Integrated Energy System Models (IESMs)

ENERGY INSTITUTE UCD

National Renewable Energy Laboratory,
August 3rd to 7th, 2015

iiESI International Institute for Energy Systems Integration

Outline

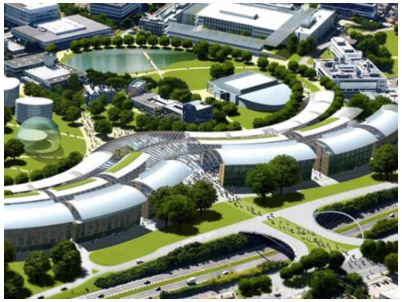
- Modelling, simulation and data
- What
- Why
- Examples

Modelling, simulation & data

Why do we need models

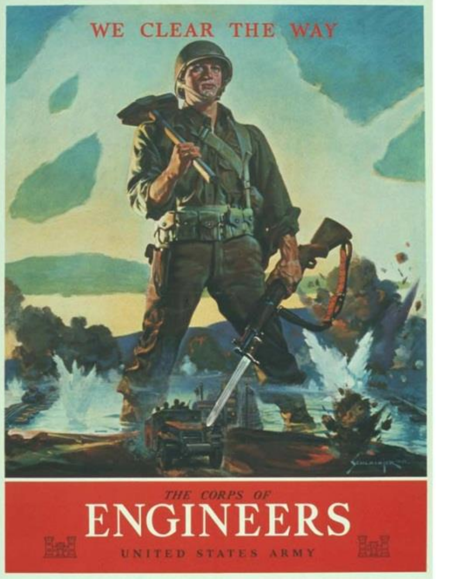
- Predict what will happen
  - design and analysis

- Different types
  - Physical models (e.g. scale models)
  - ***Mathematical models***
- Different level of details required
  - For systems we want/need:
    - Simple model for each component
    - Only interested in system issues not in detail of each component
  - For components we may need
    - Detailed models

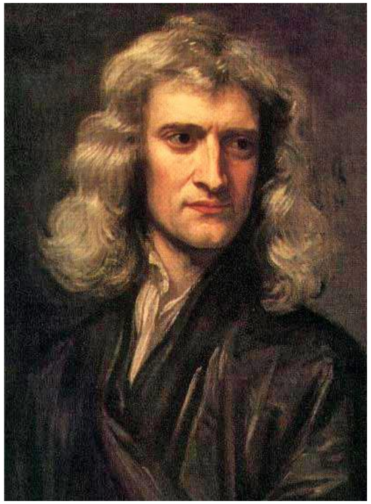


“Engineering” the art of approximation

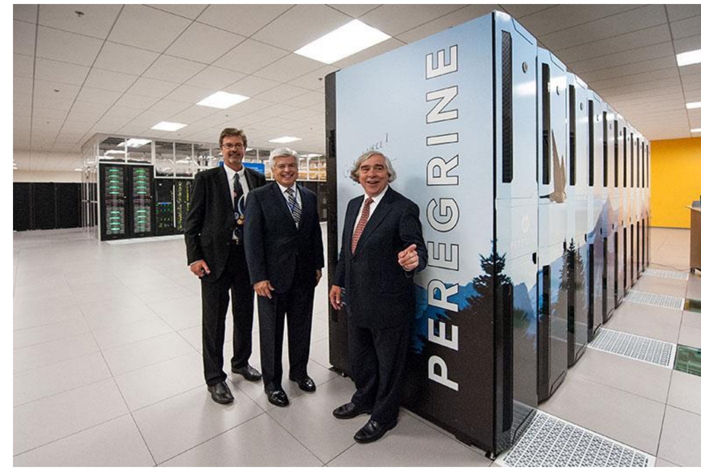
- ‘The art of being wise is the art of knowing what to overlook.’ William James, American Philosopher and Psychologist, 1842 – 1910.
- When we represent a piece of the world in our minds, we discard many aspects – we make a model.
- An approximate model is often more useful than an exact one.
  - allows insight and intuition
  - pragmatically easier to work with
  - an approximate model is all that we can understand.
- Since every model is approximate, how do we choose useful approximations?
  - by knowing the details !



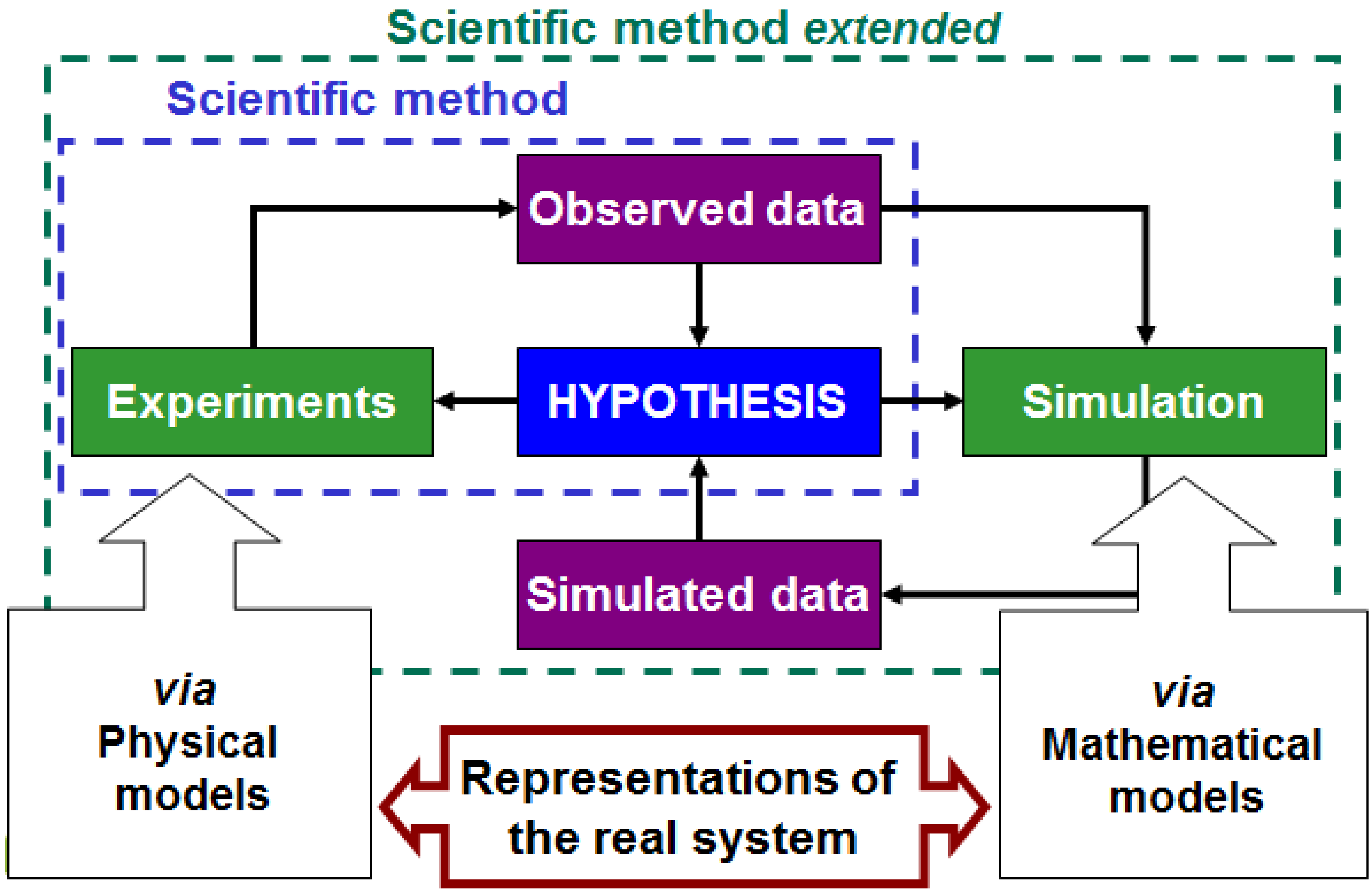
Model, Simulation & Data



"If I have seen a little further it is by standing on the shoulders of Giants"



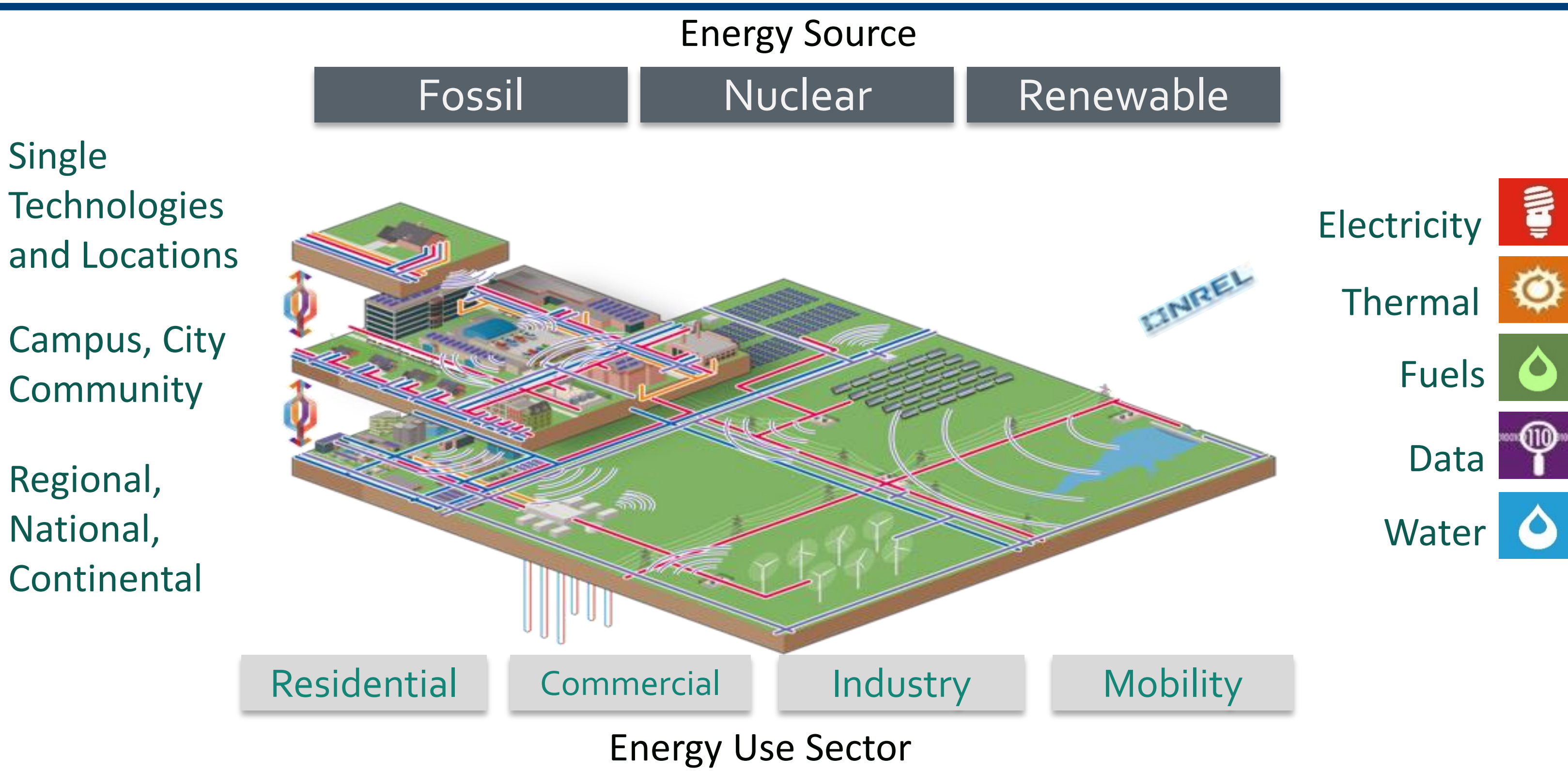
Modelling and simulation "science"



https://en.wikipedia.org/wiki/Modeling_and_simulation#Modeling_and_simulation_as_an_emerging_discipline

Modelling and ESI

Energy Systems Integration (ESI)



- optimization of energy systems across multiple pathways and scales
- increase reliability and performance, and minimise cost and environmental impacts
- most valuable at the interfaces where the coupling and interactions are strong and represent a challenge and an opportunity
- control variables are technical economic and regulatory

IESMs built on fundamental laws across may disciplines – “constraints”

Maxwell

$$\oint \mathbf{E} \cdot d\mathbf{A} = \frac{q_{enc}}{\varepsilon_0}$$

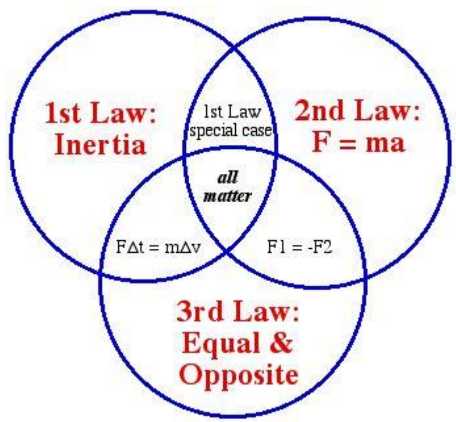
$$\oint \mathbf{B} \cdot d\mathbf{A} = 0$$

$$\oint \mathbf{E} \cdot d\mathbf{s} = -\frac{d\Phi_B}{dt}$$

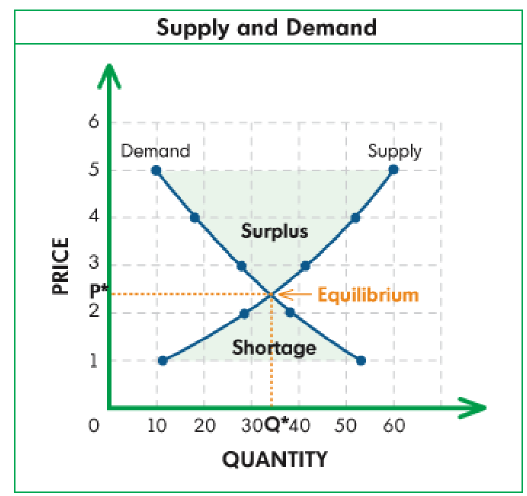
$$\oint \mathbf{B} \cdot d\mathbf{s} = \mu_0 \varepsilon_0 \frac{d\Phi_E}{dt} + \mu_0 i_{enc}$$

Laws of Thermodynamics

Zeroth: *"You must play the game."*
First: *"You can't win."*
Second: *"You can't break even."*
Third: *"You can't quit the game."*

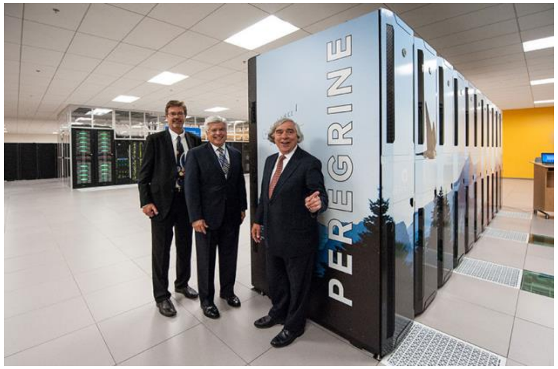


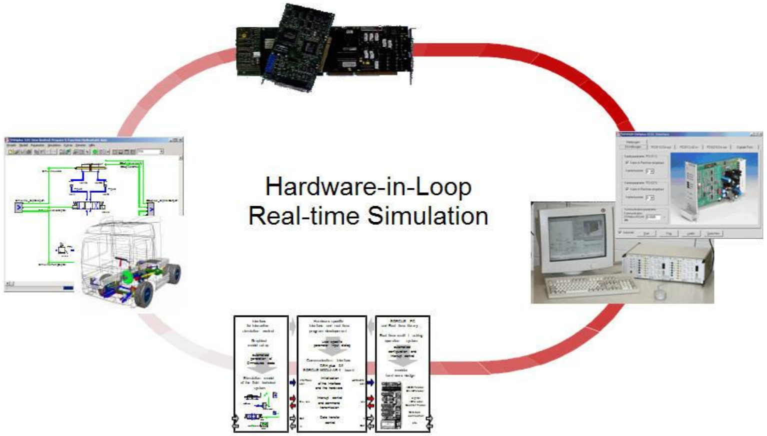
Newton's Laws



Model Types

- Planning
- Operations
- Time series
- Scenario
- Optimisation
- Dynamic/static
- Stochastic/deterministic
- Equilibrium (partial)
- Market
- Hardware in the loop
- etc.



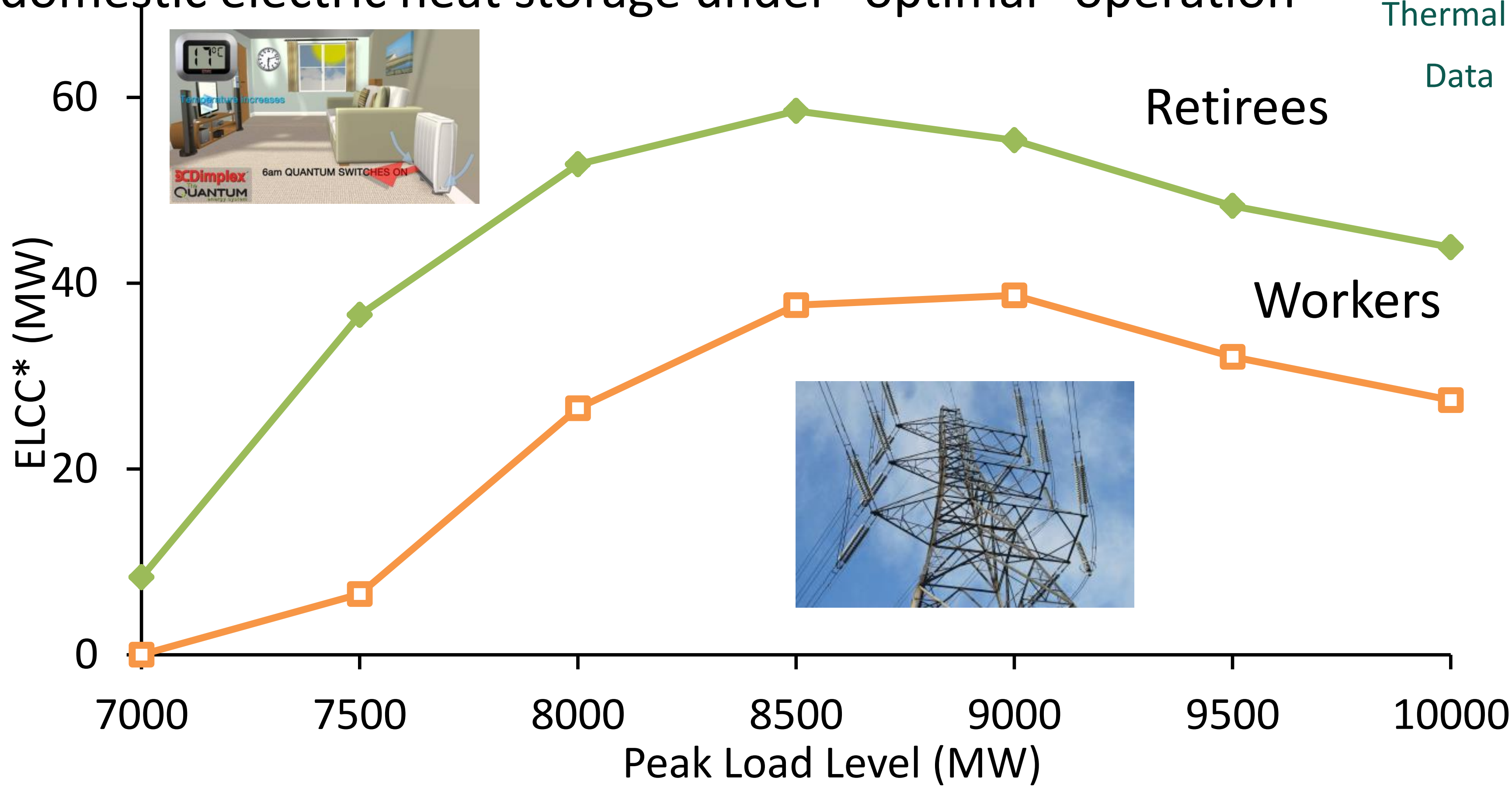


Examples of IESMs in research

Heat and Electricity

Electricity
Thermal
Data

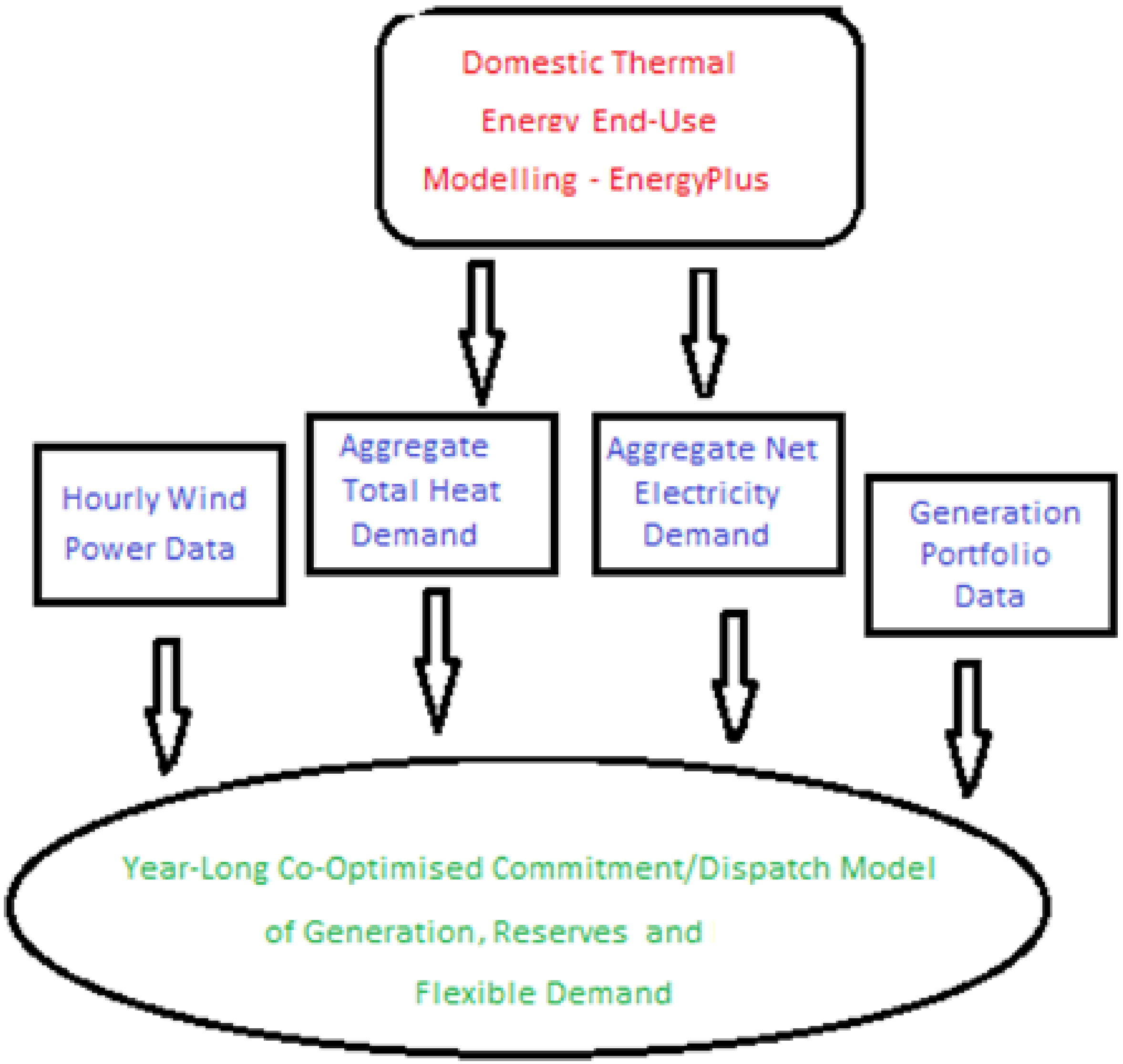
Effective Load Carrying Capability (ELCC) of 700MW of domestic electric heat storage under “optimal” operation



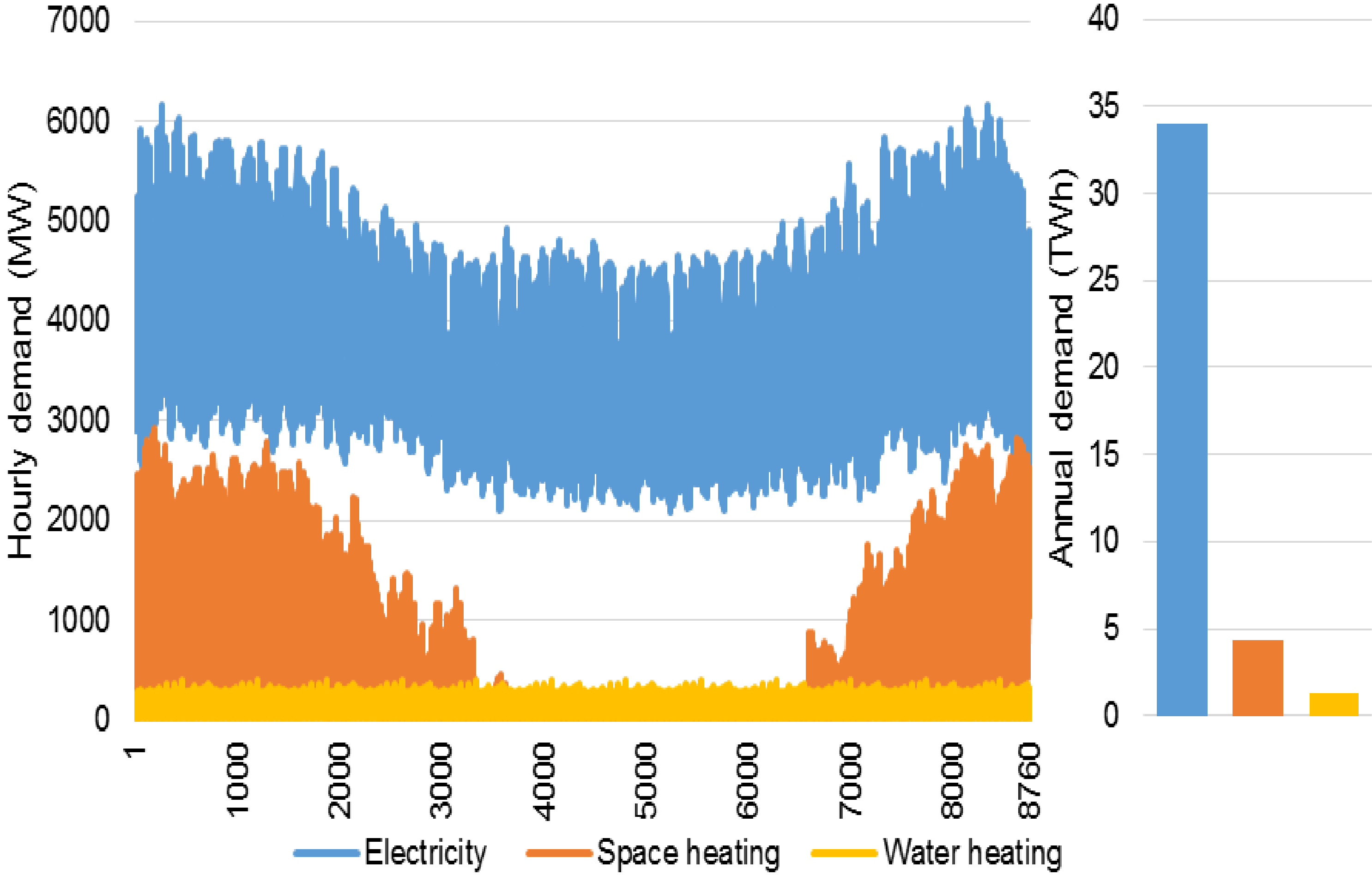
Note: These are preliminary results and are part of on-going work

Source: S. Nolan, PhD student ERC, UCD

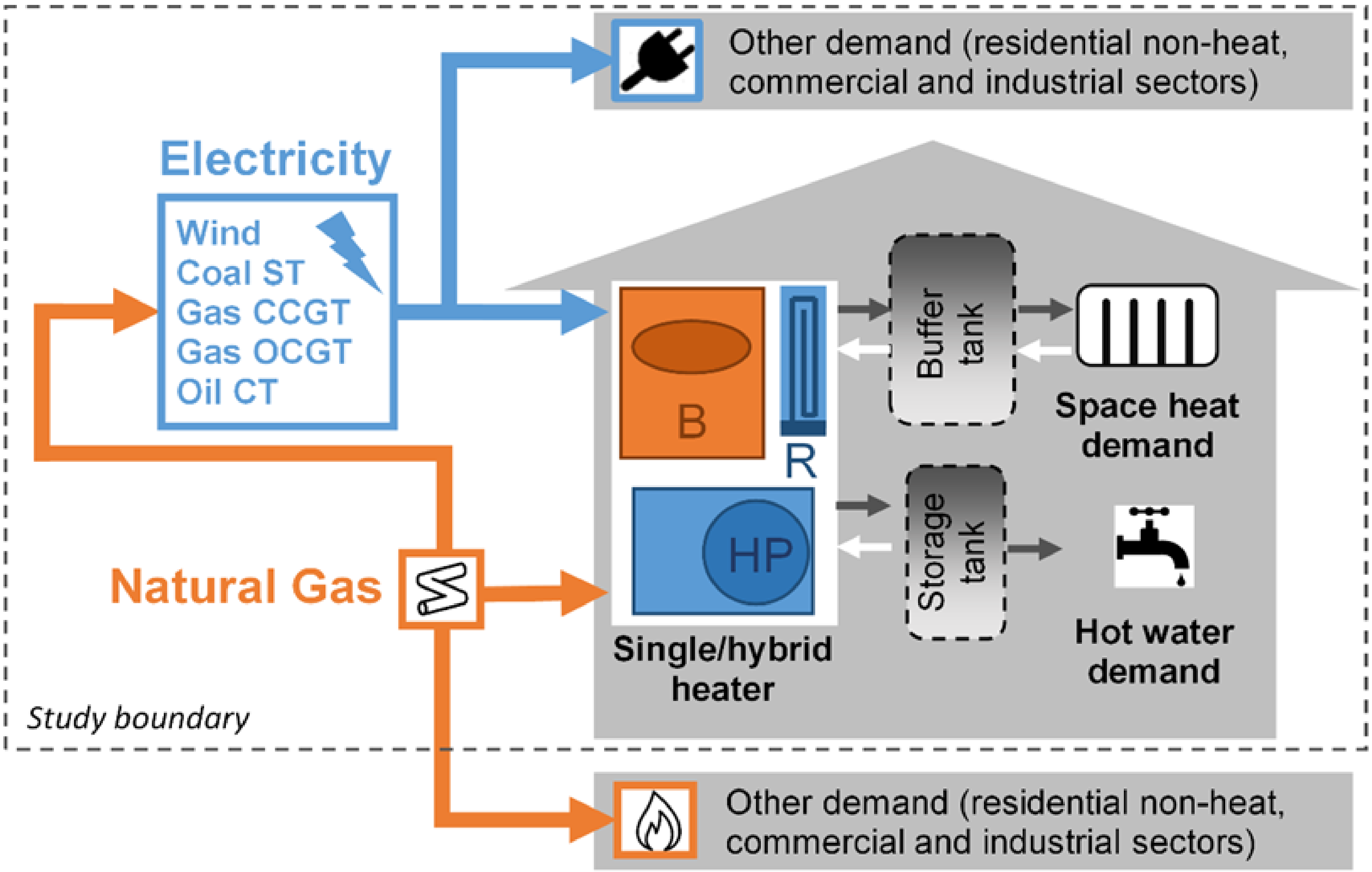
Co-Optimised IESM - Building to Grid



Electricity demand for Ireland and heat demand for 25% of Irish households



Hybrid heating systems



Investment model: Mathematical formulation

- Objective function includes total annualized investment, fuel and carbon expenditure for both power generation and residential heat, based on specific investment cost *IC*, fuel prices *FP*, carbon emission factors *CF*, carbon price *CP*, number of residential households *n,* capital cost for smart controls $C^{H}_{IT\&Com}$ for hybrid heaters and an annuity factor a

$$\min\left(\sum_{Tech=PowerGen}\left(\begin{array}{l}\underbrace{\left(a^{P}\right)^{-1}\cdot IC^{P}_{Tech}\cdot C^{P,NEW}_{Tech}}_{annualised\ investment\ power}+\\ \underbrace{\sum_{t=1}^{8760}FP^{P}_{Tech}\cdot E^{P}_{Tech}(t)+CF^{P}_{Tech}\cdot CP\cdot E^{P}_{Tech}(t)}_{annual\ fuel\ \&\ carbon\ cost\ power}\end{array}\right)+n*\left(\begin{array}{l}\sum_{Tech=\{B,HP,R\}}\left(\underbrace{\left(a^{H}\right)^{-1}\cdot\left(IC^{H}_{Tech}\cdot C^{H}_{Tech}+C^{H}_{IT\&Com}+\sum_{i=\{space,water\}}IC^{Sto,i}\cdot C^{Sto,i}\right)}_{annualised\ investment\ heat}\right)\\ +\underbrace{\sum_{t=1}^{8760}FP^{H}_{Tech=B}\cdot E^{H}_{Tech=B}(t)+CF^{H}_{Tech=B}\cdot CP\cdot E^{H}_{Tech=B}(t)}_{annual\ fuel\ \&\ carbon\ cost\ heat}\end{array}\right)\right)$$

Subject to

- Total electricity demand = electricity demand + potential electric heating demand
- Demand balance between power and heat generation technologies and demand
  - For heat, thermal storage in buffer tank is possible (L: Loading; U: Unloading)

$$n\cdot\left(\sum_{Tech=Heat}\left(\eta_{Tech}(T_{outside}(t))\cdot E^{H,i}_{Tech}(t)\right)-L^{i}(t)+U^{i}(t)\right)=D^{H,i}(t)\quad\forall i\in\{water;space\},\forall Tech\in H,\forall t$$

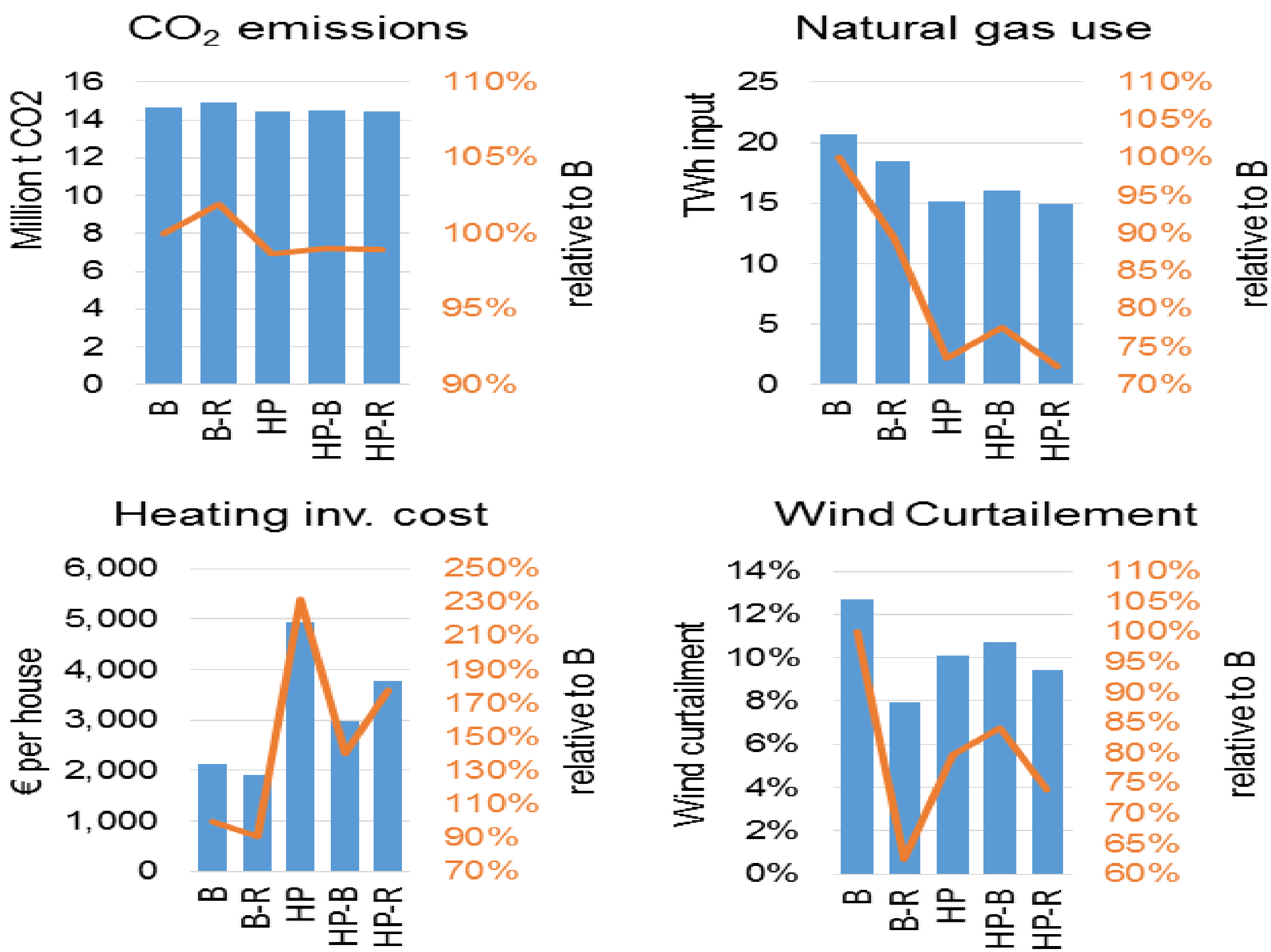
- No more energy can be generated than capacity built for power and heat generation

Power sector specific

- Capacity constraints for system adequacy based on capacity credits
- Energy generation limitation for power generation based on availability
- Limitation for instantaneous penetration of wind
- Coal ramping limitation

S. Heinen and M. O'Malley, "Power System Planning Benefits of Hybrid Heating Technologies", IEEE PowerTech, Eindhoven, June, 2915

Hybrid heating systems – results



B – gas; BR – gas and resistive; HP – heat pump

HP-B – heat pump & gas; HP-R – heat pump and resistive

Transport and Energy

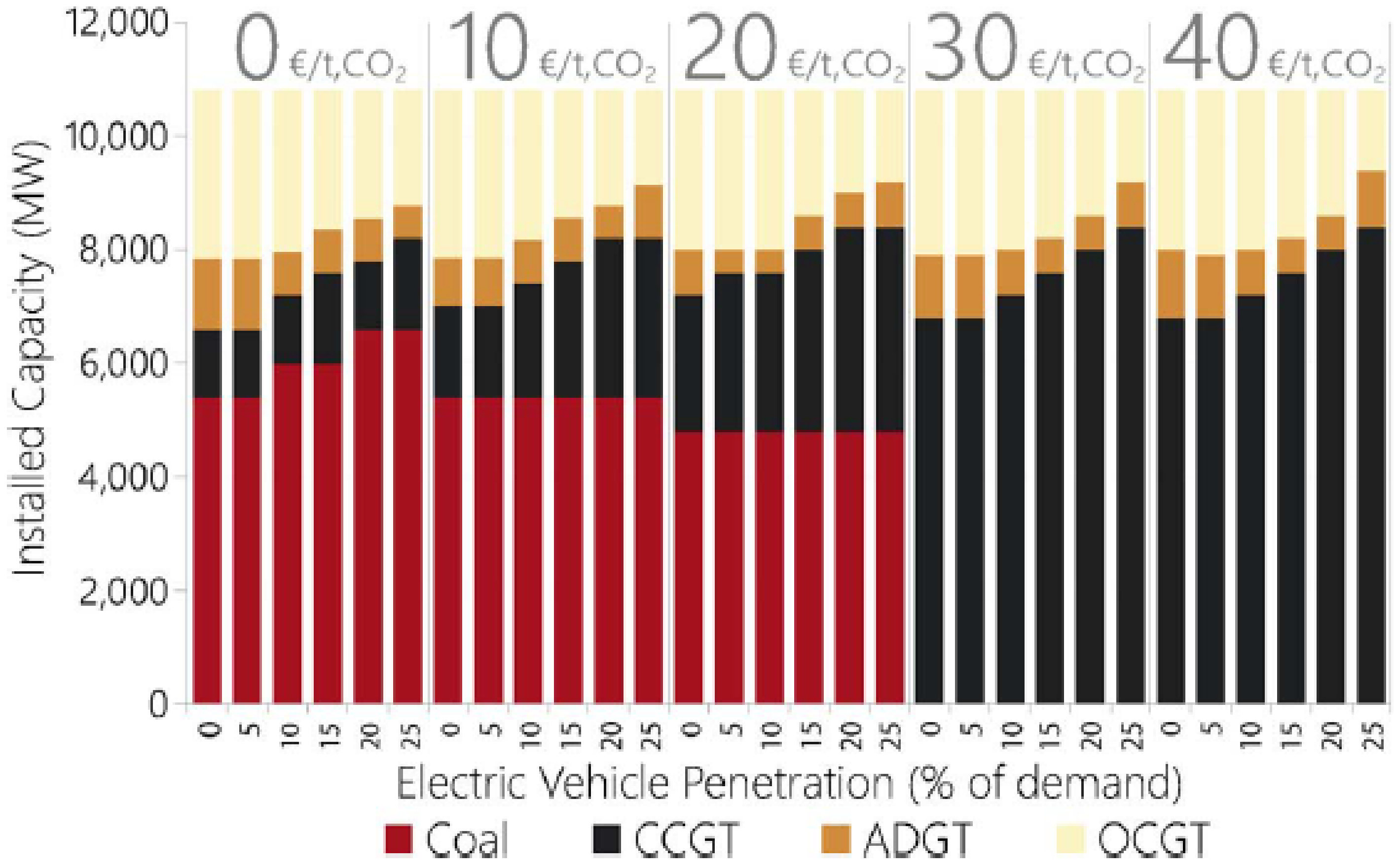


Fig. 20. Final installed capacities for selected CO_2 cost levels and electric vehicle penetrations (Ireland, 10% wind).

A. Shortt and M.J. O'Malley, "Quantifying Long-Term Impact of Electric Vehicles", IEEE Transactions on Smart Grid, Vol. 5, pp. 71-83, 2014.

Data Centres

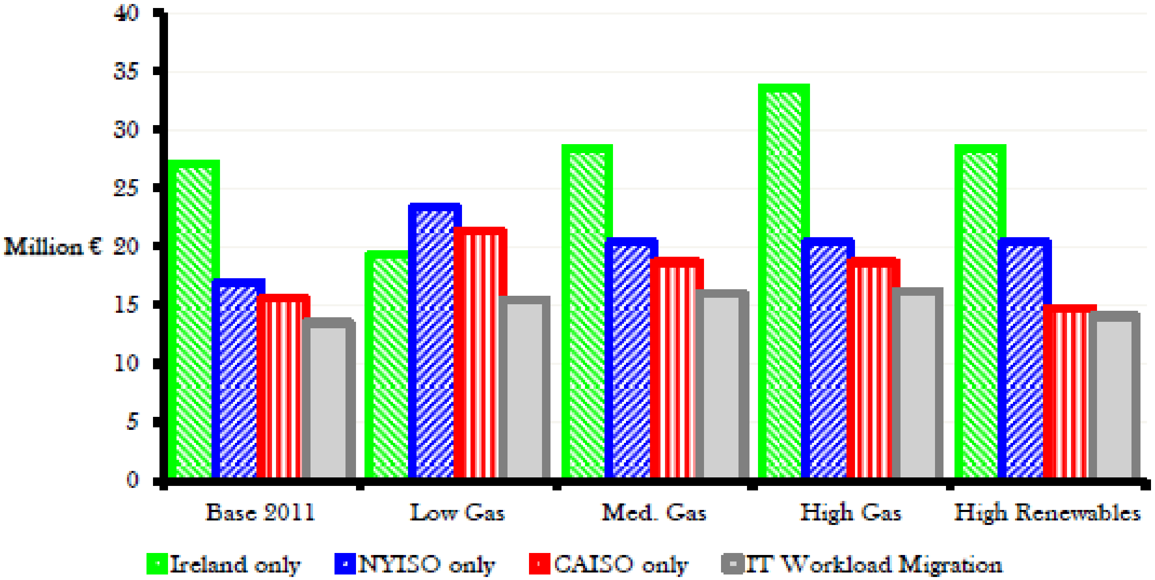


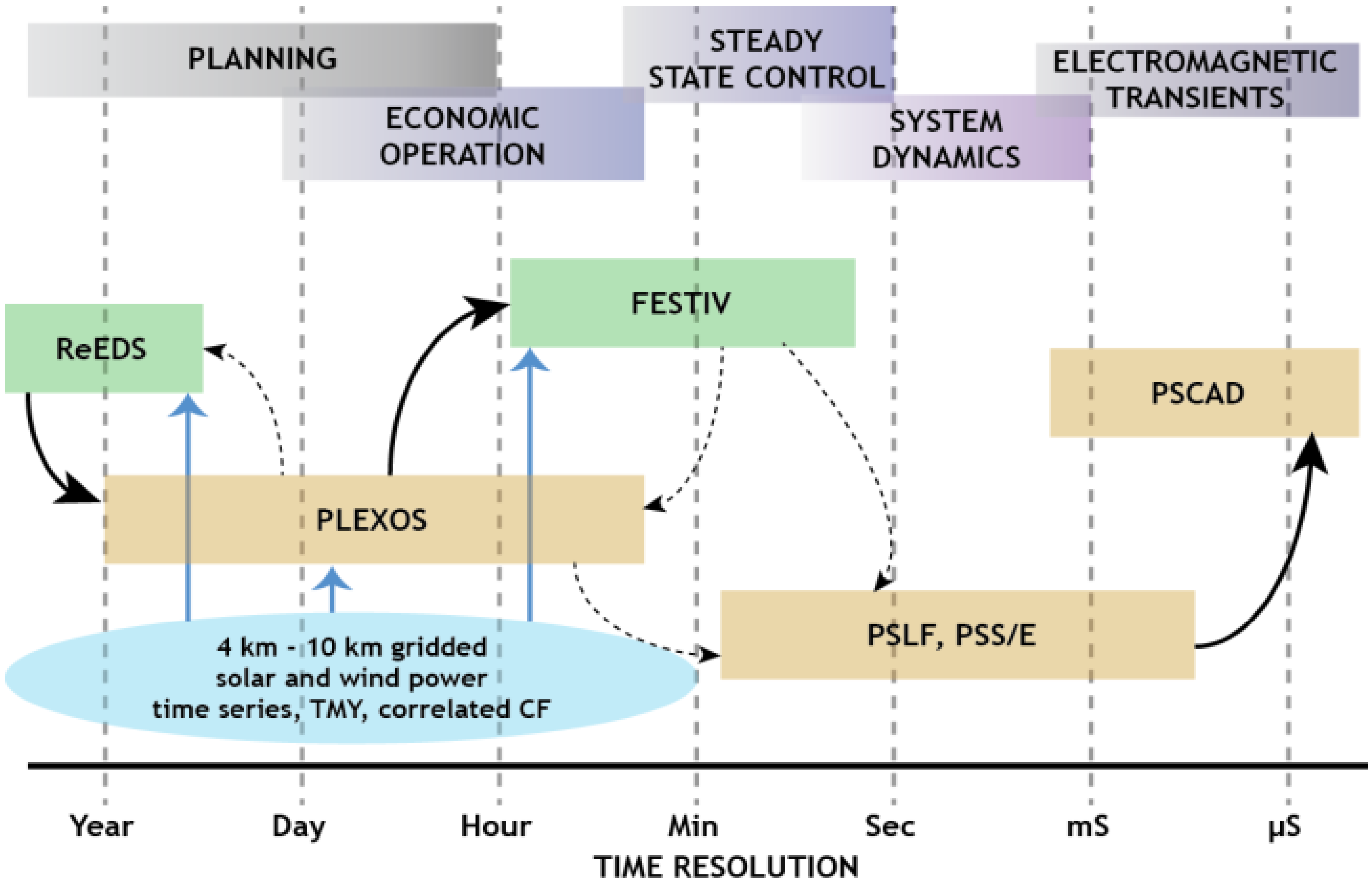
Fig. 4. Total costs of the optimized IT workload migration compared to the IT workload staying in each region with no migration.

Ruddy, J. and O'Malley, M.J., "Global shifting of data center demand", 5th IEEE PES Innovative Smart Grid Technologies (ISGT) European 2014 Conference, Istanbul, Oct. 12 - 15, 2014.

Models

- PSSE
- PLSF
- DIGSILENT
- PSCAD
- EMTP
- PLEXOS
- MARS
- Wilmar
- TIMES
- MARKAL
- EnergyPlus
- Festiv
- REEDS
- HOMER
- EnergyPlan
- Leap
- OpenDSS
- MAFRIT
- IESM
- GridLabD
- Modelica
- RetScreen
- Balmorel
- etc.

Modeling and Simulation at Multiple Temporal Scales - Electricity



NREL
NATIONAL RENEWABLE ENERGY LABORATORY

Interdisciplinary, Overlapping & Across Timescales,

Italian blackout, September 2003

Climate

Gas & Water Operations

Consumer Behaviour

Economics & Markets

Weather

Power Systems Stability Analysis

Power Electronics

Telecoms

'Welcome to the Cantareira desert'
(Cantareira reservoir, Brazil)

milliseconds seconds hours days months years

Time

Key Research Questions

- What do we need to model and why ?
  - This can be application specific
- What is the state of the art in IESMs
  - Do they meet what is needed ?
- What are the modelling gaps i.e. what models need to be developed
  - What data is required
- Develop the model
  - Integrate existing
  - Code it from basics
- Validate the model
- Apply the model
- Was it useful – go back to the top