ROYAL INSTITUTE OF TECHNOLOGY

OSeMOSYS – An Introduction

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Webinar Overview

- Introduction to energy modelling and the role of OseMOSYS
- Introduction to the OSeMOSYS Model
  - Overview
  - Interfaces
  - Modifications
  - Applications
- Discussant on policy use of OSeMOSYS

Long-term Energy Modelling

- Energy policy across the globe is grappling with a set of unprecedented challenges
- Securing access to energy and mitigating climate change are key policy goals
- Many complex issues require consideration, e.g., economic growth, resource reserves, technological development, (climate) policies

- Energy models provide essential quantitative insights into these 21st Century challenges
- Mitigation efforts & energy system infrastructure require long-term planning
- Models can help to gain strategic insights while managing the various complexities
- Energy models have very different methodologies, and are targeted at different research questions
- Energy models are built, run, critiqued and applied by people

What are Energy Models?

What models are not

- A generator of research papers or consultancy funding
- A name based on a zippy acronym
- e.g., GREEN, BLUE; PRISM, CUBE; ALPHA, GAMMA, DELTA; ALBATROSS
- An anthropogenic entity with a somewhat deranged personality

A structured approach to modelling

- There will never be a universal model which will answer all questions
- Design models to answer specific research questions
- Although some complex models can contribute to a number of different research areas
- A range of models (& model linkages) are required for any given problem
- Developing an expert/educated community of developers and users is critical
- Models of complex systems evolve through structured contact with reality
- Models are only as good as the data you have to populate / challenge them

Model Usefulness

- All models are wrong but some are useful”
  - George Box

- Alternate version
- “Some models are right, (or at least in practice, right enough), and even the wrong ones can still be useful”
  - ‘Limited validity’ of Newtonian Physics vs. general relativity and quantum mechanics
  - ‘Business-as-usual mental model’ of Shell’s executives before presentations by Pierre Wack’s team

Model Complexity

- “entia non sunt multiplicanda praeter necessitatem"
- "entities must not be multiplied beyond necessity"
  - William of Ockham: 1288 – 1348
- In modelling terms:
  - Simplicity-elegance-parsimony
  - Complexity as necessary
- BUT energy-economic system is inherently complex
- Problem drives modelling and analysis

Brussels

Last updated: November 6, 2011 7:44 pm

Credibility of EU energy review questioned

By Pilita Clark

The credibility of a European energy review has been cast into doubt by experts who point out that long-term plans to cut carbon emissions are based on an economic model owned by a single Greek university that cannot be independently scrutinised.

Experts have “raised a host of questions” about how the European Commission’s use of a non-transparent model could affect the energy review, according to a leaked report by energy specialists chosen by Brussels to advise on the forthcoming “Energy Roadmap to 2050”.

The economic model, known as “Primes”, is owned by the National Technical University of Athens and is designed to show how using different mixes of energy

More

Model Transparency 1

- "It is the [FUND model] developer's firm belief that most researchers should be locked away in an ivory tower. Models are often quite useless in inexperienced hands, and sometimes misleading."
- "No one is smart enough to master in a short period what took someone else years to develop."
- "Not-understood models are irrelevant, half-understood models treacherous, and mis-understood models dangerous."
- Richard Tol

Model Transparency 2

Open source

- Full documentation (online), including data
- Model source code
- Peer reviewed
- Journal papers
- Dedicated peer review

Expert user group

- Model developers and users in Government, industry, consultancies and academia
- International support network
- Engagement with broader stakeholders

But...

- Intellectual property issues
- Replicability of highly complex models
- Biased (even malicious) attitudes towards energy analysis

Model Quantification

"Model for insights, not numbers"

- Hill Huntington, 1982

But decision makers don't really want insights!

- They really want numbers
- And they don't deal with uncertainty very well

Examples of numbers

- Resource availability (barrels, cu.m3, tonnes)
- Energy demands (GJ, MWhrs, toe)
- Technology diffusion (number of units, % share)
- Climate change mitigation GDP costs (billion £, %)
- Investment required in power sector (million £)
- Energy price increases (p/kWh, p/litre)
- ....

Where do the numbers come from?

Model derived

- IPCC AR4
- (median values) 500ppm CO2e, -50% GHG emissions by 2050
- GDP: +1 to -3%, CO2 price 50 - 200 $/tCO2

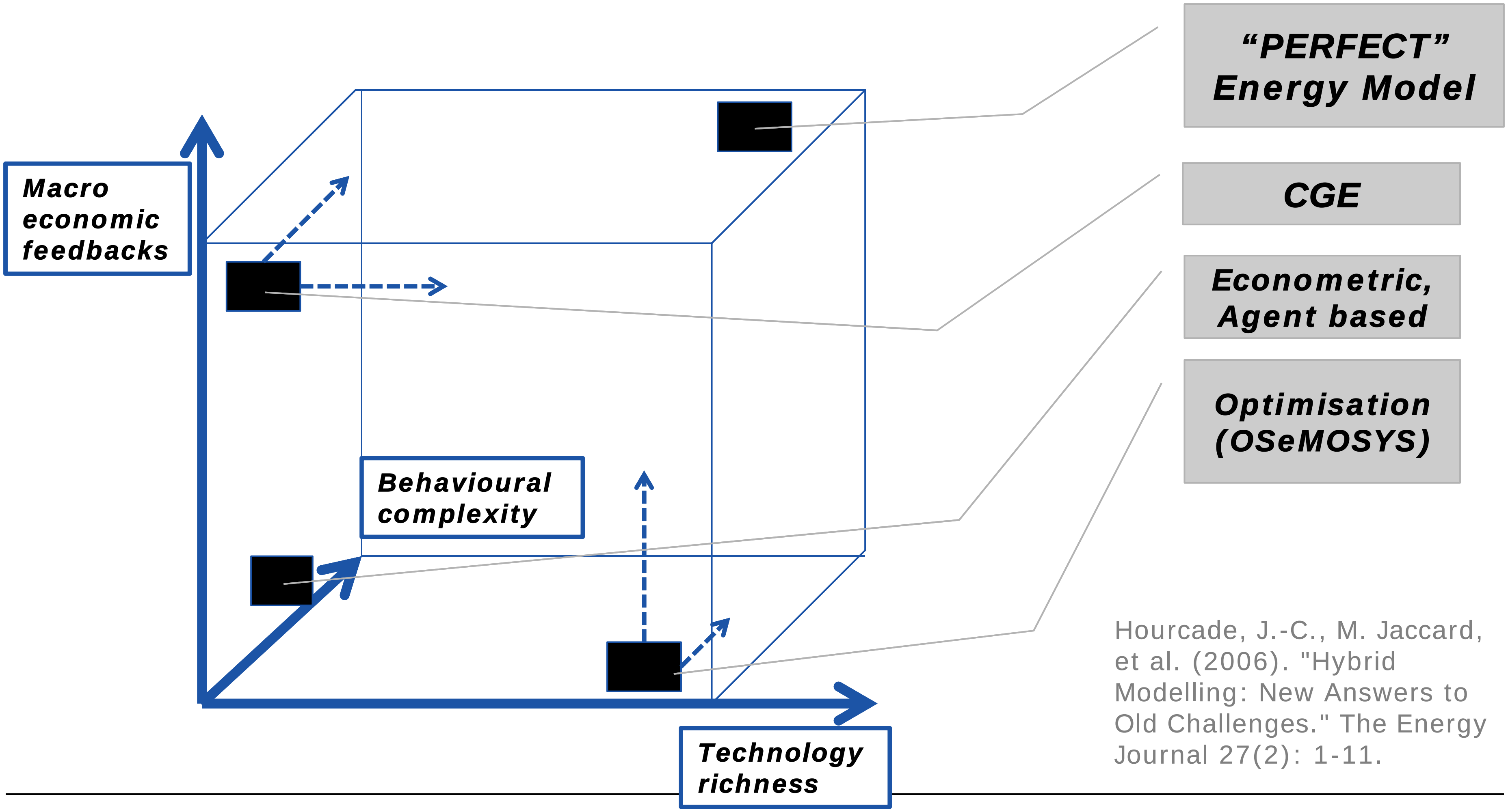
Scenarios and simple modelling

- Ofgem's Project discovery, 2009
- £95 - £200 billion investment in UK power sector by 2020

From the ether(!)

- EU's 20-20-20 target, by 2020
- 20% reduction in GHG emissions (from 1990 levels)
- 20% from renewable resources (final energy basis)
- 20% improvement in energy efficiency (final energy basis)

Energy Model Typology



Hourcade, J.-C., M. Jaccard, et al. (2006). "Hybrid Modelling: New Answers to Old Challenges." The Energy Journal 27(2): 1-11.

OSeMOSYS (Open Source Energy Modelling System)

- **At present** there exists a useful, but limited set of accessible energy systems **models**. They often **require significant investments** in terms of human resources, training and software purchases.
- **OSeMOSYS** is a fully fledged energy systems linear optimisation model, with **no associated upfront financial requirements.**
- It extends the availability of energy modelling further to researchers, business analysts and government specialists in developing countries.
- A **„lego block structure“** allows easily adding elements. Every block consists of a plain english describtion, the formulas, and the actual code.

Knowledge Partners

OSeMOSYS (Open Source Energy Modelling System)

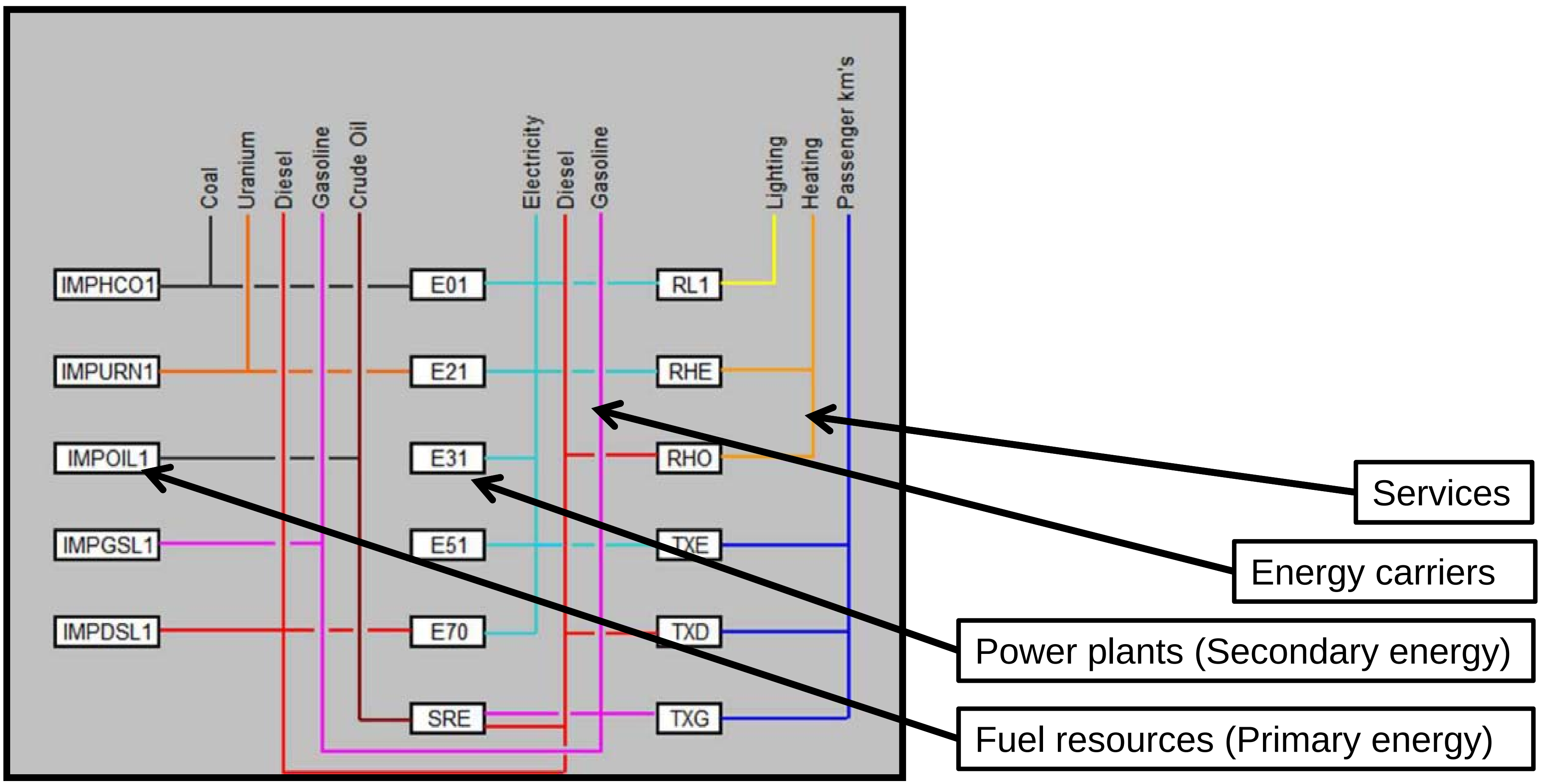
- Tool to inform the development of medium- to long-term energy strategies
- Deterministic linear optimisation model
- Demands for energy services are met by technologies which draw on resources
- Minimises the total discounted costs
- Paradigm comparable to MESSAGE or TIMES
- Integrated into LEAP
- Open source -> no associated upfront financial requirements
- Well documented, easy to modify

Knowledge Partners

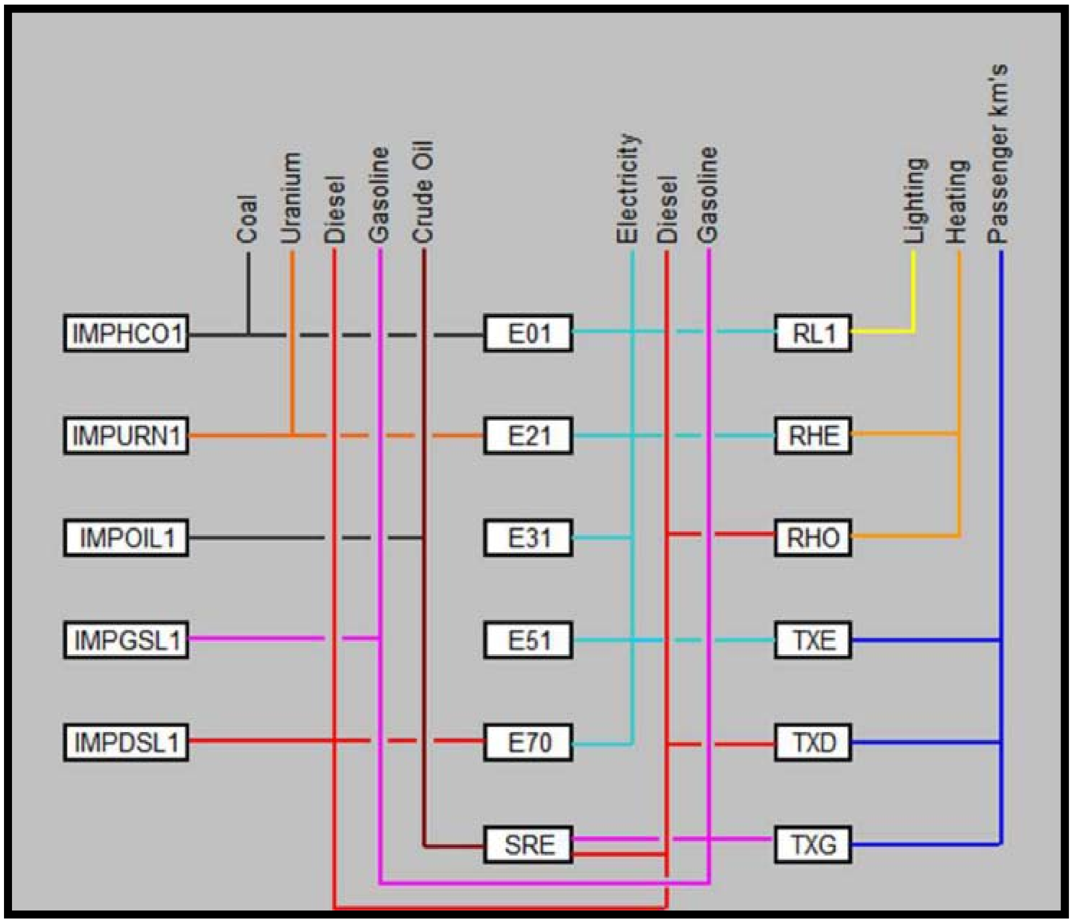
Technology Definition

- Wide and flexible.
- Any fuel use and conversion, from resource extraction and processing to generation, transmission and distribution and appliances.
- E.g., a coal mine, a wind farm or air-conditioning systems.
- Any combination of input fuels to produce any combination of output fuels.
- Defined by a set of economic, technical and environmental parameters and policy goals.
- Technologies compete against each other in order to minimise the overall discounted costs for society.

Reference Energy System (RES)



Reference Energy System (RES)



- All boxes are technologies
- All lines are fuels
- **No parameters are assigned to fuels**
- Most parameters are assigned to technologies (costs, lifetime, efficiencies, emissions, etc.)

-> e.g., fuel costs are defined as operational costs of a technology

- Non-technology parameters:
  - Demand
  - Emission constraints
  - Reserve margin, etc.

Design Features

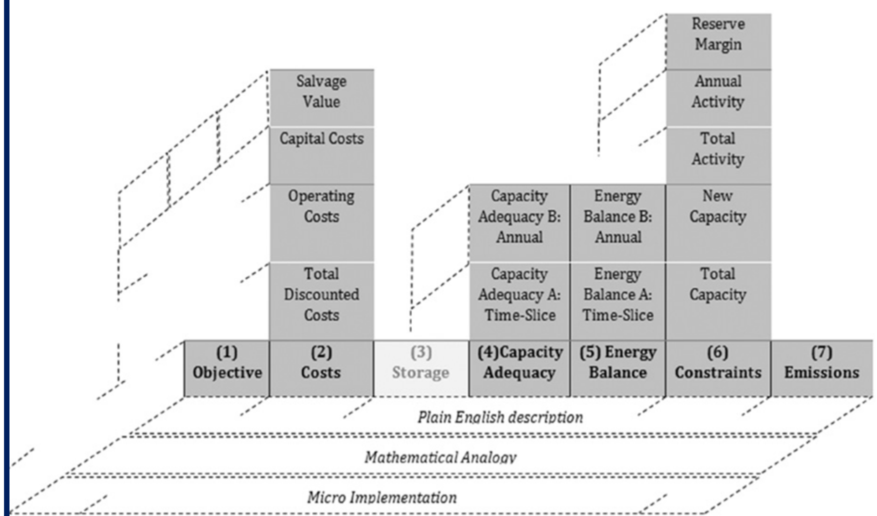
Structured in **blocks of functionality** (fig.on right)

Several **levels of abstraction**:

- A plain English description
- An algebraic formulation of the plain English description
- The model's implementation in a programming language
- The application of the model

Mathematical language: Gnu MathProg (similar to GAMS)

Solver: glpk (open-source)



Blocks of Functionality – Part I

Objective

To estimate the lowest NPV of an energy system to meet given demand(s) for energy

Costs

Account for the costs incurred by each technology in each year and in each region

Capacity adequacy

There must be enough capacity for each technology in order to meet its energy use or production requirements

- Capacity adequacy A: Each time slice / Capacity adequacy B: Each year

Energy balance

Operation levels are calculated for each time slice and each year. The production, use and demand must be feasible at each timeslice and annually

- Energy balance A: Each time slice / Energy balance B: Each year

Blocks of Functionality – Part II

Constraints

- Maximum/minimum limit on capacity of a technology allowed for a year or total period and a region
- Maximum/minimum limit on new capacities of a technology for a year and a region
- Maximum/minimum limit on activity of a technology for a year or total period and a region
- There must be enough capacity to provide a reserve margin (for specified technologies)

Emissions

- The extent to which pollutants are emitted is determined by multiplying “emissions per unit of activity” and the annual activity of a technology

Example of Mathematical Formulation

OBJECTIVE

$\text{minimize} \sum_{y,t,r} \text{TotalDiscountedCost}_{y,t,r}$ (OBJ)

COSTS

TOTAL DISCOUNTED COSTS

$\forall_{y,t,r}\ \text{TotalDiscountedCost}_{y,t,r} = \text{DiscountedOperatingCost}_{y,t,r} + \text{DiscountedCapitalInvestment}_{y,t,r} + \text{DiscountedTechnologyEmissionsPenalty}_{y,t,r} - \text{DiscountedSalvageValue}_{y,t,r}$ (TDC1)

OPERATING COSTS

$\forall_{y,l,t,r}\ \text{VariableOperatingCost}_{y,l,t,r} = \sum_m \text{AverageAnnualTechnologyActivityByMode}[y,t,m,r] * \mathbf{VariableCost}_{y,t,m,r}$ (OC1)

$\forall_{y,t,r}\ \text{AnnualVariableOperatingCost}_{y,t,r} = \sum_l \text{VariableOperatingCost}_{y,l,t,r}$ (OC2)

$\forall_{y,t,r}\ \text{AnnualFixedOperatingCost}_{y,t,r} = \text{TotalCapacityAnnual}_{y,t,r} * \mathbf{FixedCost}_{y,t,r}$ (OC3)

$\forall_{y,t,r}\ \text{OperatingCost}_{y,t,r} = \text{AnnualFixedOperatingCost}_{y,t,r} + \text{AnnualVariableOperatingCost}_{y,t,r}$ (OC4)

$\forall_{y,t,r}\ \text{DiscountedOperatingCost}_{y,t,r} = \text{OperatingCost}_{y,t,r} / ((1+\mathbf{DiscountRate}_{t,r})\wedge(y-\mathbf{StartYear}+0.5)$ (OC5)

CAPITAL COSTS

$\forall_{y,t,r}\ \text{CapitalInvestment}_{y,t,r} = \mathbf{CapitalCost}_{y,t,r} * \text{NewCapacity}_{y,t,r}$ (CC1)

$\forall_{y,t,r}\ \text{DiscountedCapitalInvestment}_{y,t,r} = \text{CapitalInvestment}_{y,t,r} / ((1+\mathbf{DiscountRate}_{t,r})\wedge(y-\mathbf{StartYear}))$ (CC2)

Example of Code

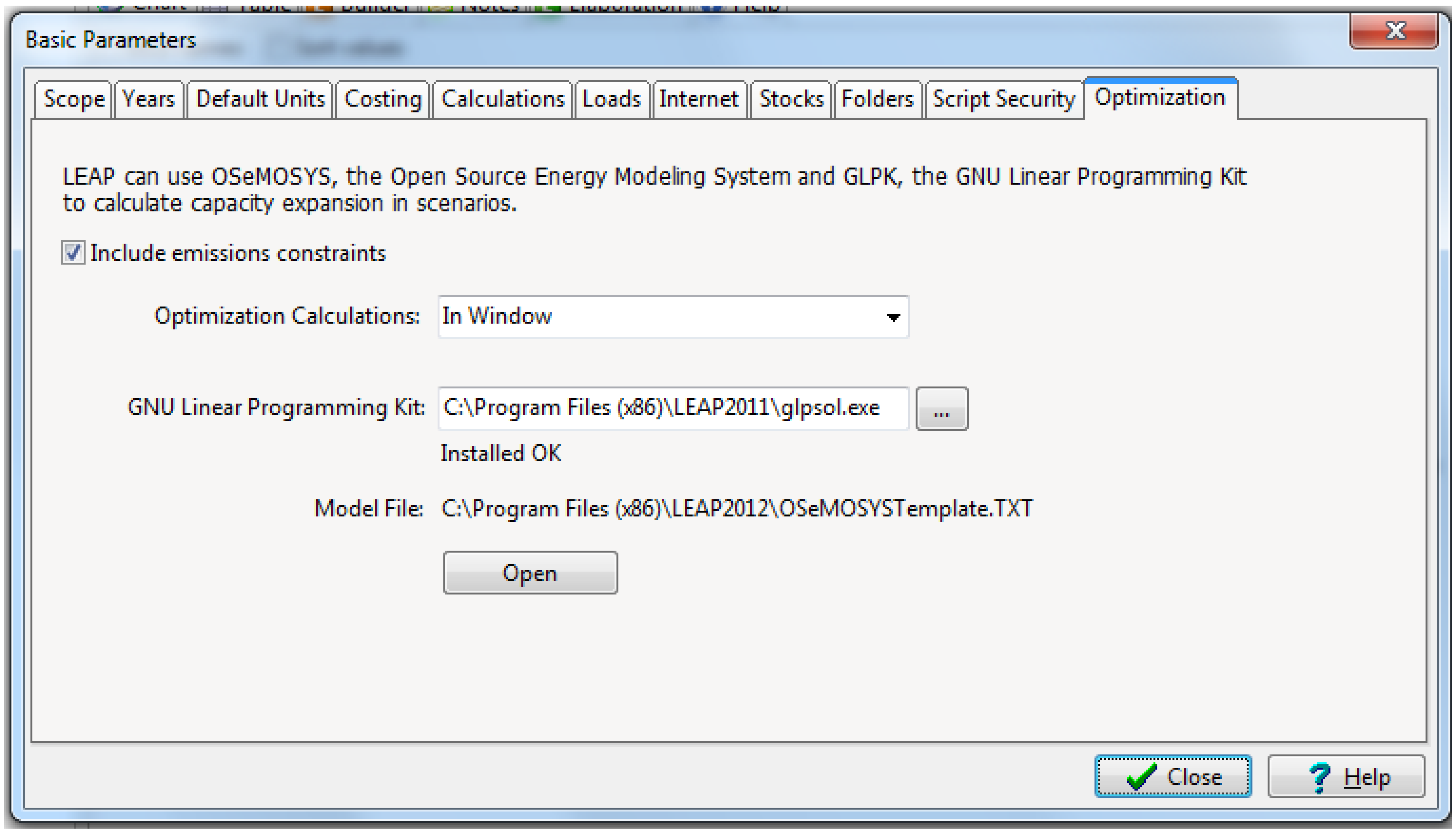
```
# OBJECTIVE #

minimize OBJ_TotalNPVCost: sum{y in YEAR, t in TECHNOLOGY, r in REGION} TotalDiscountedCost[y,t,r];

# CONSTRAINTS AND EQUATIONS #

# TOTAL DISCOUNTED COSTS  #

s.t. TDC1_TotalDiscountedCostByTechnology{y  in YEAR, t in TECHNOLOGY, r in REGION}:
DiscountedOperatingCost[y,t,r]+DiscountedCapitalInvestment[y,t,r]  + AnnualTechnologyEmissionsPenalty[y,t,r]- DiscountedSalvageValue[y,t,r] =
TotalDiscountedCost[y,t,r];

# OPERATING COSTS  #

s.t. OC1_OperatingCostsVariable{y in YEAR,l in TIMESLICE, t in TECHNOLOGY, r in REGION}: sum{m in MODE_OF_OPERATION}
    AverageAnnualTechnologyActivityByMode[y,t,m,r]*VariableCost[y,t,m,r] = VariableOperatingCost[y,l,t,r];
s.t. OC2_OperatingCostsVariableAnnual{y in YEAR,t in TECHNOLOGY, r in REGION}: sum {l in TIMESLICE} VariableOperatingCost[y,l,t,r] =
    AnnualVariableOperatingCost[y,t,r];

s.t. OC3_OperatingCostsFixedAnnual{y in YEAR,t in TECHNOLOGY, r in REGION}: TotalCapacityAnnual[y,t,r]*FixedCost[y,t,r] =
    AnnualFixedOperatingCost[y,t,r];
s.t. OC4_OperatingCostsTotalAnnual{y in YEAR,t in TECHNOLOGY,r in REGION}: AnnualFixedOperatingCost[y,t,r]+AnnualVariableOperatingCost[y,t,r] =
    OperatingCost[y,t,r];
s.t. OC5_DiscountedOperatingCostsTotalAnnual{y  in YEAR, t in TECHNOLOGY, r in REGION}: OperatingCost[y,t,r]/((1+DiscountRate[t,r])^(y-
    StartYear+0.5)) = DiscountedOperatingCost[y,t,r];

# CAPTIAL COSTS #

s.t. CC1_UndiscountedCapitalInvestment{y  in YEAR, t in TECHNOLOGY, r in REGION}: CapitalCost[y,t,r] * NewCapacity[y,t,r] = CapitalInvestment[y,t,r];
s.t. CC2_DiscountingCapitalInvestmenta{y  in YEAR, t in TECHNOLOGY, r in REGION}: CapitalInvestment[y,t,r]/((1+DiscountRate[t,r])^(y-StartYear)) =
    DiscountedCapitalInvestment[y,t,r];
```

Interfaces

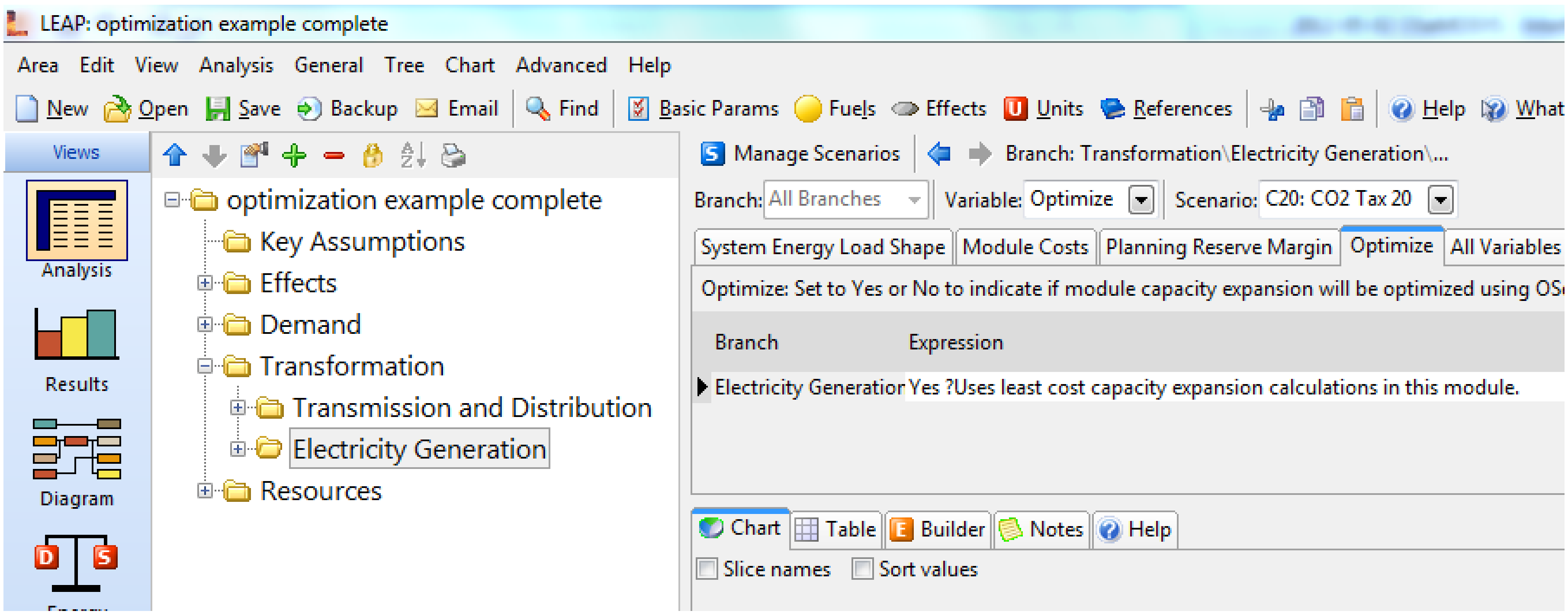
Current ways to use OSeMOSYS

- **LEAP interface**
- **OSeMOSYS interface (under development)**
- **Run an input file**
  - in the command prompt, e.g, using Notepad++ to write input file
  - GUSEK
  - Matlab

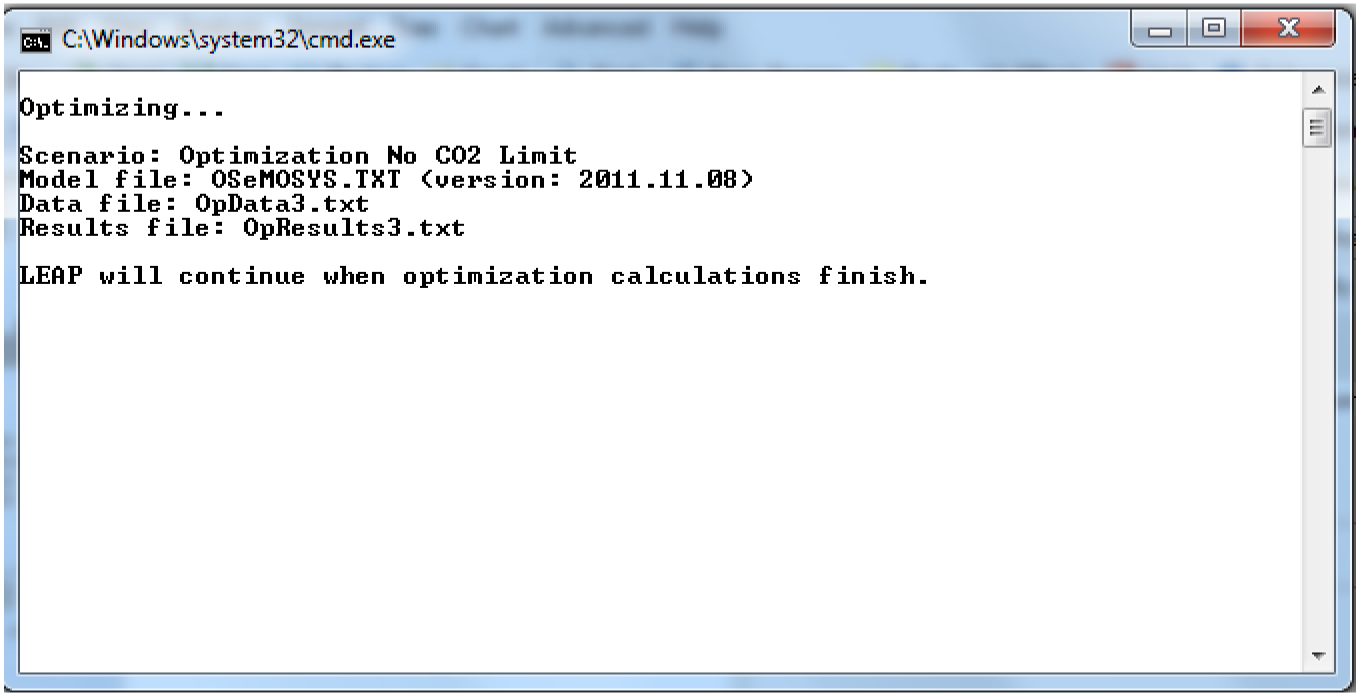
LEAP Interface



LEAP Interface



LEAP Interface



Input File - Example of Data File

```
set EMISSION    :=  CO2 NOX ;
set TECHNOLOGY  :=  E01 E21 E31 E51 E70 IMPDSL1 IMPGSL1 IMPHCO1 IMPOIL1 IMPURN1 RHE RHO RL1 SRE
set FUEL    :=  CSV DSL ELC GSL HCO HYD LTH OIL URN RH  RL  TX  ;
set YEAR    :=  1990    1991    1992    1993    1994    1995    1996    1997    1998    1999
set TIMESLICE   :=  ID  IN  SD  SN  WD  WN  ;
set MODE_OF_OPERATION   :=  1 2 ;
set REGION  :=  UTOPIA  ;
```

```
param   FixedCost   default 0   :=
[*,*,UTOPIA]:       E01 E21 E31 E51 E70 RHO RL1     TXD TXE TXG :=
1990                40  500 75  30  30  1   9.46    52  100 48
1991        40  500 75  30  30  1   9.46    52  100 48
1992        40  500 75  30  30  1   9.46    52  100 48
1993        40  500 75  30  30  1   9.46    52  100 48
1994        40  500 75  30  30  1   9.46    52  100 48
1995        40  500 75  30  30  1   9.46    52  100 48
```

Input File - Example of Data File

```
param   OutputActivityRatio default 0   :=
[*,*,RH,1,UTOPIA]         :   RHE RHO RHu:=
1990            1   1   1
1991            1   1   1
1992            1   1   1
1993            1   1   1
1994            1   1   1
1995            1   1   1
```

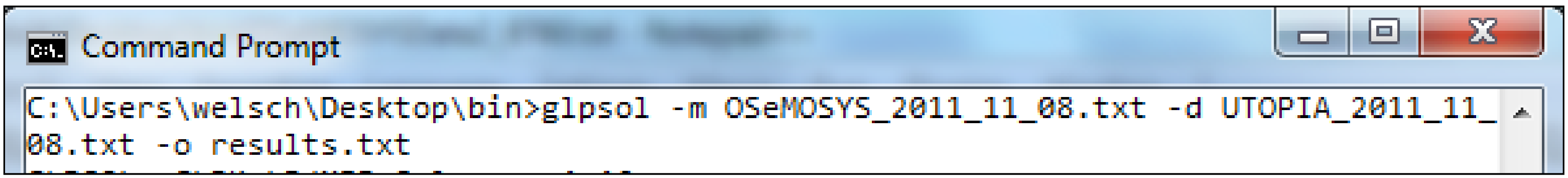
```
param   InputActivityRatio  default 0   :=
[*,*,DSL,1,UTOPIA]      :   E70 RHO TXD :=
1990            3.4 1.428571429 1
1991            3.4 1.428571429 1
1992            3.4 1.428571429 1
1993            3.4 1.428571429 1
1994            3.4 1.428571429 1
1995            3.4 1.428571429 1
```

Example of Output File

1742	TotalAnnualCapacity (Capacity Units)												
1743		Coal	Biogas	Waste	Peat	CC	CC-new	Gas	Hydro	Distillate	Wind	OilSteam	Solar
1744	2009	0.84	0	0	0.347	1.422	1.137	0.3833	0.2175	0.496	1.2846	1.149	0
1745	2010	0.84	0	0	0.347	1.422	1.137	0.3667	0.219	0.496	1.5592	1.149	0
1746	2011	0.84	0	0	0.347	1.422	1.664	0.35	0.2205	0.496	1.8338	1.149	0
1747	2012	0.84	0	0	0.347	1.422	1.664	0.3333	0.222	0.496	2.1083	0	0
1748	2013	0.84	0	0	0.347	1.422	1.664	0.3167	0.2235	0.496	2.3829	0	0
1749	2014	0.84	0	0	0.347	1.422	1.664	0.3	0.225	0.496	2.6575	0	0
1750	2015	0.84	0	0	0.347	1.422	1.664	0.2833	0.2265	0.496	2.9321	0	0
1751	2016	0.84	0.022	0.021	0.347	1.422	1.664	0.2667	0.228	0.496	3.2067	0	0
1752	2017	0.84	0.022	0.021	0.347	1.422	1.664	0.25	0.2295	0.496	3.4813	0	0
1753	2018	0.84	0.022	0.021	0.347	1.422	1.664	0.2333	0.231	0.496	3.7558	0	0
1754	2019	0.84	0.022	0.021	0.347	1.422	1.664	0.2167	0.2325	0.496	4.0304	0	0
1755	2020	0.84	0.022	0.021	0.347	1.422	1.664	0.2	0.234	0.496	4.305	0	0
1756	2021	0.84	0.022	0.021	0.347	1.422	1.664	0.2	0.234	0.496	4.2986	0	0
1757	2022	0.84	0.022	0.021	0.347	1.422	1.664	0.2	0.234	0.496	4.2658	0	0
1758	2023	0.84	0.022	0.021	0.347	1.422	1.664	0.2	0.23	0.496	4.241	0	0
1759	2024	0.84	0.022	0.021	0.347	1.422	1.664	0.2	0.215	0.496	4.2335	0	0
1760	2025	0.535	0.022	0.021	0.347	1.422	1.664	0.2	0.215	0.496	4.1867	0	0
1761	2026	0.23	0.022	0.021	0.347	1.422	2.05491	0.2	0.215	0.497379	4.27409	0	0

SelectedResults

Input File (1) – Command Prompt



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Input File (1) – Command Prompt

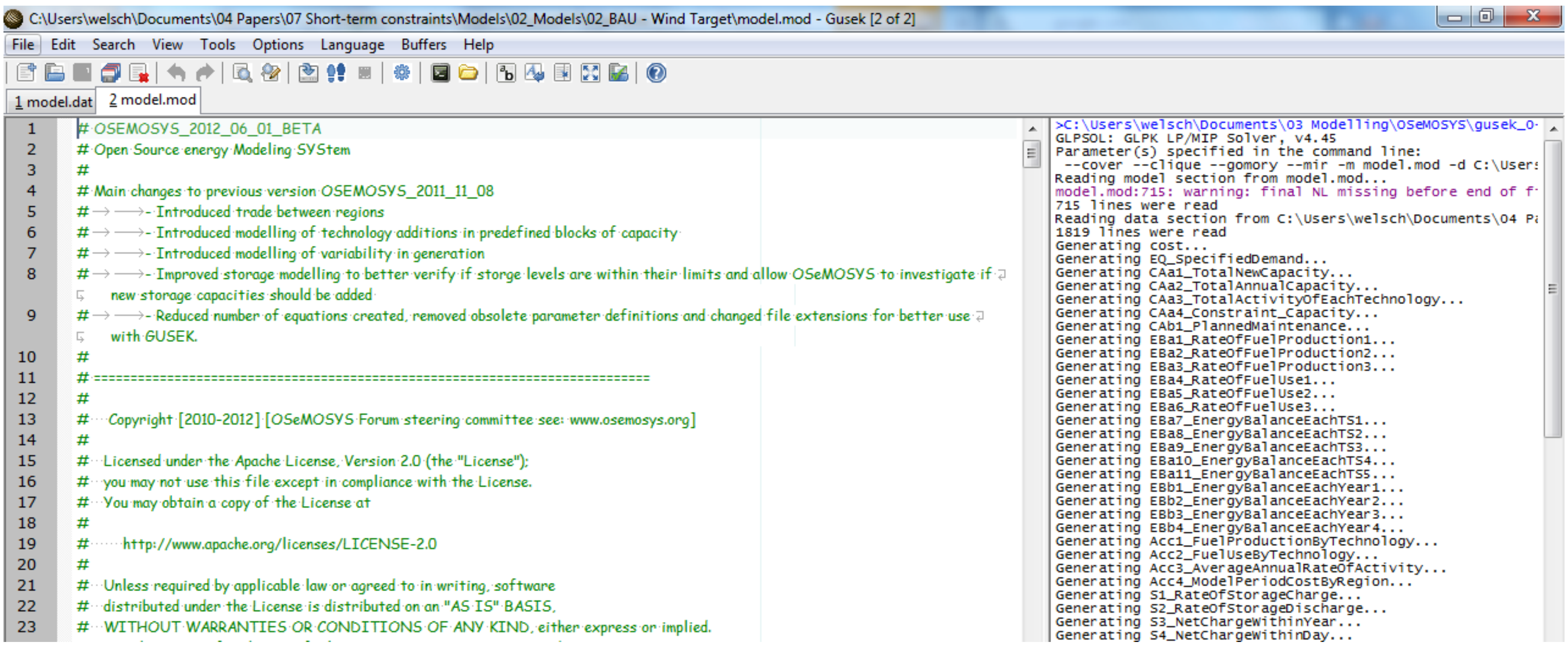
Command Prompt

```
C:\Users\welsch\Desktop\bin>glpsol -m OSeMOSYS_2011_11_08.txt -d UTOPIA_2011_11_
08.txt -o results.txt
GLPSOL: GLPK LP/MIP Solver, v4.46
Parameter(s) specified in the command line:
 -m OSeMOSYS_2011_11_08.txt -d UTOPIA_2011_
Reading model section from OSeMOSYS_2011_11
OSeMOSYS_2011_11_08.txt:615: warning: final
615 lines were read
Reading data section from UTOPIA_2011_11_08
968 lines were read
Generating cost...
Generating EQ_SpecifiedDemand...
Generating S1_StorageCharge...
Generating S2_StorageDischarge...
Generating S3_NetStorageCharge...
Generating S4_StorageLevelAtInflection...
```

```
Generating E9_ModelPeriodEmissionsLimit...
Model has been successfully generated
GLPK Simplex Optimizer, v4.46
291855 rows, 293773 columns, 661031 non-zeros
Preprocessing...
22663 rows, 23895 columns, 61908 non-zeros
Scaling...
 A: min|aij| = 1.000e-005  max|aij| = 1.000e+005  ratio = 1.000e+010
GM: min|aij| = 1.727e-001  max|aij| = 5.790e+000  ratio = 3.352e+001
EQ: min|aij| = 3.024e-002  max|aij| = 1.000e+000  ratio = 3.307e+001
Constructing initial basis...
Size of triangular part = 20397
      0: obj =  8.383416370e+002  infeas = 6.623e+003 (2266)
    500: obj =  1.369784397e+003  infeas = 4.297e+003 (2266)
   1000: obj =  1.868863782e+003  infeas = 4.125e+003 (2266)
   1500: obj =  4.681099291e+003  infeas = 3.891e+003 (2265)
   2000: obj =  1.218014691e+004  infeas = 3.056e+003 (2263)
*  2368: obj =  4.049204369e+004  infeas = 7.872e-013 (2263)
*  2500: obj =  3.005622362e+004  infeas = 6.056e-013 (2257)
*  3000: obj =  2.718891021e+004  infeas = 3.472e-013 (2255)
*  3500: obj =  2.662935465e+004  infeas = 3.066e-013 (2255)
*  3724: obj =  2.662935464e+004  infeas = 3.489e-013 (2255)
OPTIMAL SOLUTION FOUND
Time used:   3.3 secs
Memory used: 491.5 Mb (515402524 bytes)
Model has been successfully processed
Writing basic solution to `results.txt'...

C:\Users\welsch\Desktop\bin>
```

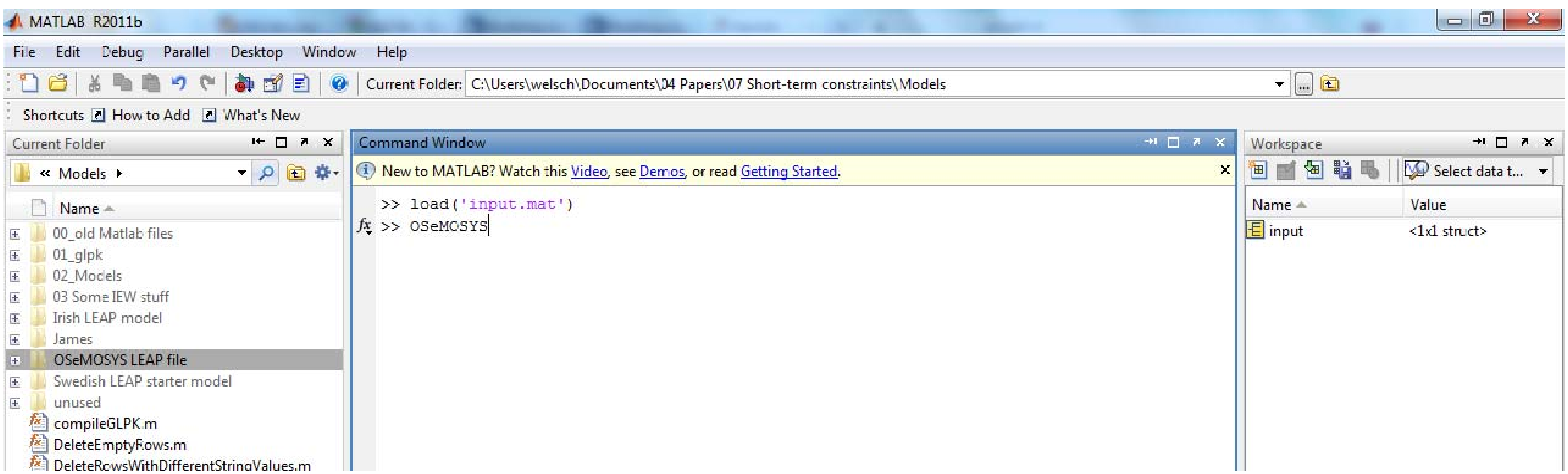
Input File (2) – GUSEK

Integrated development environment, combines solver (glpk) and editor, freely available



Input File (3) – Matlab

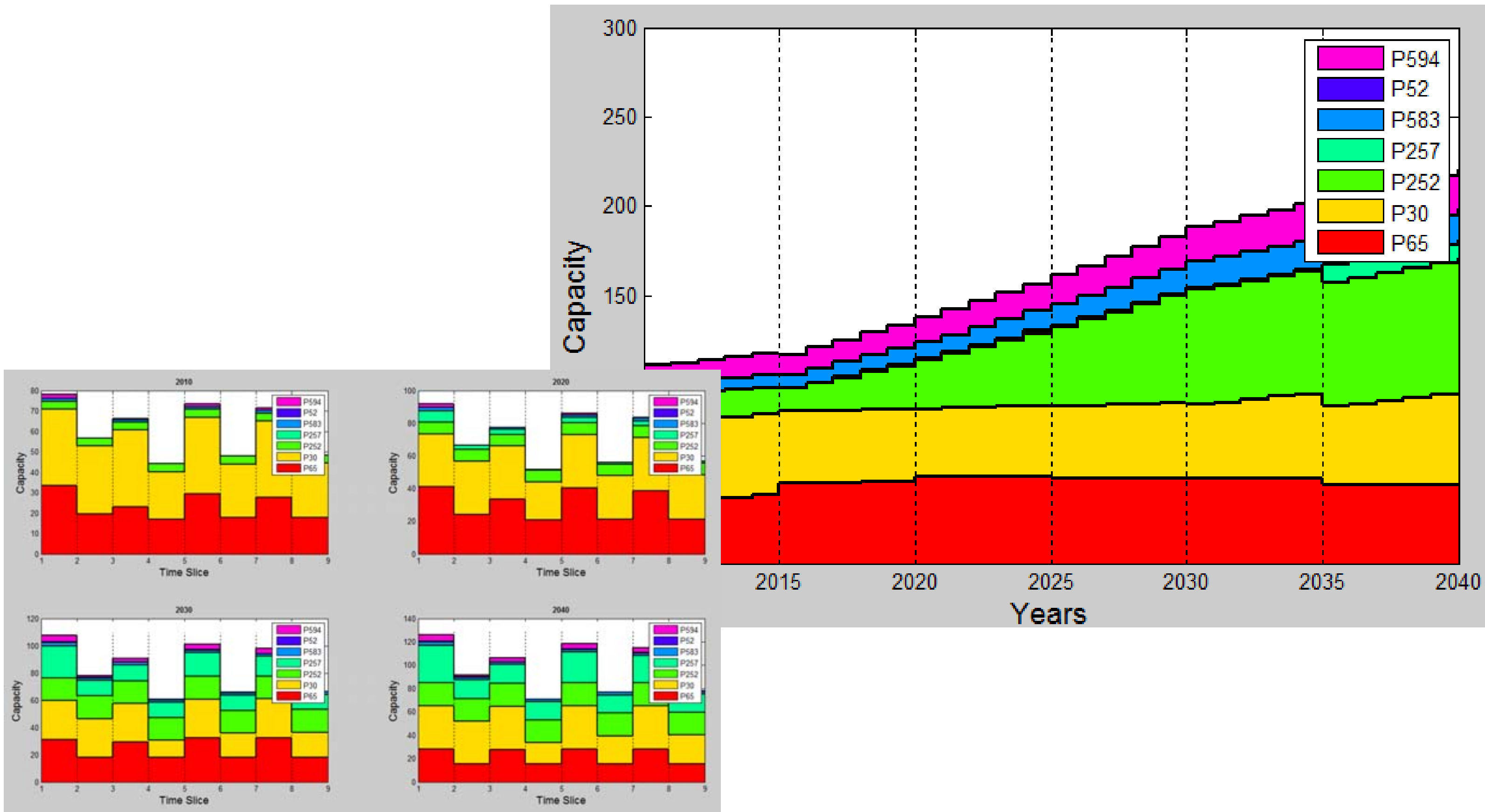
- Commercial software
- Certain processes can be automised
  - (e.g., drawing graphs,
  - comparing data
  - Scenario management (e.g., saving input and output files in a scenario folder)



Input File (3) – Matlab

```
function output = compileglpk(glpkFolder, modelFolder, scenarioFolder)

output.paths.curFolder = pwd;
output.paths.glpkFolder = strcat(output.paths.curFolder, filesep, glpkFolder);
output.paths.modFolder = strcat(output.paths.curFolder, filesep, modelFolder);
output.paths.modFolder.scen = strcat(output.paths.modFolder, filesep, scenarioFolder);
output.model.name = 'model';

GLPKmodel = strcat(output.paths.modFolder.scen, filesep, output.model.name, '.mod');
GLPKdata = strcat(output.paths.modFolder.scen, filesep, output.model.name, '.dat');
% GLPKout = strcat(output.paths.modFolder.scen, filesep, output.model.name, '.out');

glpsol = strcat(output.paths.glpkFolder, filesep, 'glpsol.exe');

% cmdLine = ['"' glpsol '" -m "', GLPKmodel, '" -d "', GLPKdata,'" -o "', GLPKout,'"']
cmdLine = ['"' glpsol '" -m "', GLPKmodel, '" -d "', GLPKdata,'"']
system(cmdLine);
```

Input File (3) – Matlab



Modifying OSeMOSYS – An Illustration

Facts & Figures

In **2012**, renewable energy (RE) sources contributed 70% to all electricity capacity additions in the EU.

US blueprint for a secure energy future: By **2035**, 80% from clean energy sources

RE generation may triple until **2035** (IEA's New Policies Scenario).

By **2050**, the EU intends to reduce GHG emissions by 80% – 95% below 1990 levels.

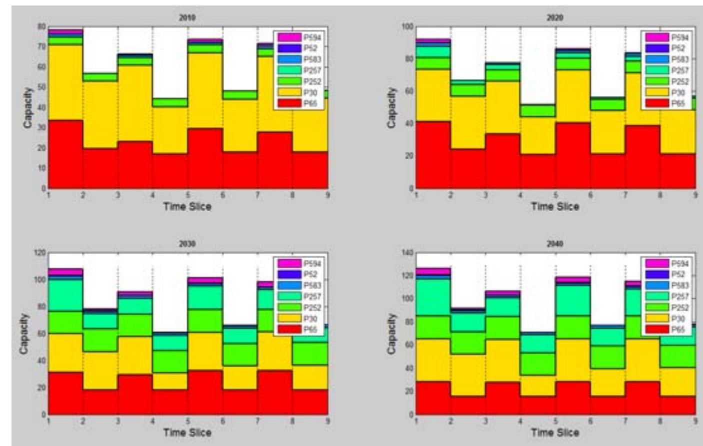
- Variable RE sources add to overall fluctuations between supply and demand.
- This requires increasingly flexible power systems.

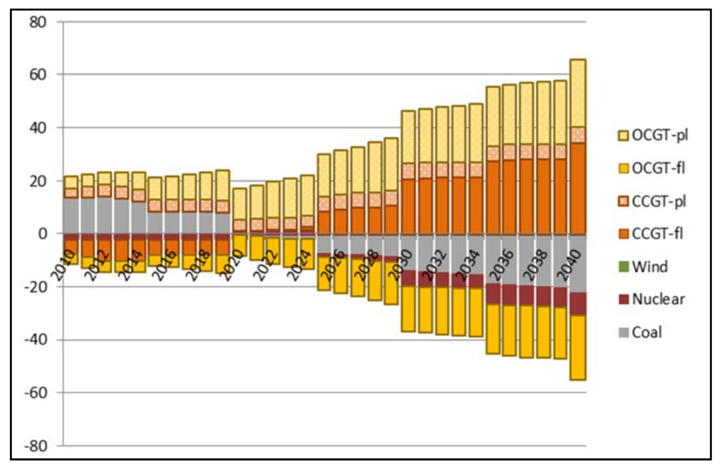
Integration of Short-term Dynamics into Long-term Models

- Long-term energy system models cannot incorporate daily operation of power plants
- Related short term constraints may significantly impact longer term investments
- But constraints like ramping rates, start-up costs, minimum stable generation, etc., are usually not considered
- OSeMOSYS was enhanced to capture the impacts of variability on **system adequacy and security** requirements
- System adequacy: Endogenous calculation of capacity credit by OSeMOSYS

System Security – Operating Reserve

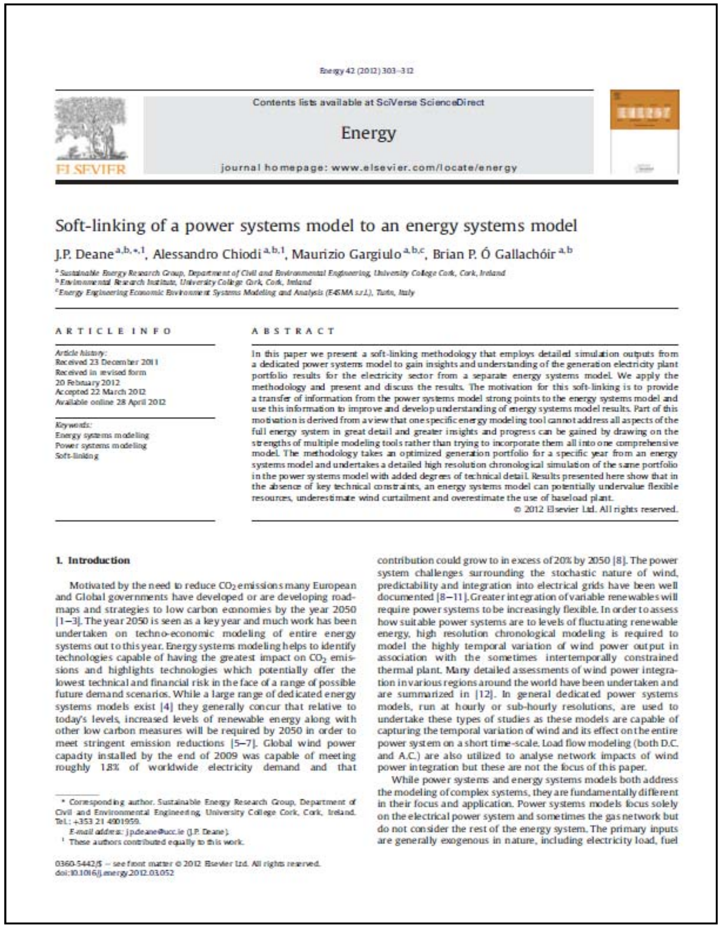
- Primary & secondary, upward & downward reserve
- Specific reserve contributions based on ramping rates can be defined for any technology, also demand-side
- Minimum stable generation levels considered
- Minimum level of spinning reserve can be defined
- Cycling constraints: changes of online capacity and generation from one time slice to another can be limited
- No mixed-integer programming introduced





Irish Case Study - Background

- Comparative UCC study linking TIMES & PLEXOS
- Modelled Irelands 40% RE generation target for 2020
- Set up OSeMOSYS in a similar fashion as Irish TIMES model (12 time slices)
- Added detail taken from the PLEXOS model (8760 time slices), but maintained 12 time slices
- Compared results with TIMES-PLEXOS
- **Publication:** Deane, J.P., Chiodi, A., Gargiulo, M., Ó Gallachóir, B.P., 2012. Soft-linking of a power systems model to an energy systems model. Energy 42, 303–312.



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Energy

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Soft-linking of a power systems model to an energy systems model

J.P. Deane[a,b,*,1], Alessandro Chiodi[a,b,1], Maurizio Gargiulo[a,b,c], Brian P. Ó Gallachóir[a,b]

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ABSTRACT

In this paper we present a soft-linking methodology that employs detailed simulation outputs from a dedicated power systems model to gain insights and understanding of the generation electricity plant portfolio results for the electricity sector from a separate energy systems model. We apply the methodology and present and discuss the results. The motivation for this soft-linking is to provide a transfer of information from the power systems model strong points to the energy systems model and use this information to improve and develop understanding of energy systems model results. Part of this motivation is derived from a view that one specific energy modeling tool cannot address all aspects of the full energy system in great detail and greater insights and progress can be gained by drawing on the strengths of multiple modeling tools rather than trying to incorporate them all into one comprehensive model. The methodology takes an optimized generation portfolio for a specific year from an energy systems model and undertakes a detailed high resolution chronological simulation of the same portfolio in the power systems model with added degrees of technical detail. Results presented here show that in the absence of key technical constraints, an energy systems model can potentially undervalue flexible resources, underestimate wind curtailment and overestimate the use of baseload plant.

1. Introduction

Motivated by the need to reduce CO_2 emissions many European and Global governments have developed or are developing road-maps and strategies to low carbon economies by the year 2050 [1–3]. The year 2050 is seen as a key year and much work has been undertaken on techno-economic modeling of entire energy systems out to this year. Energy systems modeling helps to identify technologies capable of having the greatest impact on CO_2 emissions and highlights technologies which potentially offer the lowest technical and financial risk in the face of a range of possible future demand scenarios. While a large range of dedicated energy systems models exist [4] they generally concur that relative to today's levels, increased levels of renewable energy along with other low carbon measures will be required by 2050 in order to meet stringent emission reductions [5–7]. Global wind power capacity installed by the end of 2009 was capable of meeting roughly 1.8% of worldwide electricity demand and that contribution could grow to in excess of 20% by 2050 [8]. The power system challenges surrounding the stochastic nature of wind, predictability and integration into electrical grids have been well documented [8–11]. Greater integration of variable renewables will require power systems to be increasingly flexible. In order to assess how suitable power systems are to levels of fluctuating renewable energy, high resolution chronological modeling is required to model the highly temporal variation of wind power output in association with the sometimes intertemporally constrained thermal plant. Many detailed assessments of wind power integration in various regions around the world have been undertaken and are summarized in [12]. In general dedicated power systems models, run at hourly or sub-hourly resolutions, are used to undertake these types of studies as these models are capable of capturing the temporal variation of wind and its effect on the entire power system on a short time-scale. Load flow modeling (both D.C. and A.C.) are also utilized to analyse network impacts of wind power integration but these are not the focus of this paper.

While power systems and energy systems models both address the modeling of complex systems, they are fundamentally different in their focus and application. Power systems models focus solely on the electrical power system and sometimes the gas network but do not consider the rest of the energy system. The primary inputs are generally exogenous in nature, including electricity load, fuel

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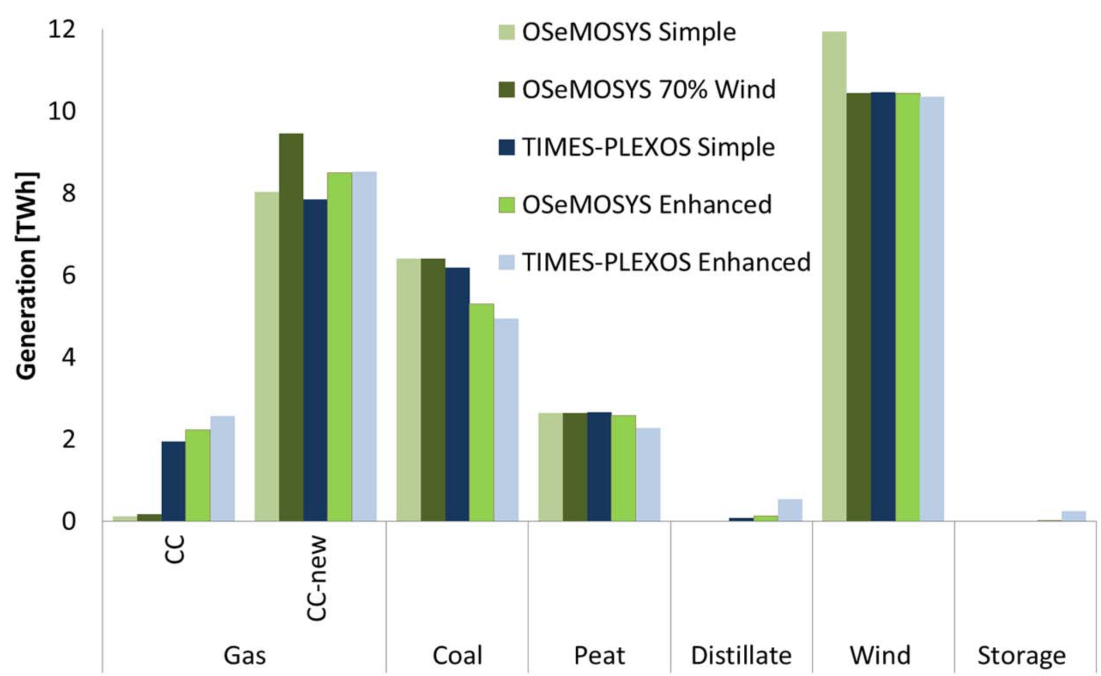
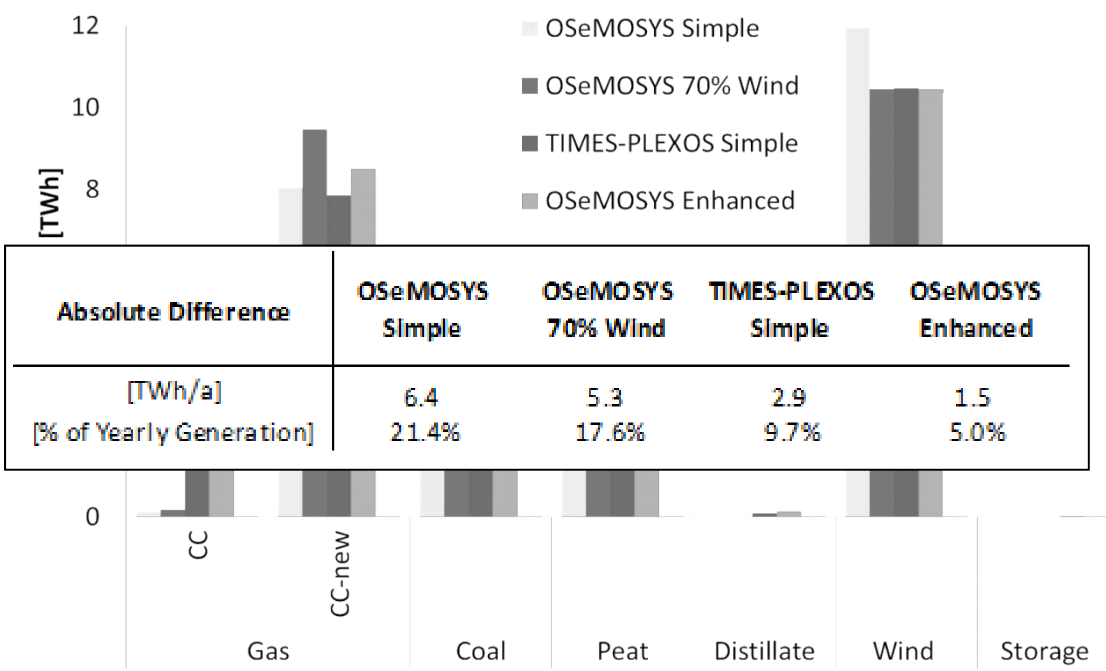
Irish Test Case – Results for 2020



Annual generation of the modelled power plant types
OSeMOSYS results in shades of green, TIMES-PLEXOS results in shades of blue.

Irish Test Case – Results for 2020



Absolute Difference	OSeMOSYS Simple	OSeMOSYS 70% Wind	TIMES-PLEXOS Simple	OSeMOSYS Enhanced
[TWh/a] [% of Yearly Generation]	6.4 21.4%	5.3 17.6%	2.9 9.7%	1.5 5.0%

Annual generation of the modelled power plant types
OSeMOSYS results in shades of green, TIMES-PLEXOS results in shades of blue.

Irish Test Case – Results for 2050

Deviation of capacities, discounted costs and emissions from enhanced OSeMOSYS model

OSeMOSYS Simple	Unit	2020	2025	2030	2035	2040	2045	2050
Total capacity	%	0.0	4.0	4.6	3.8	3.3	-2.1	-14.1
Σ |Plant capacity deviations| / Capacity OSeMOSYS Enhanced	%	0.0	4.0	17.4	20.3	15.1	19.3	23.5
Discounted costs	%	-9.0	40.5	-11.3	-4.0	-5.8	-21.5	-14.3
Emissions	%	-1.3	-7.6	-14.4	-5.4	0.0	0.0	0.0

OSeMOSYS 70% Wind	Unit	2020	2025	2030	2035	2040	2045	2050
Total capacity	%	0.0	0.0	-1.4	-1.3	-1.2	-6.4	-7.8
Σ |Plant capacity deviations| / Capacity OSeMOSYS Enhanced	%	0.0	0.0	7.3	12.8	9.4	14.1	13.0
Discounted costs	%	-2.3	-1.9	-0.2	-3.0	-9.1	-15.2	-3.9
Emissions	%	3.5	0.3	-1.3	2.5	0.0	0.0	0.0

Conclusions

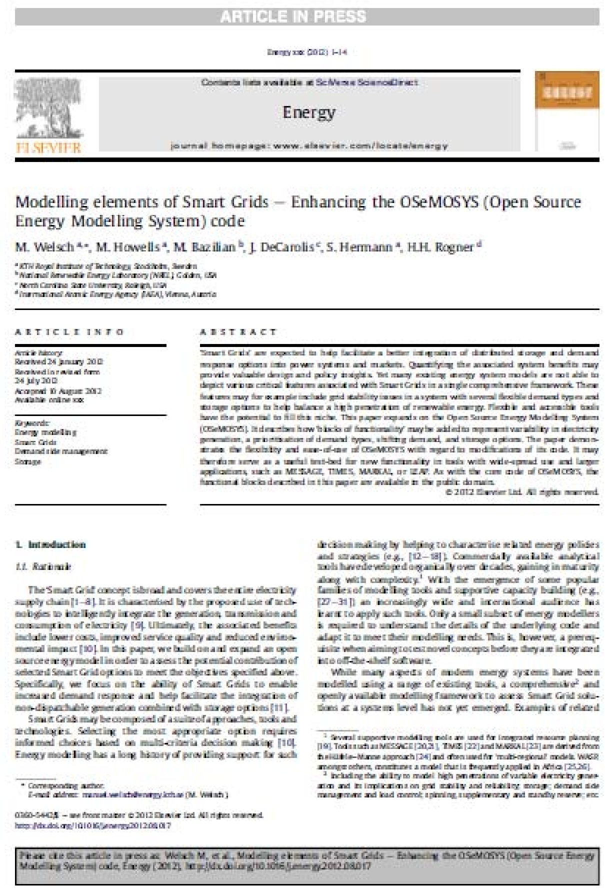
Long-term models which omit short-term constraints: Need for flexible power systems may be underestimated -> potentially skewed insights for policy development.

Soft-linking: two separate models required; no overall optimisation across the two models -> identified capacity investments may not present the economically most efficient pathway.

Integrating operational aspects into the long-term models: 95.0% of dispatch results of enhanced OSeMOSYS model matched those of an interlinked model with a 700 times higher temporal resolution.

Publications

- M. Welsch, M. Howells, M. Hesamzadeh, B. Ó Gallachóir, P. Deane, N. Strachan, et al. **Supporting Security and Adequacy in Future Energy Systems – The need to enhance long-term energy system models to better treat issues related to variability.** Revisions submitted.
- M. Welsch, P. Deane, F. Rogan., M. Howells, B. Ó Gallachóir, H.H. Rogner, et al. **Incorporating Flexiblity Requirements into Long-term Models – A Case Study on High Levels of Renewable Electricity Penetration in Ireland.** Submitted.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Energy

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Modelling elements of Smart Grids – Enhancing the OSeMOSYS (Open Source Energy Modelling System) code

M. Welsch [a,*], M. Howells [a], M. Bazilian [b], J. DeCarolis [c], S. Hermann [a], H.H. Rogner [d]

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ABSTRACT

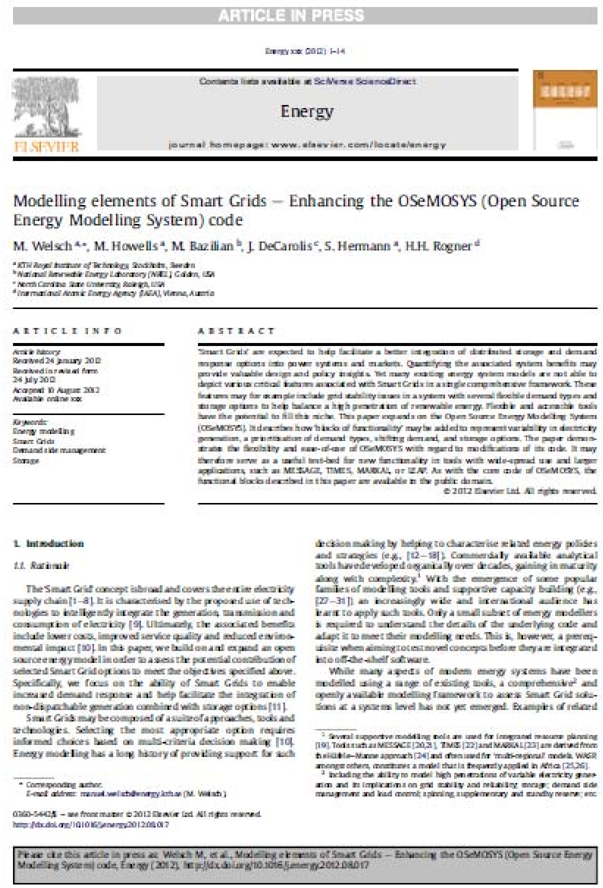
'Smart Grids' are expected to help facilitate a better integration of distributed storage and demand response options into power systems and markets. Quantifying the associated system benefits may provide valuable design and policy insights. Yet many existing energy system models are not able to depict various critical features associated with Smart Grids in a single comprehensive framework. These features may for example include grid stability issues in a system with several flexible demand types and storage options to help balance a high penetration of renewable energy. Flexible and accessible tools have the potential to fill this niche. This paper expands on the Open Source Energy Modelling System (OSeMOSYS). It describes how 'blocks of functionality' may be added to represent variability in electricity generation, a prioritisation of demand types, shifting demand, and storage options. The paper demonstrates the flexibility and ease-of-use of OSeMOSYS with regard to modifications of its code. It may therefore serve as a useful test-bed for new functionality in tools with wide-spread use and larger applications, such as MESSAGE, TIMES, MARKAL, or LEAP. As with the core code of OSeMOSYS, the functional blocks described in this paper are available in the public domain.

1. Introduction

1.1. Rationale

Publications

- M. Welsch, M. Howells, M. Bazilian, J. DeCarolis, S. Hermann, H.H. Rogner. **Modelling Elements of Smart Grids – Enhancing the OSeMOSYS (Open Source Energy Modelling System) code**. Energy 46 (1), pp. 337–350, 2012.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1. Introduction

1.1. Rationale

Selected OSeMOSYS Applications

Global CLEWs MODEL – C. Taliotis, M. Weirich (KTH)

Developed in OSeMOSYS in collaboration with UNDESA

Aim

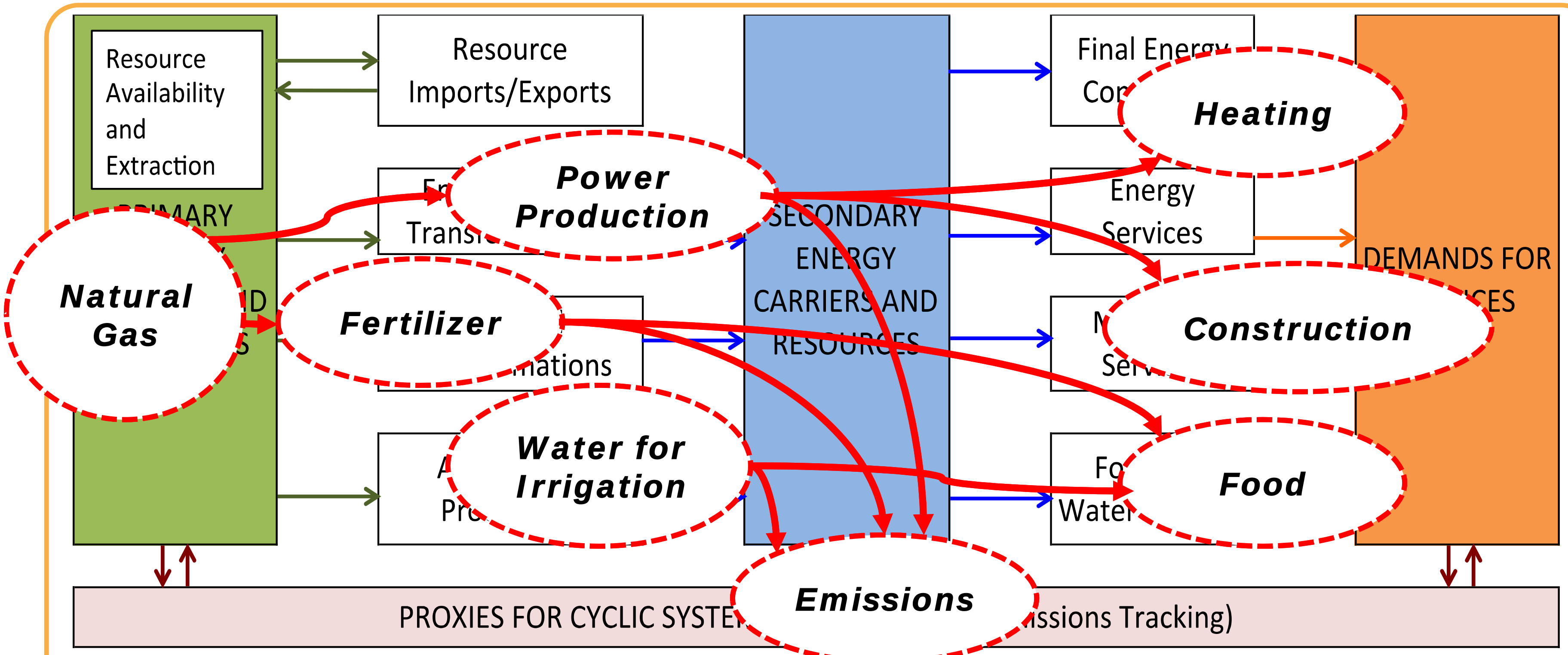
- *Provide a transparent tool that facilitates the assessment of various policy pathways associated with integrated resource management and keeps sustainable development as an overarching theme.*

Objectives

- *Served as input to UN Sustainable Development Report*
- *Simplified testing ground for policies*
- *Trade-offs and synergies between CLEW and materials sectors*

KTH - dESA
develops a novel approach to tackle Climate, Land, Energy and Water interlinkages (CLEWs)

Global CLEWs MODEL – C. Taliotis, M. Weirich (KTH)



The OSeMOSYS model, along with a generic database will be fully open-source
TRANSPARENCY – ACCESSIBILITY – COLLABORATION – SCALABILITY

Assessing the climate vulnerability of the African continent – Mark Howells (KTH)

Key Actors

Commissioning Institution:	The World Bank (WB)
Leading Partner Institutions:	Stockholm Environment Institute (SEI)
	The RAND Corporation

Objectives

- Study the interactions of a constrained and aging system under future climate uncertainties
- Quantified network infrastructure performance for 4 Power Pools and 7 Water Basins to enable identification of Robust Adaptation strategies
- Integration of water and energy modelling efforts

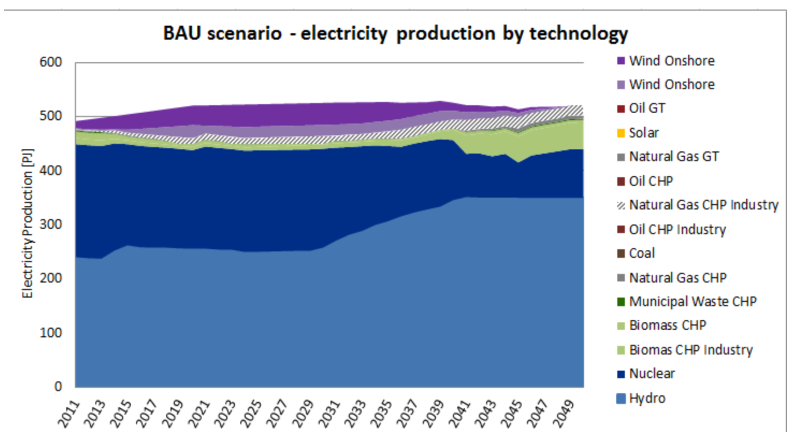
Work Progress

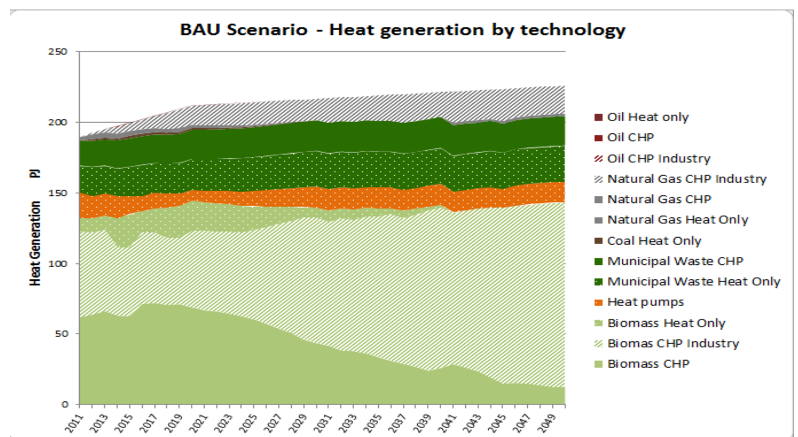
- OSeMOSYS model of South African Power Pool
- Includes 12 countries; > 620 technologies; > 120 fuels; 48 characteristic time periods for each year; Modelling horizon: up until 2050
- ‘Detailed’ hydro availability representation
- Multiple scenarios showing (a) the impact of reduced hydro availability as compared to a baseline scenario and (b) as compared to a low GI baseline

Sweden Energy Model – Nawfal Saadi (KTH)

- Electricity and heat systems from resource extraction to final use.
- Energy demand of all sectors including residential, industry, agriculture, commercial, services and transport.
- Assessment of energy system's economical and environmental costs from 2010-2050

- Open source – from data to code
- Bridging the gap between science and policy
- Inspired by the success of the DECC 2050 Pathways Calculator(link)





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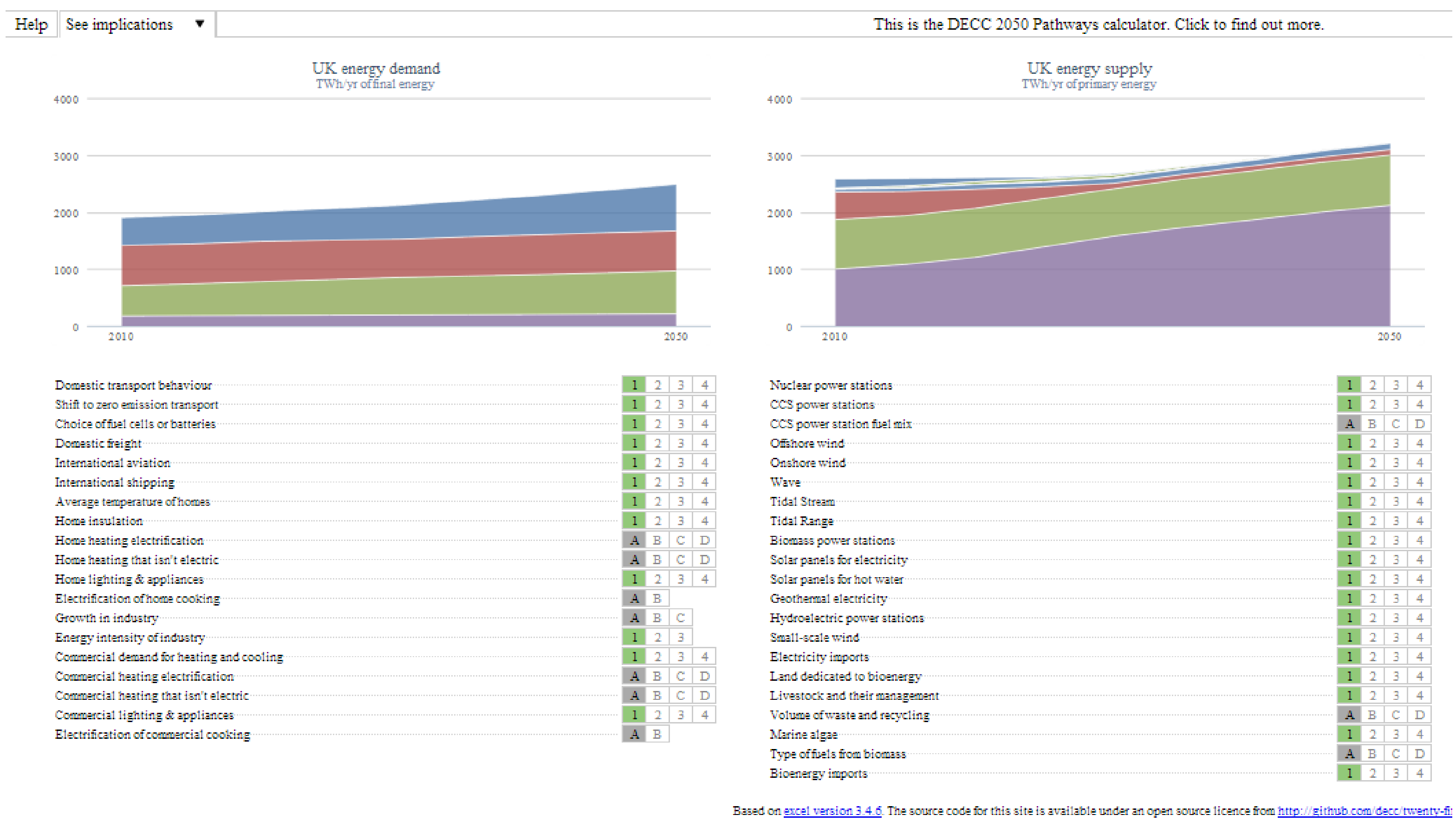
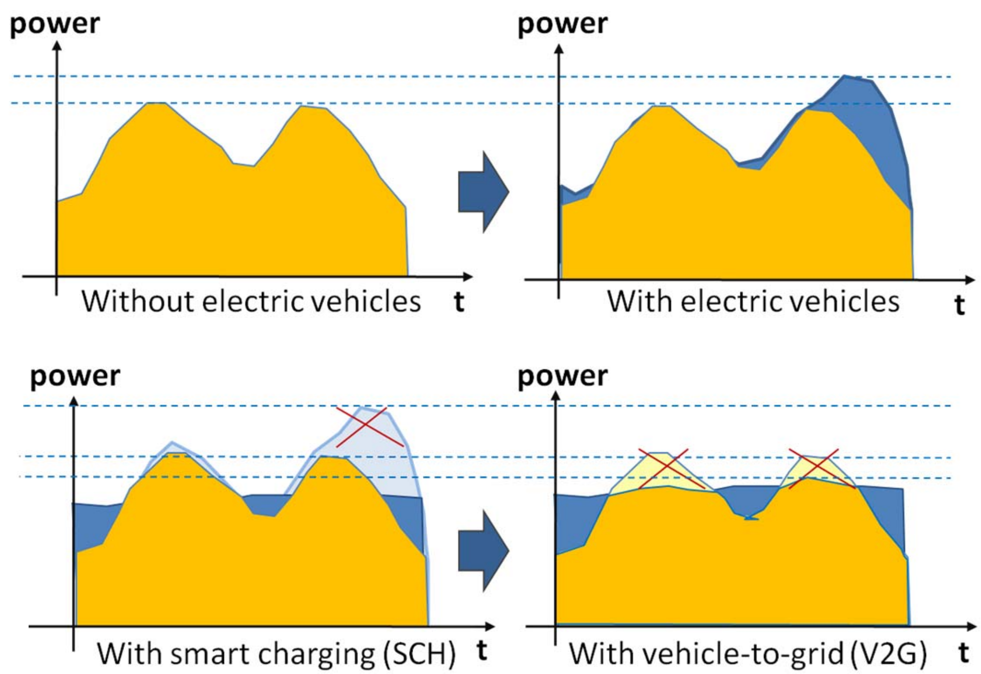


Electric vehicles and related smart controls – Fabrizio Fattori (University of Pavia)

<u>In order to consider:</u>

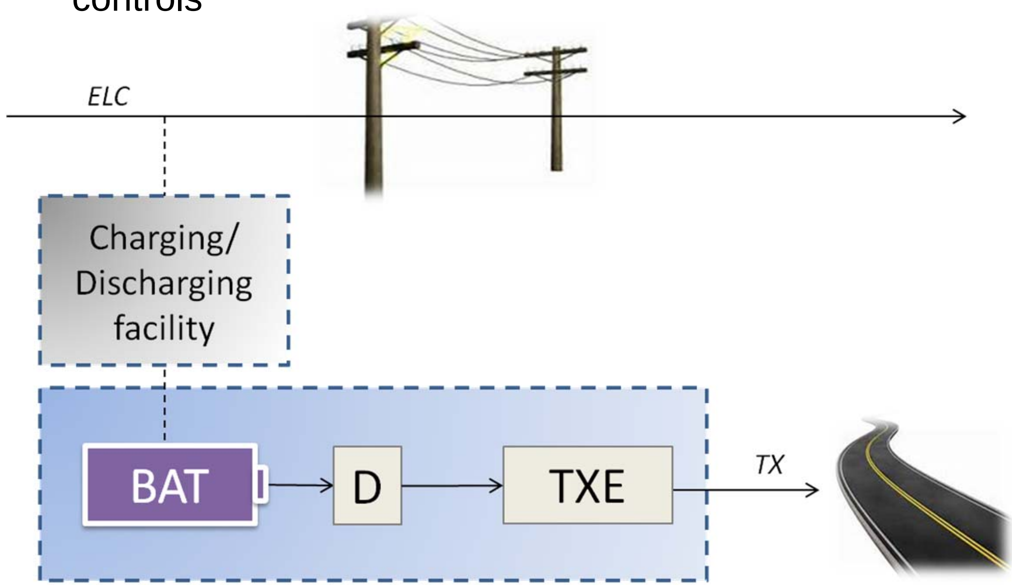
- Additional load on the grid (thus a different capacity need, different emission factor, etc.)
- Benefits of smart charging (mainly avoiding additional peaks, improving emission factor, etc.)
- Benefits of vehicle-to-grid (mainly serving the grid with reserve backup service)
- Investment and operational costs or the long term



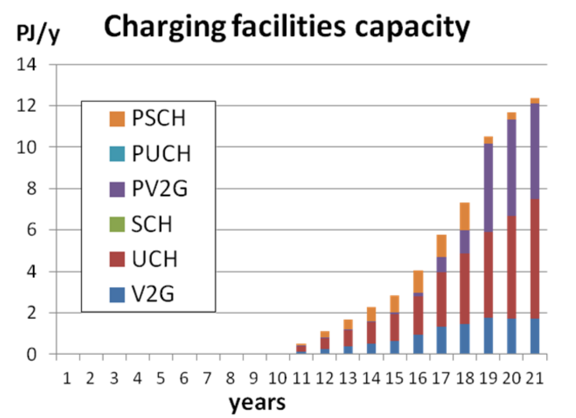
Electric vehicles and related smart controls – Fabrizio Fattori (University of Pavia)

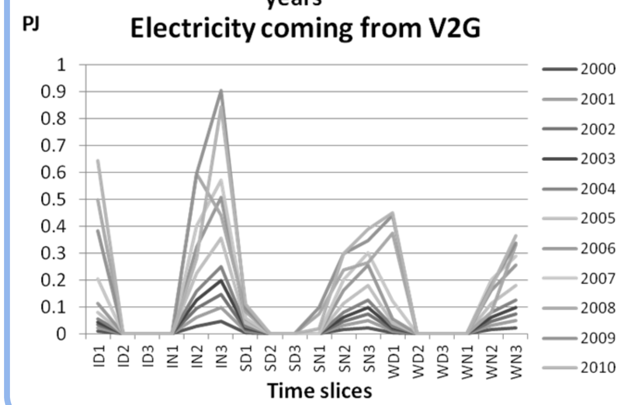
Implementation in OSeMOSYS

- The basic modeling structure was used
- Some specific equations and parameters were added and apply only to electric vehicles and related intelligent controls



Some results





Implementing Big Hydro – Taco Niet (British Columbia Institute of Technology)

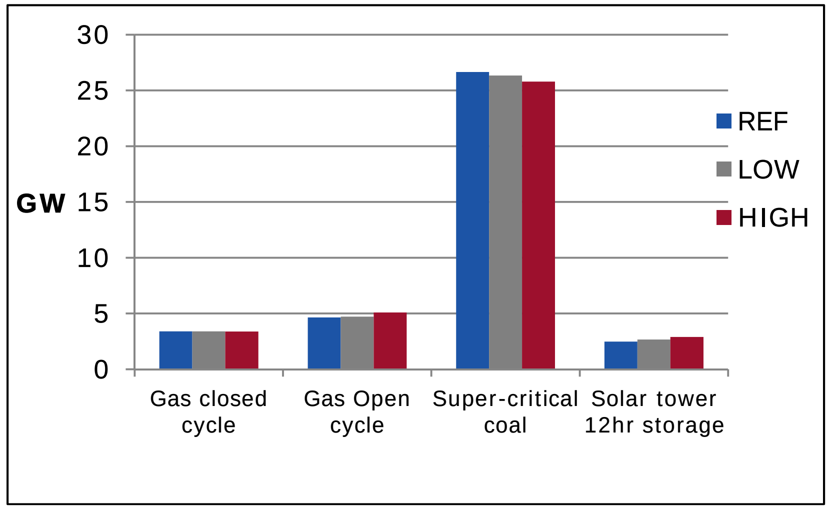
- Grid Interconnection Group
- Models of Alberta, BC System
- Implemented Big Hydro in OSeMOSYS
- Looking at effects of load/time groupings
- -> Cascading hyrdo power

The Peace/Williston Fish and Wildlife Compensation Program'. [Online]. Available: http://www.bchydro.com/pwcp/program.html. [Accessed: 05-Mar-2013].

Net metering in South Africa – Bryce McCall (University of Cape Town)

Objective: *to understand how net metering of solar rooftop PV may affect the electricity investments in South Africa*

Created an energy model of the electricity sector using OSeMOSYS and data from South African TIMES model (SATIM) from the ERC



Notes on OSeMOSYS usage

- *Required several new parameters involving production limits.*
- *Very easy to learn and understand how OSeMOSYS works and how to add new parameters, especially for anyone experienced in coding or programming.*
- *Interface would greatly improve the user-friendliness of OSeMOSYS*

OSeMOSYS (Open Source Energy Modelling System)

- **OSeMOSYS** is a fully fledged energy systems linear optimisation model, with **no associated upfront financial requirements.**
- It is (comparatively) easy to adjust the model to anyone's particular needs!
- It is a collaborative effort -> join in!
- For further information and downloads, visit www.osemosys.org

Knowledge Partners

Thank you for your attention