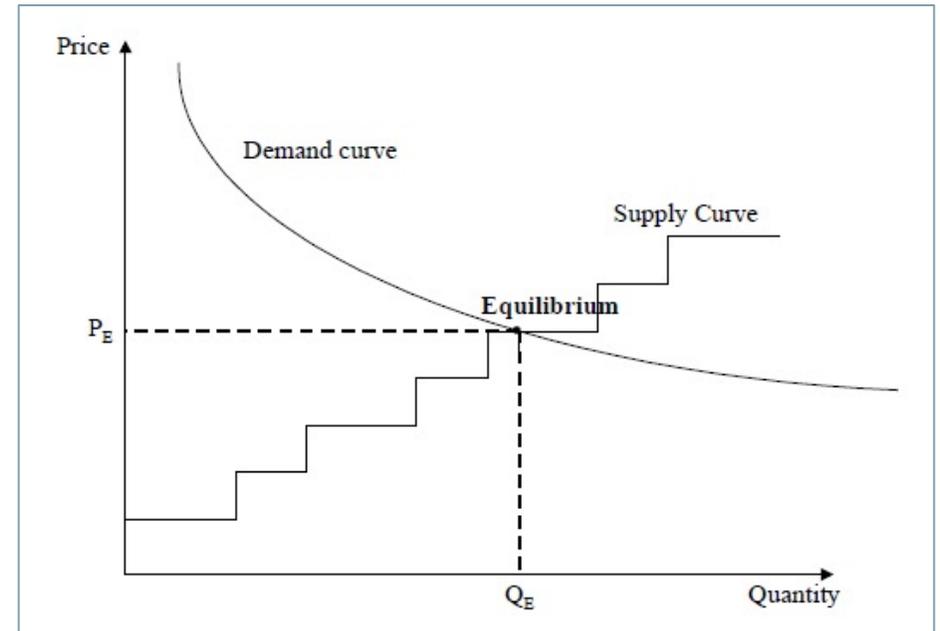
# Fixed demand vs. partial equilibrium

## Fixed demand

- Demand does not depend on supply
- Demand determined first, then supply found through optimization

## Partial equilibrium

- Demand subject to price elasticity, price depends on supply
  - Supply-demand equilibrium found through optimization
  - Motivated by neoclassical economic hypotheses:
    - Competitive markets
    - Profit-maximizing firms
    - Utility-maximizing consumers
- 
- Most energy system models consider demand to be fixed



# Perfect vs. limited foresight

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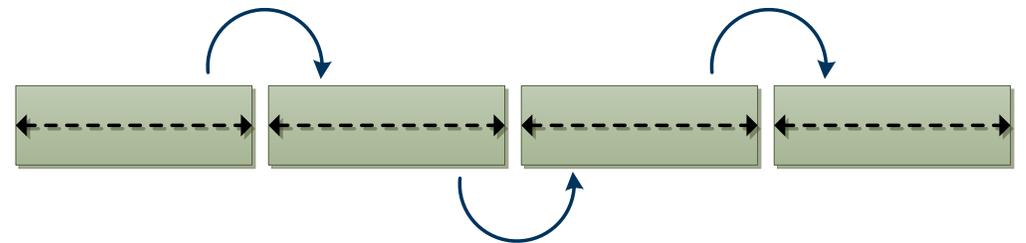
## Perfect foresight

- Costs for all years in planning horizon minimized simultaneously (global optimum found)



## Limited foresight

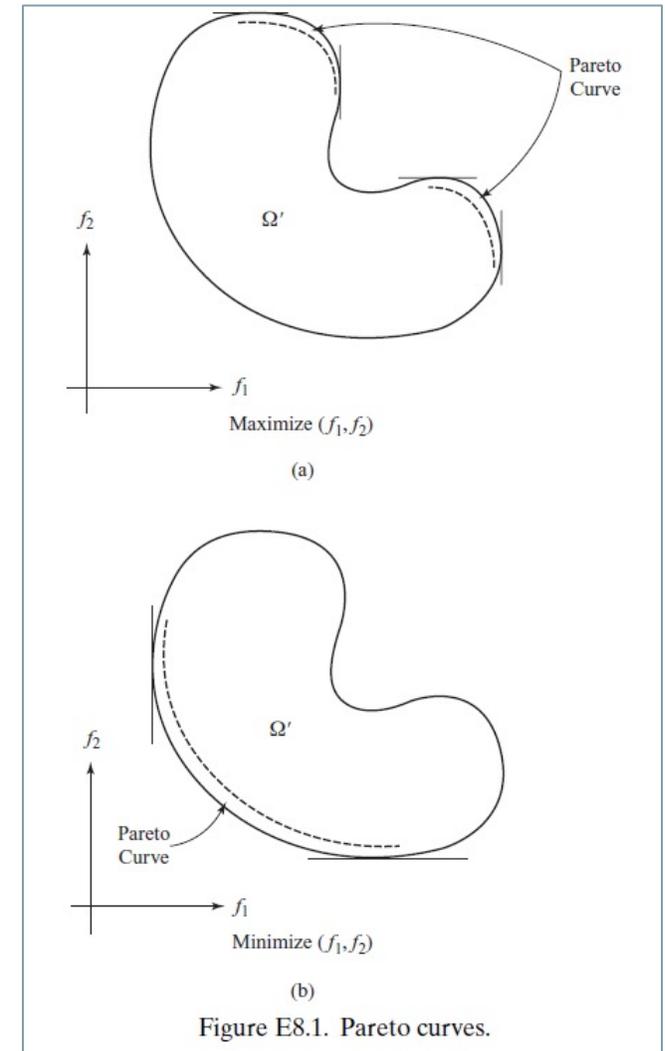
- Costs for subsets of years minimized
- Results from first interval provide starting conditions for second, and so on



# Multi-objective optimization

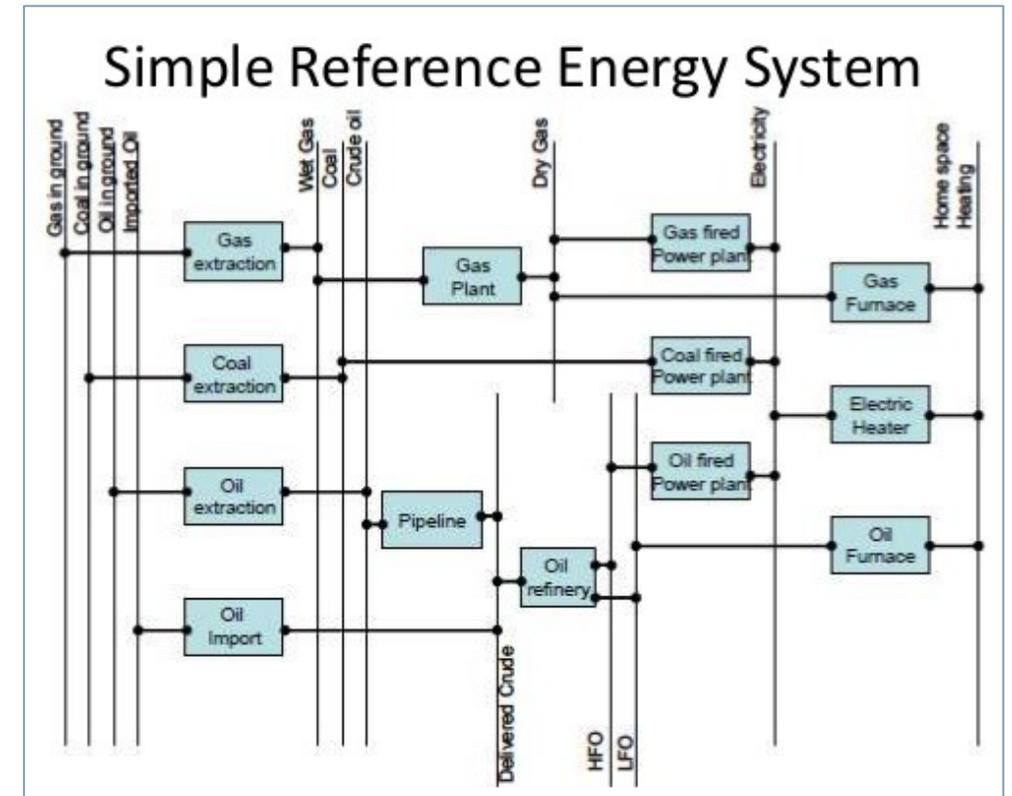
*Pareto-optimum: can't improve one objective without worsening another*

- Minimize costs *and*
  - Minimize environmental impacts
  - Maximize energy independence
  - ...
- Various approaches
  - Weight objectives
  - Optimize primary objective but with limits on allowed values for others
  - Find Pareto-optimum solutions and choose the one that minimizes the maximum deviation from single-objective optima (“min-max”)



# Reference energy system

- A common way of conceptualizing **structure of energy optimization models**
- A **network description** of an energy system showing **connections between energy producers and consumers**
  - How does energy flow from primary resources to consumers?
  - What provides energy to what, and with what transformations?
- Lends itself to bottom-up, technologically explicit modeling
- Provides a framework for defining technical and cost characteristics of energy production – a basis for optimization



# Computation

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**Special-purpose software tools are used to specify models** as a linear or non-linear programming problem (depending on linearity of objective and constraints)

- GAMS
- MATLAB
- Julia
- Or even Excel for simple models

Most tools work in concert with separate **“solvers,”** which are used to find the solution to a problem (if there is one!). Some solvers are open source and free, such as:

- GLPK
- COIN-OR (Cbc/Clp)

Others are commercially available but are faster and capable of handling more difficult problems. Examples include:

- CPLEX
- Gurobi
- Mosek
- FICO Xpress

**LEAP and NEMO work with all of the solvers above**

# Practical considerations

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## Data intensiveness

- Optimization requires considerably more data than some other approaches to energy modeling (e.g., trends analysis, professional judgement)
  - Particularly costs: capital, O&M, etc.
  - Current and projected values needed
- Requirements can be lessened with a more aggregate model structure, but this risks eliding important system dynamics

# Practical considerations

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## Sensitivity and plausibility

- Many optimization models are quite sensitive to their parameters (exogenous inputs)
- Their initial tendency is to produce a corner solution – e.g., building only one technology
- This compels modeler to add constraints to attain a plausible result
- The content of these iteratively determined constraints is critically important – in many ways, it decides the outcome!



# Practical considerations

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## Complexity and performance

- Optimization modeling is computationally intense
- There is a significant trade-off between model specificity / resolution / complexity and run time
  - Important drivers: numbers of dimensions (e.g., years, technologies) and constraints
- Key points to keep in mind:
  - What questions is the modeling trying to answer?
  - What dynamics affect these questions?
- Long-term and short-term models typically have very different resolutions

# NEMO: Next Energy Modeling system for Optimization

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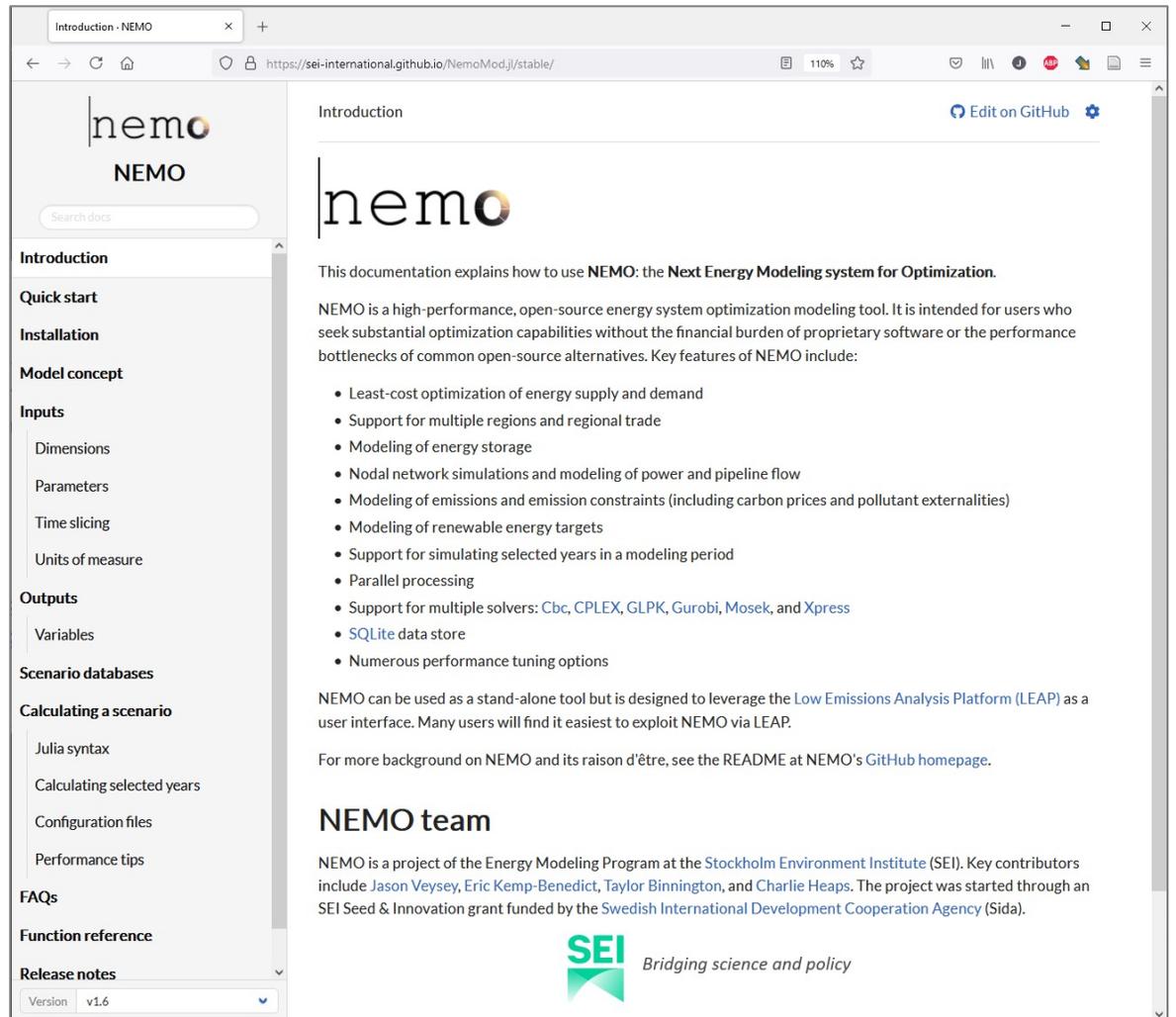
- High performance, open source energy system optimization tool
- Integrates with LEAP as a graphical user interface
- Key features for decarbonization and electricity system analyses
  - Energy storage
  - Nodal networks, power and pipeline flow
  - Emission and renewable energy targets
  - Carbon/pollutant pricing
  - Regional modeling and energy trade
- Parallel processing
- Support for simulating selected years in a modeling period
- Compatible with multiple solvers; numerous performance tuning options



<https://leap.sei.org/nemo>

# Code and documentation

- NEMO is programmed in **Julia**, a high performance language for mathematical computing
- Code available at:  
<https://github.com/sei-international/NemoMod.jl>
- Full documentation online at:  
<https://sei-international.github.io/NemoMod.jl/stable/>



The screenshot shows a web browser displaying the NEMO documentation page. The page title is "Introduction - NEMO" and the URL is "https://sei-international.github.io/NemoMod.jl/stable/". The page features a navigation sidebar on the left with sections like "Introduction", "Quick start", "Installation", "Model concept", "Inputs", "Outputs", "Scenario databases", "Calculating a scenario", "FAQs", "Function reference", and "Release notes". The main content area is titled "Introduction" and contains the NEMO logo and a list of key features. The SEI logo and tagline "Bridging science and policy" are visible at the bottom right.

Introduction

**nemo**  
NEMO

Search docs

**Introduction**

**Quick start**

**Installation**

**Model concept**

**Inputs**

- Dimensions
- Parameters
- Time slicing
- Units of measure

**Outputs**

- Variables

**Scenario databases**

**Calculating a scenario**

- Julia syntax
- Calculating selected years
- Configuration files
- Performance tips

**FAQs**

**Function reference**

**Release notes**

Version v1.6

**nemo**

This documentation explains how to use **NEMO**: the **Next Energy Modeling system for Optimization**.

NEMO is a high-performance, open-source energy system optimization modeling tool. It is intended for users who seek substantial optimization capabilities without the financial burden of proprietary software or the performance bottlenecks of common open-source alternatives. Key features of NEMO include:

- Least-cost optimization of energy supply and demand
- Support for multiple regions and regional trade
- Modeling of energy storage
- Nodal network simulations and modeling of power and pipeline flow
- Modeling of emissions and emission constraints (including carbon prices and pollutant externalities)
- Modeling of renewable energy targets
- Support for simulating selected years in a modeling period
- Parallel processing
- Support for multiple solvers: Cbc, CPLEX, GLPK, Gurobi, Mosek, and Xpress
- SQLite data store
- Numerous performance tuning options

NEMO can be used as a stand-alone tool but is designed to leverage the Low Emissions Analysis Platform (LEAP) as a user interface. Many users will find it easiest to exploit NEMO via LEAP.

For more background on NEMO and its raison d'être, see the README at NEMO's GitHub homepage.

**NEMO team**

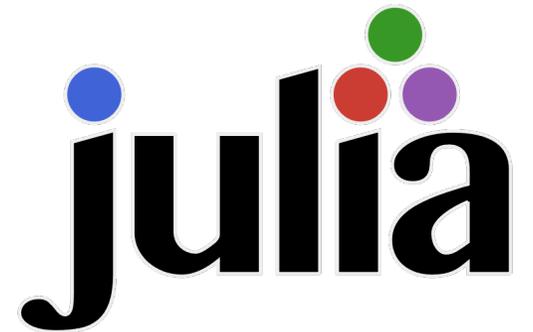
NEMO is a project of the Energy Modeling Program at the Stockholm Environment Institute (SEI). Key contributors include Jason Veysey, Eric Kemp-Benedict, Taylor Binnington, and Charlie Heaps. The project was started through an SEI Seed & Innovation grant funded by the Swedish International Development Cooperation Agency (Sida).

**SEI** Bridging science and policy

# Prerequisites

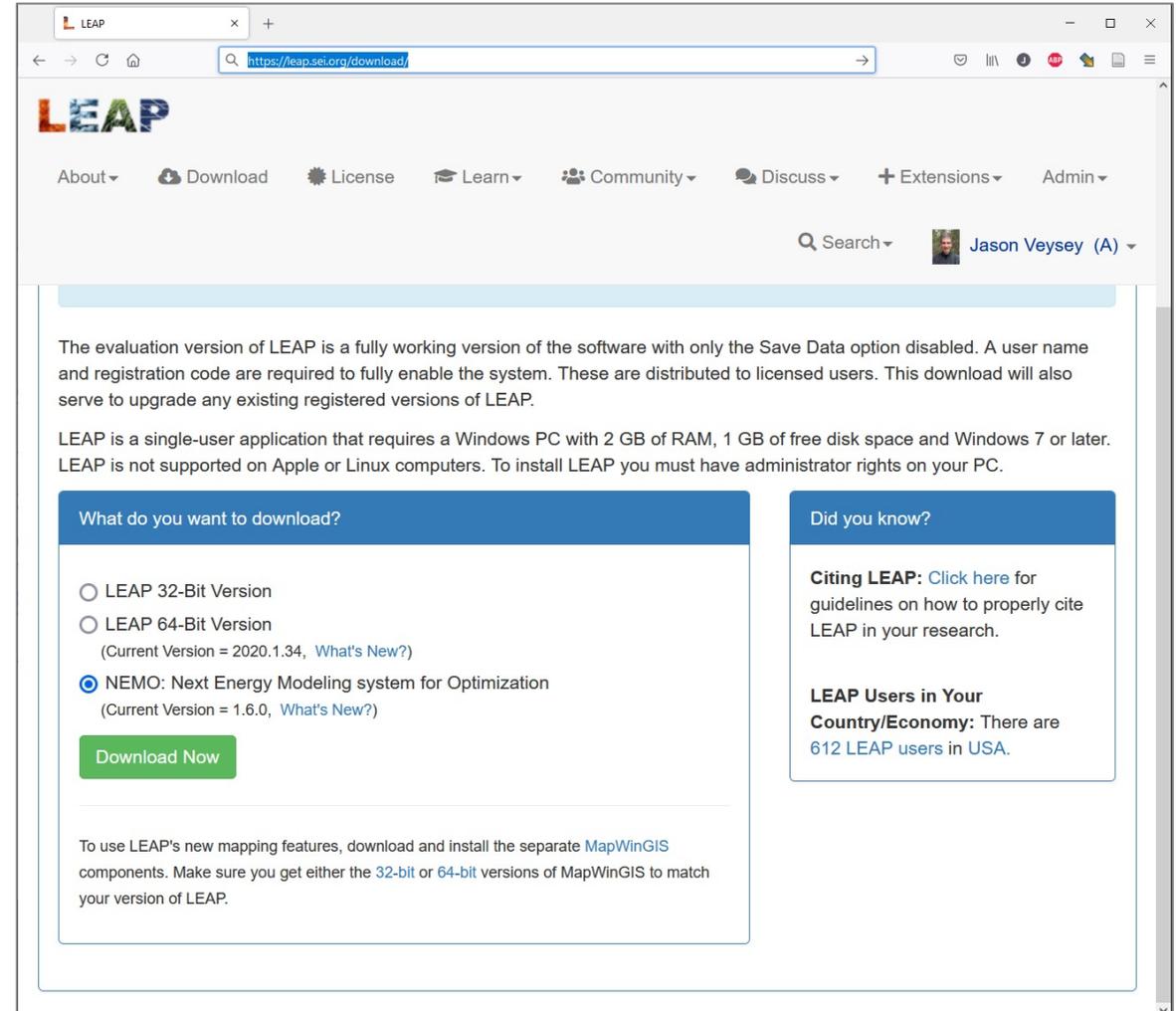
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- NEMO can run on **any system compatible with Julia**:  
Windows, macOS, Linux, FreeBSD
- **To use NEMO with LEAP, a Windows computer is necessary**
- Hardware requirements depend on model size; for most models, following specifications are advisable:
  - **Multi-core processor**
  - **At least 8 GB RAM**
  - **At least 500 MB free disk space**
- **Administrator privileges** facilitate installation



# Installation

- For best performance with LEAP, install NEMO with installer program on LEAP website (<https://leap.sei.org/download/>)
- Can also install from source code – directions at <https://se-international.github.io/NemoMod.jl/stable/installation/>



The screenshot shows a web browser window displaying the LEAP website's download page. The browser's address bar shows the URL <https://leap.sei.org/download/>. The website header includes the LEAP logo and a navigation menu with links for About, Download, License, Learn, Community, Discuss, Extensions, and Admin. A search bar and a user profile for Jason Veysey (A) are also visible.

The main content area contains the following text:

The evaluation version of LEAP is a fully working version of the software with only the Save Data option disabled. A user name and registration code are required to fully enable the system. These are distributed to licensed users. This download will also serve to upgrade any existing registered versions of LEAP.

LEAP is a single-user application that requires a Windows PC with 2 GB of RAM, 1 GB of free disk space and Windows 7 or later. LEAP is not supported on Apple or Linux computers. To install LEAP you must have administrator rights on your PC.

Below this text is a section titled "What do you want to download?" with three radio button options:

- LEAP 32-Bit Version
- LEAP 64-Bit Version (Current Version = 2020.1.34, [What's New?](#))
- NEMO: Next Energy Modeling system for Optimization (Current Version = 1.6.0, [What's New?](#))

A green "Download Now" button is positioned below these options.

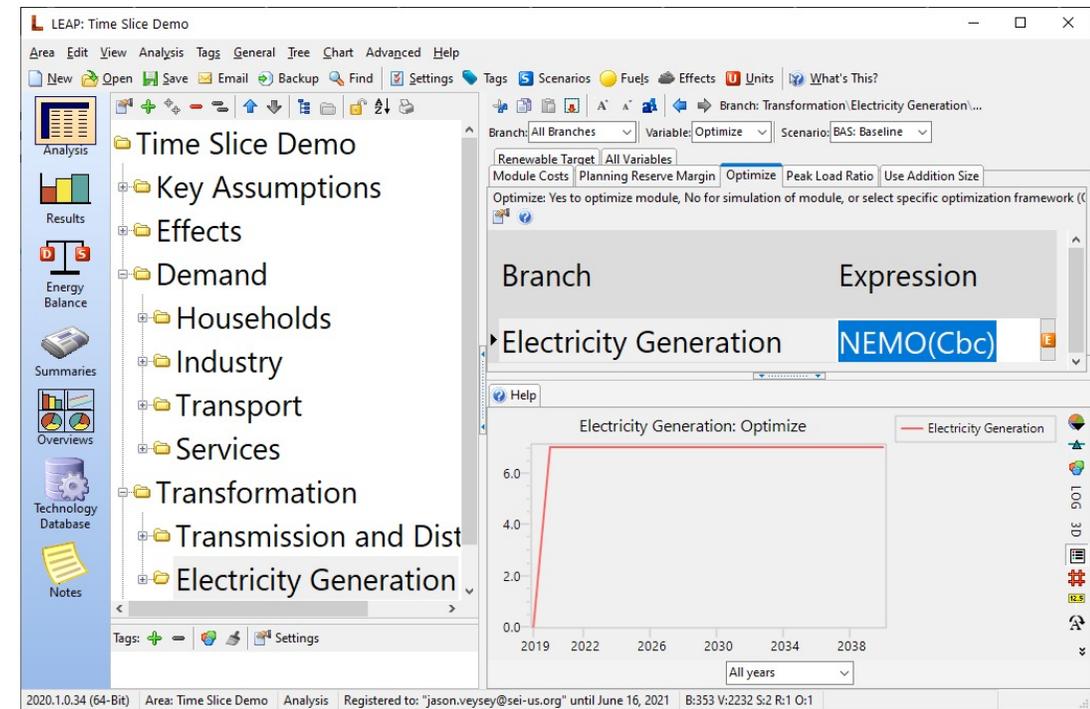
At the bottom of the page, there is a note: "To use LEAP's new mapping features, download and install the separate [MapWinGIS](#) components. Make sure you get either the 32-bit or 64-bit versions of MapWinGIS to match your version of LEAP."

On the right side of the page, there is a "Did you know?" sidebar with two sections:

- Citing LEAP:** [Click here](#) for guidelines on how to properly cite LEAP in your research.
- LEAP Users in Your Country/Economy:** There are **612 LEAP users in USA.**

# Enabling optimization in LEAP

- At present, LEAP can optimize one transformation module (supply sector) in a model
- Module-level Optimize variable activates optimization with NEMO and selects solver
  - Optimize only available in projection scenarios
- Costs and capacities must be enabled in optimized module, and process costs (including fuel costs) and performance parameters must be populated
- Optimized results are calculated and displayed when Results View is selected



# Additional variables in optimized modules

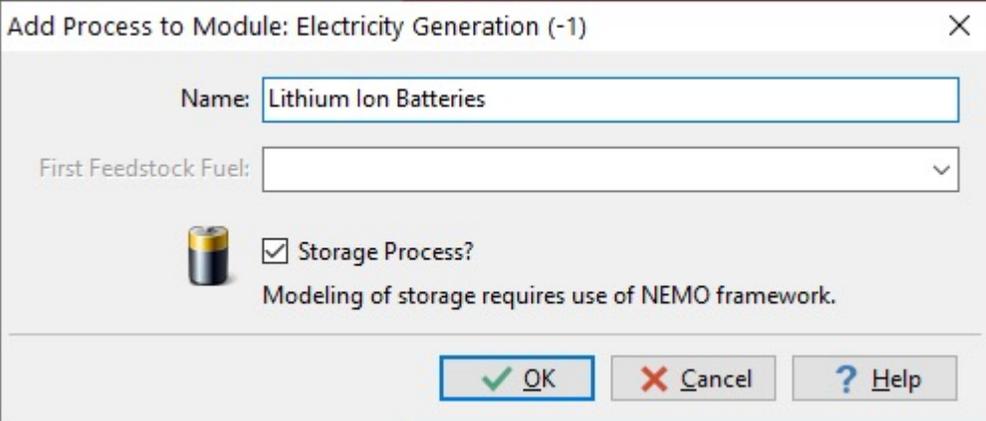
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- LEAP provides a number of additional variables in Analysis View for optimized modules
- These allow **specification of various constraints on optimization**, e.g.:
  - Renewable energy production targets
  - Minimum and maximum capacity and capacity additions
  - Discrete addition sizes for new capacity
  - Operating rules for storage

Carefully review variables and documentation (help)  
when calibrating an optimization model

# Modeling energy storage

- When used with NEMO, LEAP can simulate energy storage
- In an optimized module, processes can be identified as storage when they are created
- In addition to normal process variables, LEAP displays a number of storage-specific variables used to control simulation in NEMO
  - Starting Charge
  - Minimum Charge
  - Full Load Hours
  - Energy carryover rules



Add Process to Module: Electricity Generation (-1)

Name:

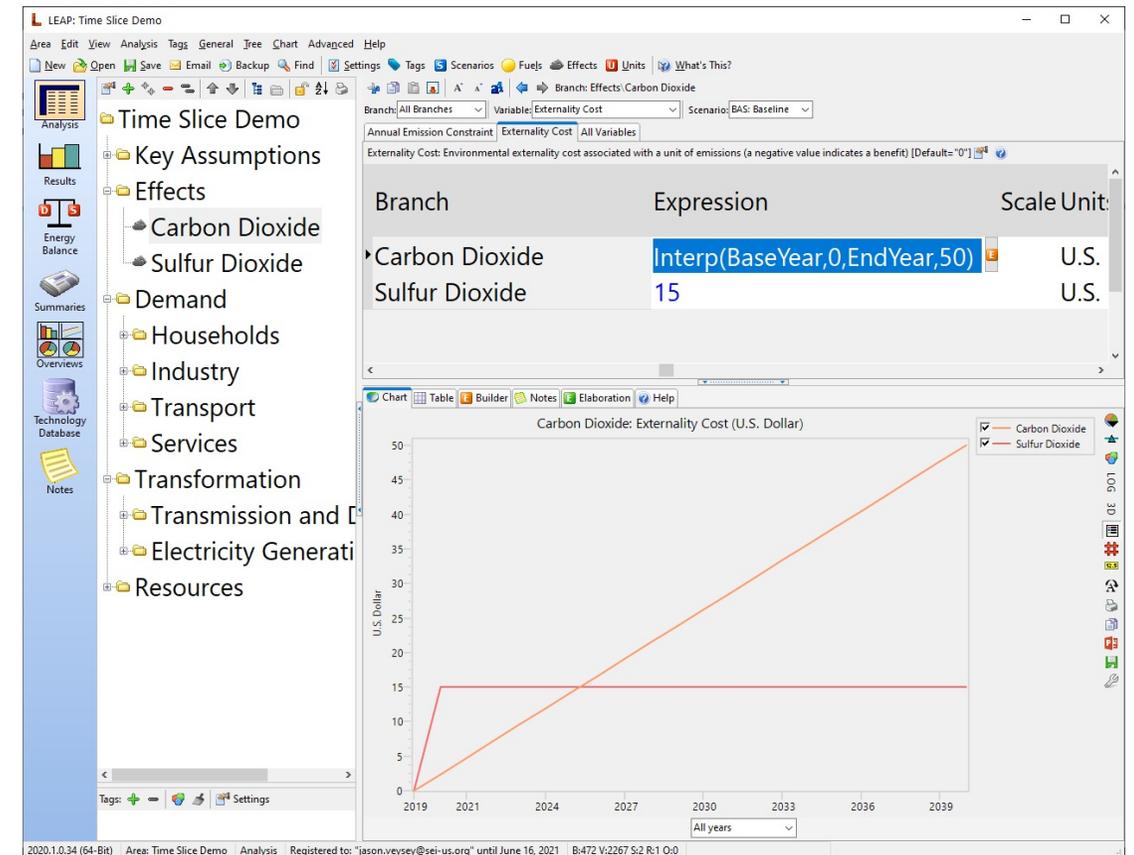
First Feedstock Fuel:

  Storage Process?

Modeling of storage requires use of NEMO framework.

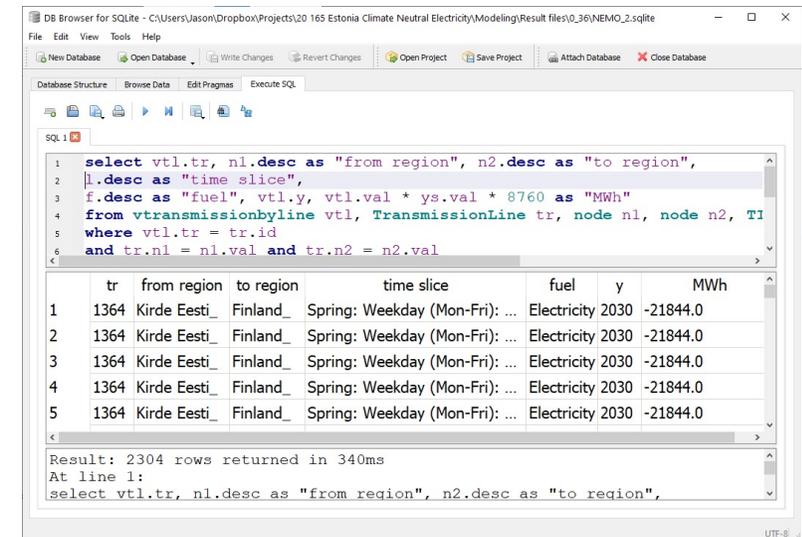
# Emission costs and constraints

- Emission costs and limits can be included in LEAP-NEMO optimization
- Activation in Settings
  - Emission costs
    - Scope & Scale => Energy Effects
    - Scope & Scale => Costs
    - Costs => Environmental externality costs
  - Emission limits
    - Scope & Scale => Energy Effects
    - Optimization => Enable Emissions Constraints
- Costs and limits to use in a scenario are then **added under Effects branch**



# Additional NEMO results

- LEAP's Results View displays a small set of NEMO outputs – capacity expansion and dispatch
- Other outputs can be accessed in NEMO scenario databases, which LEAP creates when calculating optimized scenarios
- NEMO scenario databases are in SQLite format
- Scenario databases can be saved in LEAP areas repository when saving a model: Settings => Optimization => Keep Intermediate Results
- Useful tool for working with scenario databases: DB Browser for SQLite (<https://sqlitebrowser.org/>)
- Information on scenario database structure and available outputs in NEMO documentation:
  - [https://sei-international.github.io/NemoMod.jl/stable/scenario\\_db/](https://sei-international.github.io/NemoMod.jl/stable/scenario_db/)
  - <https://sei-international.github.io/NemoMod.jl/stable/variables/>



The screenshot shows the DB Browser for SQLite interface. The SQL query is as follows:

```
1 select vtl.tr, n1.desc as "from region", n2.desc as "to region",
2 |.desc as "time slice",
3 f.desc as "fuel", vtl.y, vtl.val * ys.val * 8760 as "MWh"
4 from vtransmissionbyline vtl, TransmissionLine tr, node n1, node n2, TI
5 where vtl.tr = tr.id
6 and tr.n1 = n1.val and tr.n2 = n2.val
```

The results table is as follows:

	tr	from region	to region	time slice	fuel	y	MWh
1	1364	Kirde Eesti_	Finland_	Spring: Weekday (Mon-Fri): ...	Electricity	2030	-21844.0
2	1364	Kirde Eesti_	Finland_	Spring: Weekday (Mon-Fri): ...	Electricity	2030	-21844.0
3	1364	Kirde Eesti_	Finland_	Spring: Weekday (Mon-Fri): ...	Electricity	2030	-21844.0
4	1364	Kirde Eesti_	Finland_	Spring: Weekday (Mon-Fri): ...	Electricity	2030	-21844.0
5	1364	Kirde Eesti_	Finland_	Spring: Weekday (Mon-Fri): ...	Electricity	2030	-21844.0

Result: 2304 rows returned in 340ms  
At line 1:  
select vtl.tr, n1.desc as "from region", n2.desc as "to region",

# NEMO configuration files

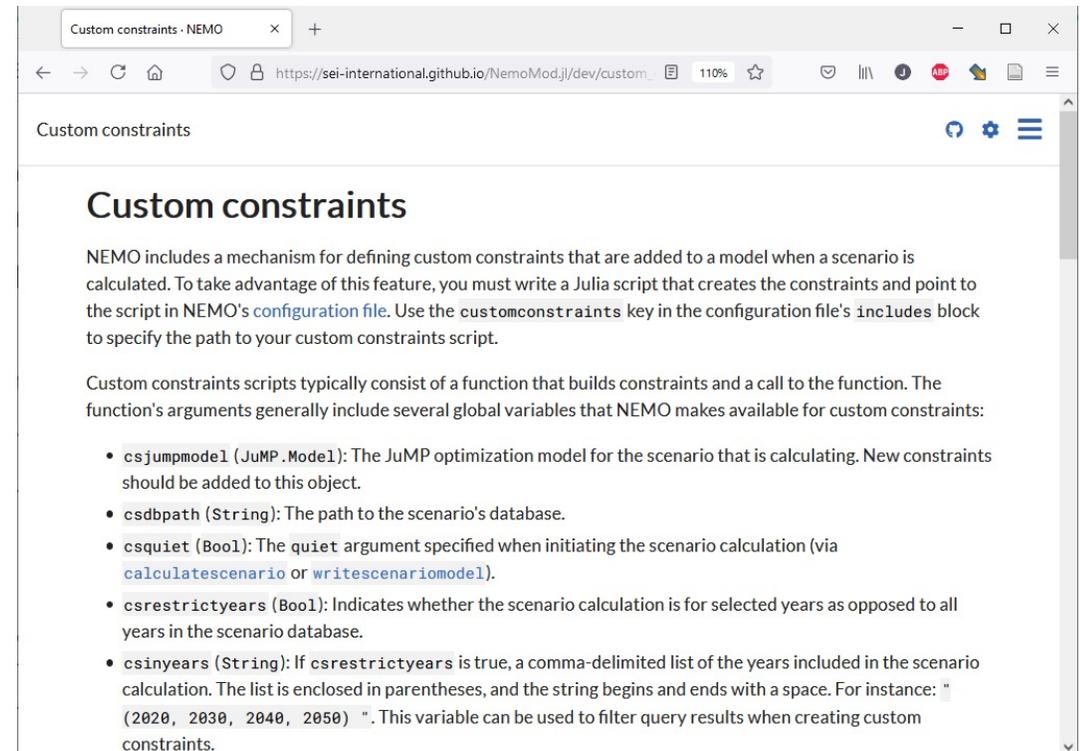
- When using NEMO with LEAP, users can **modify NEMO's run-time settings** for a model by adding a **configuration file named "nemo.cfg"** to the model's folder in the LEAP areas repository
- Configuration files can be used to specify **solver parameters**, tell NEMO to save **additional output variables**, run **custom Julia scripts**, and more
- Settings in a configuration file overwrite run-time defaults LEAP provides to NEMO
- NEMO documentation contains a full list of options
  - [https://sei-international.github.io/NemoMod.jl/stable/configuration\\_file/](https://sei-international.github.io/NemoMod.jl/stable/configuration_file/)

```
nemo.cfg - Notepad
File Edit Format View Help
; Configuration file for NEMO

; Currently supported sections and keys:
;
; [calculatescenarioargs]
; calyears=Comma-delimited list of years to include in scenario calculation
; varstosave=Comma-delimited list of model output variables to save
; numprocs=Number of Julia processes to use for parallelized operations (a positive integer or 0 for half the number of logical
processors on the executing machine)
; targetprocs=List of target process numbers
; restrictvars=true or false
; reportzeros=true or false
; continuoustransmission=true or false
; forcemip=true or false
; quiet=true or false
;
; [solver]
; parameters=Comma-delimited list of solver parameters and values in the form parameter1=value1,parameter2=value2
;
; [includes]
; beforescenarioalc=path
; customconstraints=path
;
; Notes
; • NEMO searches for this file (nemo.ini or nemo.cfg) in the Julia working directory.
;
; • Values for keys in [calculatescenarioargs] are string representations of arguments to pass to calculatescenario().
;   See the documentation for calculatescenario() for more information.
; • calyears overrides calyears specified on command line.
; • varstosave adds to varstosave specified on command line.
; • numprocs overrides numprocs specified on command line.
; • targetprocs adds to targetprocs specified on command line.
; • restrictvars overrides restrictvars specified on command line.
; • reportzeros overrides reportzeros specified on command line.
; • continuoustransmission overrides continuoustransmission specified on command line.
; • forcemip overrides forcemip specified on command line.
; • quiet overrides quiet specified on command line.
;
; • NEMO infers types of values specified in [solver] parameters using Julia's tryparse function. Values are tested to see if
they parse to Bool, Int, and Float64 types. Values that do not parse to any of these types are passed to the solver as strings.
;
; • beforescenarioalc defines a path to a Julia file to be included before each
scenario calculation in NEMO (i.e., before each execution of calculatescenario()).
;   It is optional.
; • customconstraints defines a path to a Julia file to be included when building
constraints during a scenario calculation in NEMO. It is optional.
; • All paths should be defined relative to the current working directory.
[calculatescenarioargs]
continuoustransmission=true
varstosave=vtransmissionannual,vtransmissionbylineannual,vtransmissionexists,vtransmissionbuilt,vtransmissionbyline,vtotaltechnol
annualactivityannualtechnology...
```

# Custom NEMO constraints

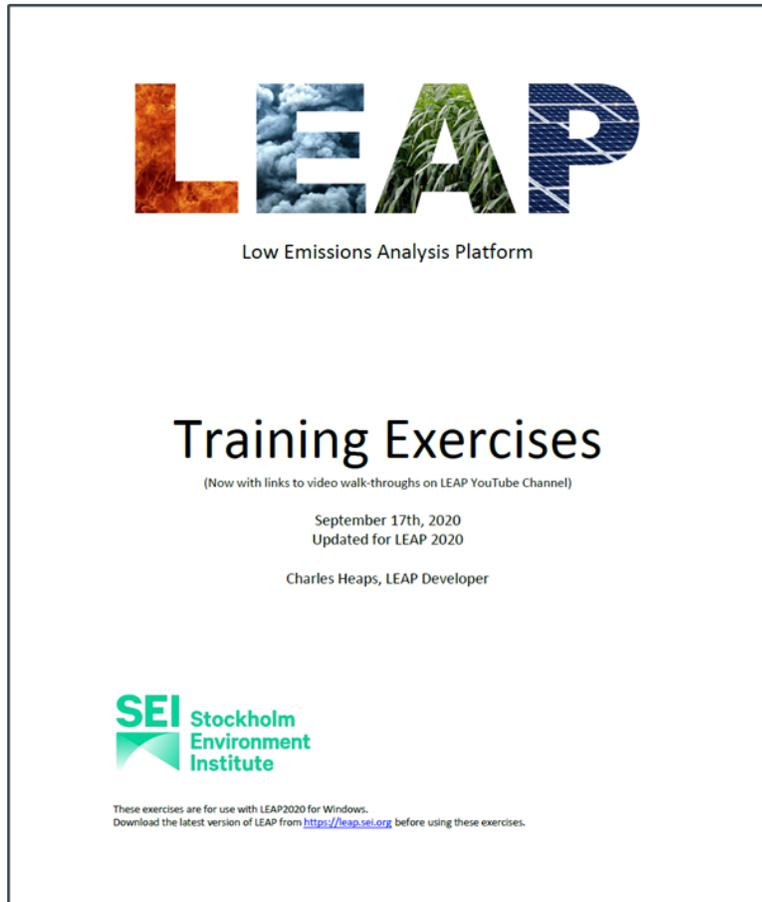
- Custom constraints can be added to a LEAP-NEMO model by writing a Julia script that defines the constraints
- Script is referenced in a NEMO configuration file and loaded when NEMO calculates a scenario
- Custom constraints can be used for a **wide range of purposes**:
  - Share resource limits among multiple processes
  - Link capacity additions or retirements across processes
  - Create supplemental constraints for ensuring system reliability
  - ...
- Detailed instructions at: [https://sei-international.github.io/NemoMod.jl/dev/custom\\_constraints/](https://sei-international.github.io/NemoMod.jl/dev/custom_constraints/)



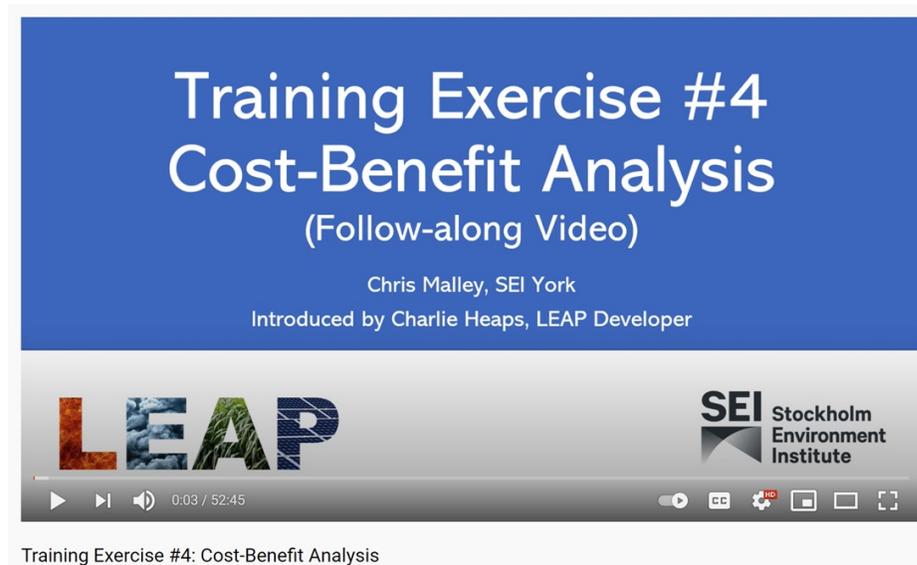
# Exercise 3: Cost-benefit analysis



# Freedonia



## Workshop Exercise 3: Chapter 4 in Training Exercises document



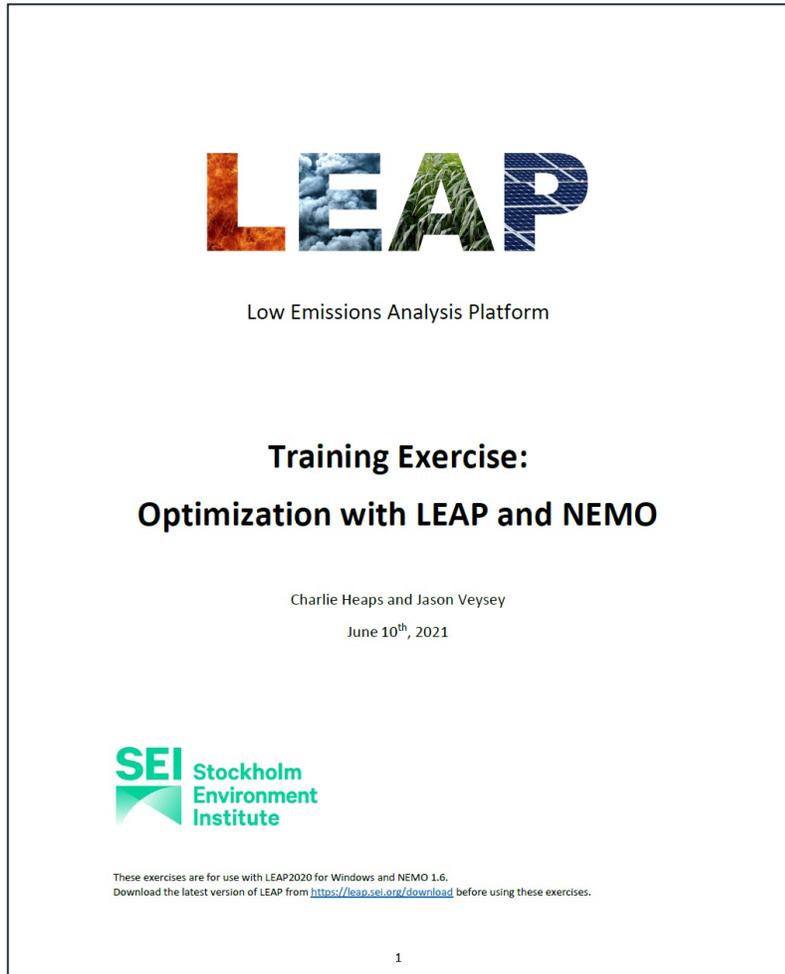
<https://youtu.be/au99KzpHmio>

# **Exercise 4: Optimization modeling**



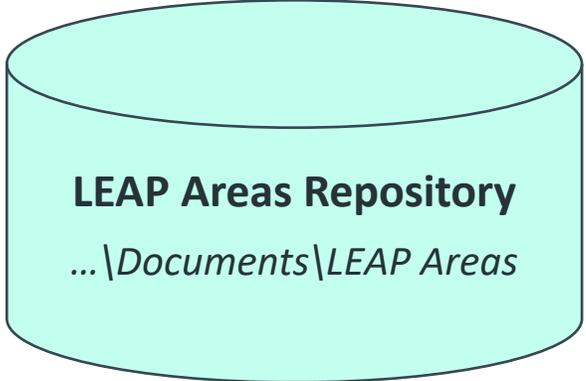
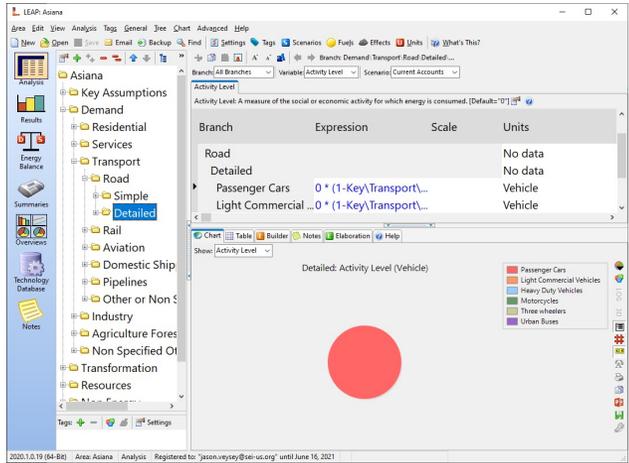
# Optimization Exercise

---

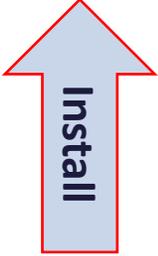
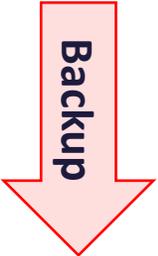


- Optimization Exercise area installed with LEAP
- Supporting Excel file – Yearly Shape Data.xlsx – in shared materials folder

# Saving and sharing models



*One folder with multiple files per area*



*One zipped file per area*

Installing an area from a .LEAP file overwrites what's in local LEAP areas repository

**Be careful, you can lose work!**