TIMES modeling for International Electricity Markets

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- Role of models in Energy-environment policy
- ETSAP methodology and tools
- Structure of a typical TIMES model
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- TIMES-IEM

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KANUDIA OPERATIONS RESEARCH SOFTWARE

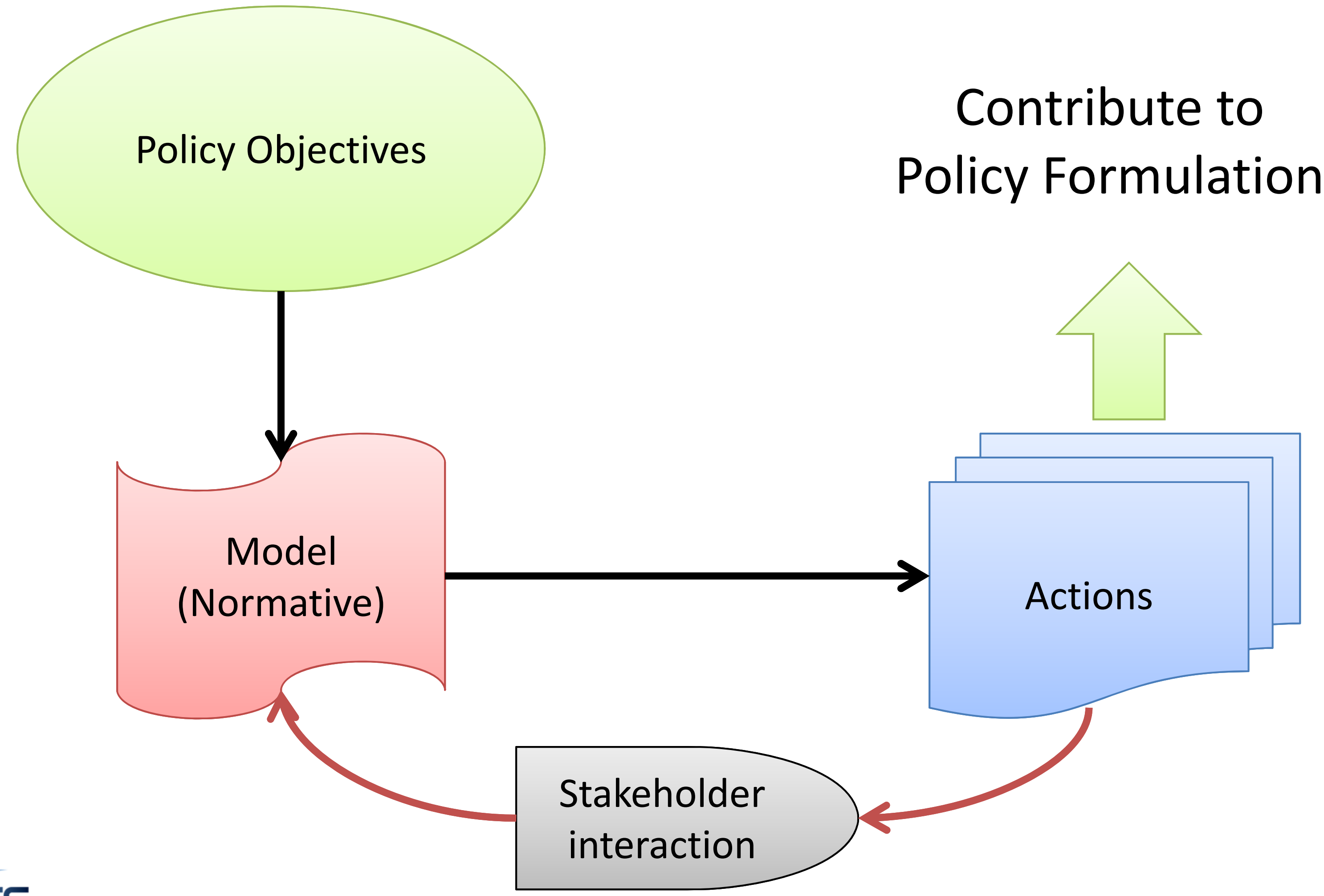
Important definitions

1. Policy objectives
   - The basic need for which intervention is considered necessary
2. Measures and targets
   - Influence the decision-making environment to meet objectives
3. Actions
   - New decisions that address #1
   - Some of these can be triggered by #2

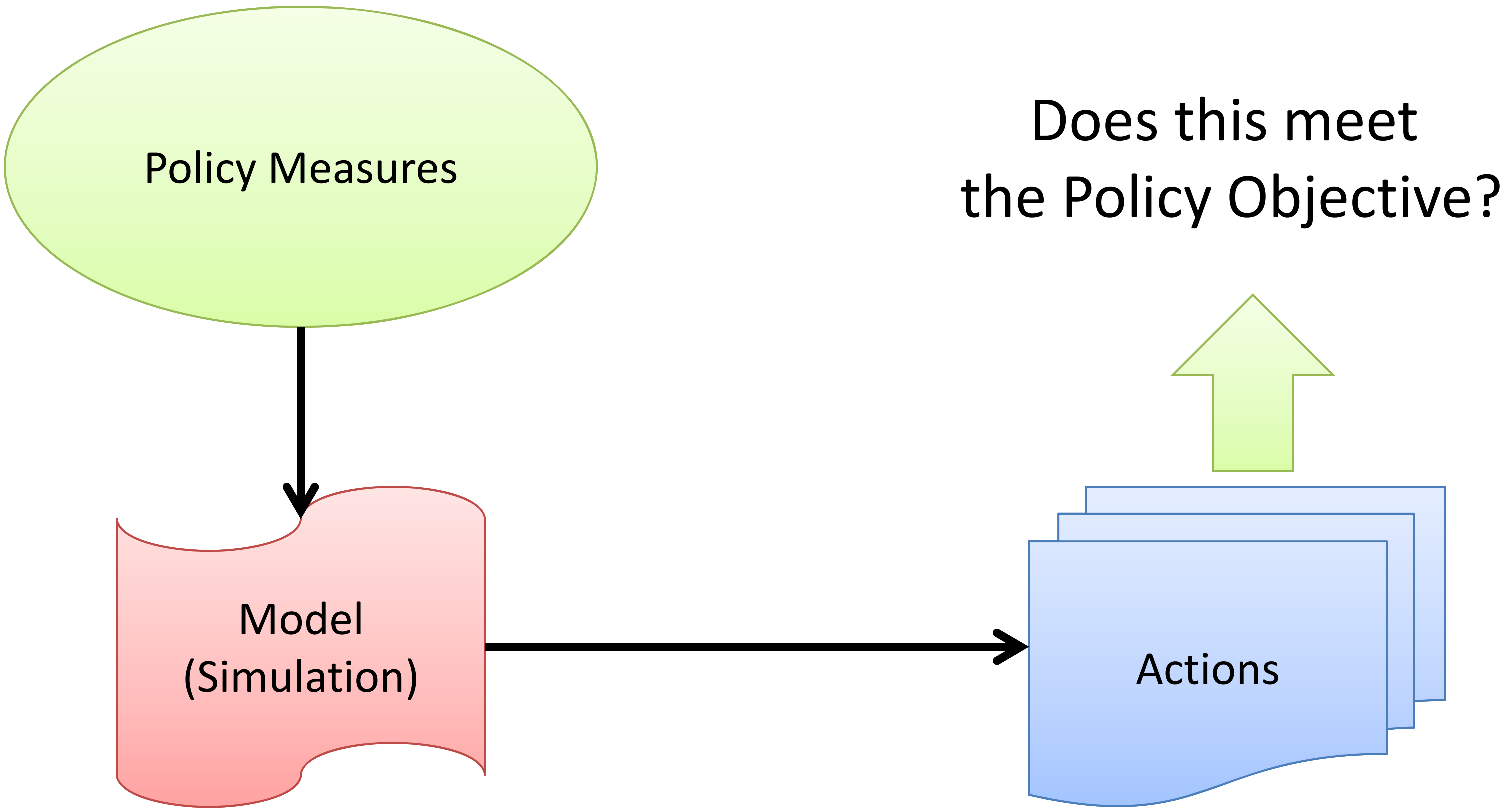
Examples of Objectives, Measures and Actions

1. Policy objectives
   - o Sustainability (reliable energy supply, clean air, climate)
   - o Security (Import dependence)
2. Measures and targets
   - o Taxes & subsidies
   - o Renewable portfolio/clean energy standards
   - o ETS cap & trade
3. Actions
   - o Deployment of solar/wind electricity
   - o Substitution of high carbon fuels with low/no carbon for space heating
   - o Installation of scrubbers in power plants
   - o Use of electric vehicles

Modeling for policy formulation

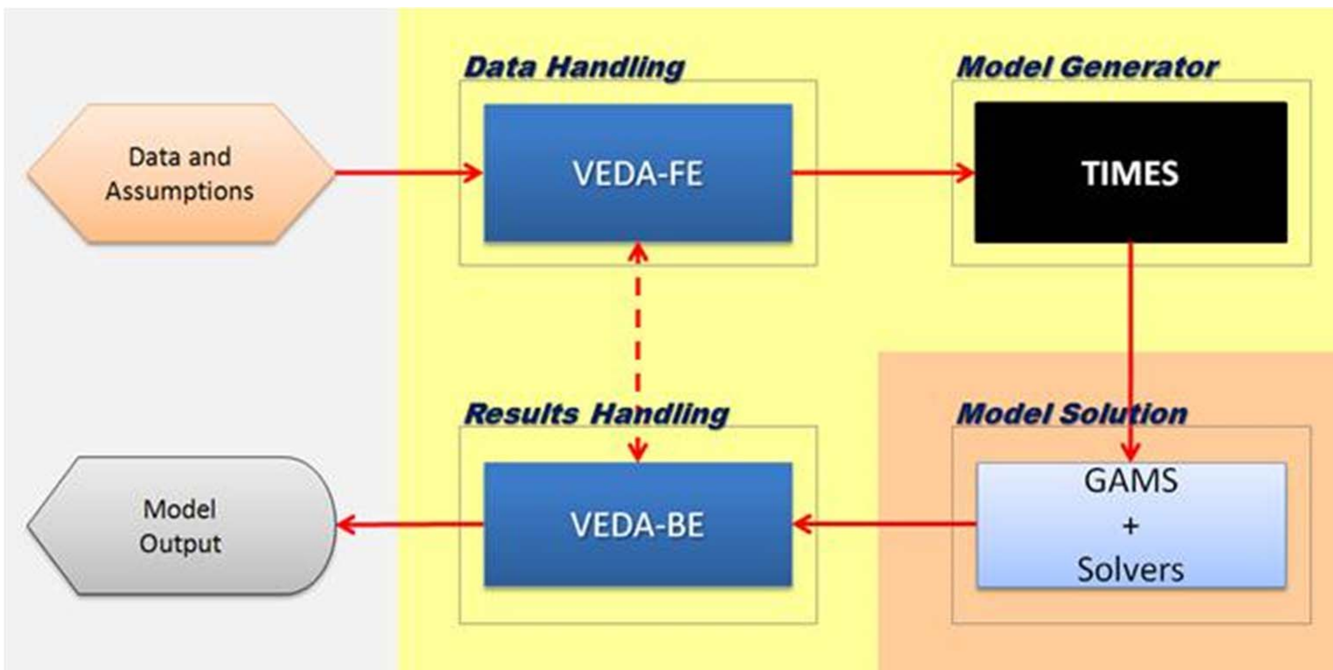


Modeling for policy evaluation



ETSAP methodology and tools

The Energy Technology Systems Analysis Program (ETSAP) is an Implementing Agreement of the International Energy Agency (IEA), first established in 1976. It functions as a consortium of member country teams and invited teams that actively cooperate to establish, maintain, and expand a consistent multi-country energy/economy/environment/engineering (4E) analytical capability.



http://www.iea-etsap.org

ETSAP contracting parties

- Beglium
- Canada
- Denmark
- EU
- Finland
- France
- Germany
- Greece
- Ireland
- Italy
- Japan
- S. Korea
- Netherlands
- Norway
- Sweden
- Switzerland
- United Kingdom
- United States
- Spain

Active users of ETSAP methodology/tools

University of Cape Town · iYunivesithi yaseKapa · Universiteit van Kaapstad

AUSTRIAN ENERGY AGENCY

EDF

ECN

IPP Max-Planck-Institut für Plasmaphysik

DTU

IAE The Institute of Applied Energy

RSE Ricerca sul Sistema Energetico

ENEA

CSTEP CENTER FOR STUDY OF SCIENCE, TECHNOLOGY & POLICY

ΚΑΠΕ CRES

ITRI Industrial Technology Research Institute

FUJITSU

VTT

Imperial College London

IER

United States Environmental Protection Agency

iet Institute for Energy and Transport

EDF ENVIRONMENTAL DEFENSE FUND® Finding the ways that work

UCL

ifp Energies nouvelles

ipts Institute for Prospective Technological Studies

USAID FROM THE AMERICAN PEOPLE

U.S. DEPARTMENT OF ENERGY

IFE Institute for Energy Technology

GERAD

GOBIERNO DE ESPAÑA MINISTERIO DE CIENCIA E INNOVACIÓN

Ciemat Centro de Investigaciones Energéticas, Medioambientales y Tecnológicas

FCT FACULDADE DE CIÊNCIAS E TECNOLOGIA UNIVERSIDADE NOVA DE LISBOA

NCCS NATIONAL CLIMATE CHANGE SECRETARIAT PRIME MINISTER'S OFFICE SINGAPORE

Politecnico di Torino 1859 1906

NAZARBAYEV UNIVERSITY

JRC EUROPEAN COMMISSION

TSINGHUA UNIVERSITY 1911

Energimyndigheten

PAUL SCHERRER INSTITUT PSI

KEMCO KOREA ENERGY MANAGE

teri

MINES ParisTech

Energy Technology Perspectives 2012 Pathways to a Clean Energy System

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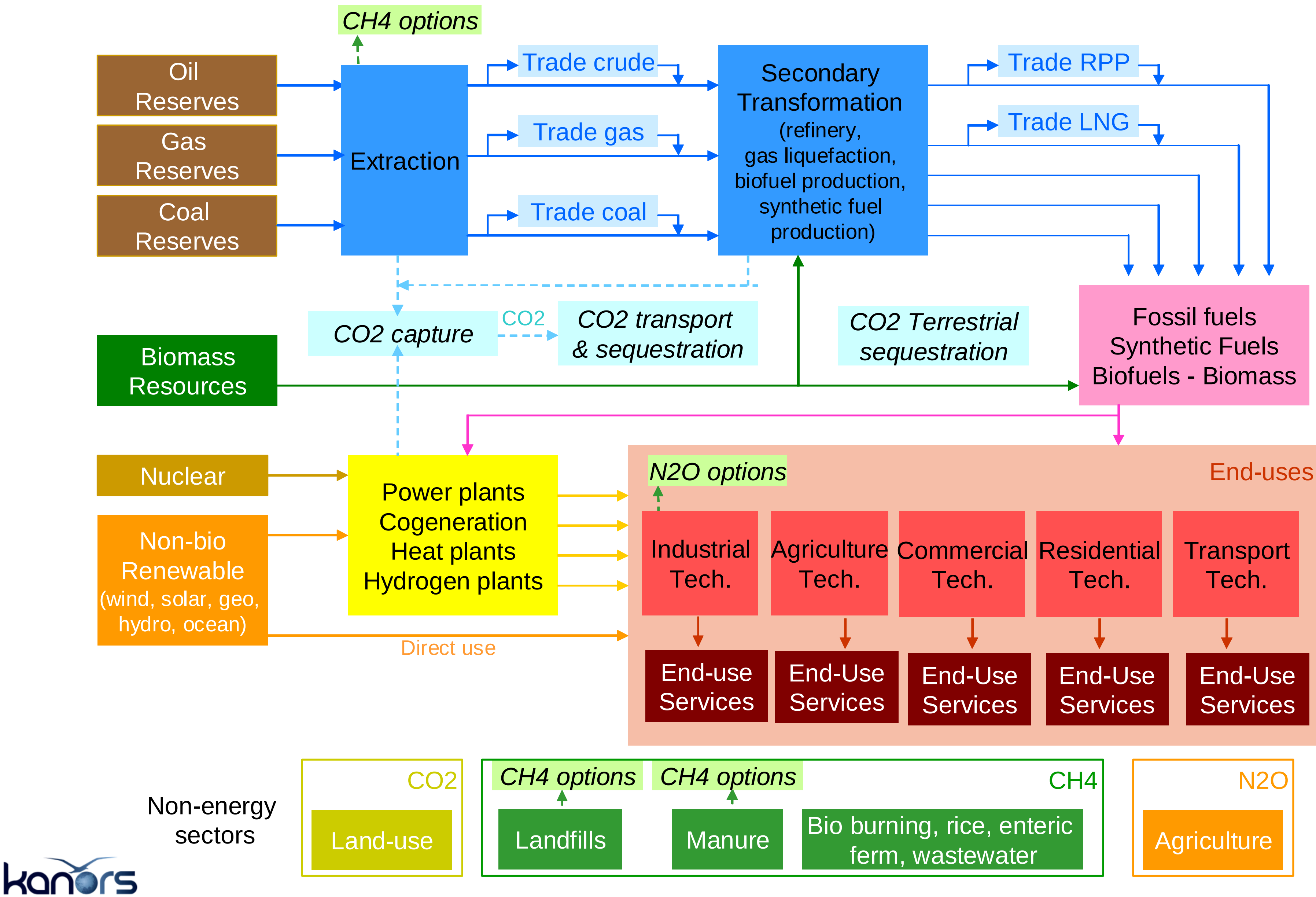
UCC University College Cork, Ireland Coláiste na hOllscoile Corcaigh

UCDAVIS UNIVERSITY OF CALIFORNIA

vito vision on technology

Typical TIMES model

TIAM – Reference Energy System



TIMES formulation

- Input
  - Energy service demands
  - Technologies
  - Resources
  - Various system constraints
  - Policy objectives/measures
- Output
  - investments/capacity/operation of all technologies
  - flows of energy, materials, and emissions
  - marginal values (shadow price) of energy, of CO_2
  - imports/exports, extraction
  - demand reductions
  - other mitigation options (CH_4, N_2O)

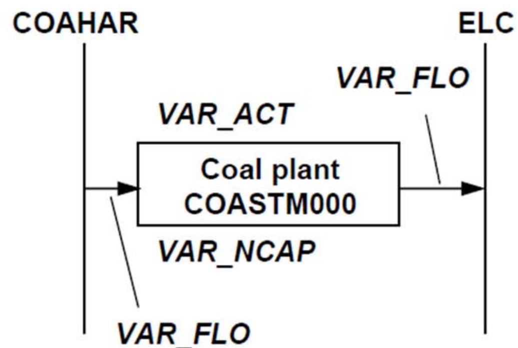
TIMES Variables

Variables

Associated bound parameters

- Process oriented: *region*, *vintage period*, *actual period*, *process*, *timeslice*

  i. VAR_ACT(r,v,t,p,s): activity of a process — ACT_BND(r,t,p,s,l) (*lo,up or fx*)



  ii. VAR_CAP(r,v,p): installed capacity = previous investments + new investments + past investments still existing — CAP_BND(r,v,p,l)

  iii. VAR_NCAP(r,v,p): new investment in period v — NCAP_BND(r,v,p,l)

- Flow oriented:

  i. VAR_FLO(r,v,t,p,c,s): flow level of commodity c linked to process p

  ii. VAR_IRE(all_reg,v,t,p,c,s,ie): inter-regional exchange variable (ie: *imp or exp*) — IRE_BND(r,t,c,s,all_reg,ie,l), IRE_XBND(all_reg,t,c,s,ie,l)

  iii. VAR_SIN / VAR_SOUT(r,v,t,p,c,s): flows entering/leaving a process p storing a commodity c — STG_IN/OUTBND(r,t,c,s,all_reg,ie,l)

TIMES Variables

Variables contd.

Associated bound parameters

- Commodity oriented (only created if bound provided):

  i. VAR_COMPRD(r,t,c,s): total production of a commodity — COM_BNDPRD(r,t,c,s,l)

  ii. VAR_COMCON(r,t,c,s): total consumption of a commodity — COM_BNDCON(r,t,c,s,l)

  iii. VAR_COMNET(r,t,c,s): net level of a commodity (production – consumption) — COM_BNDNET(r,t,c,s,l)

- Blending variables

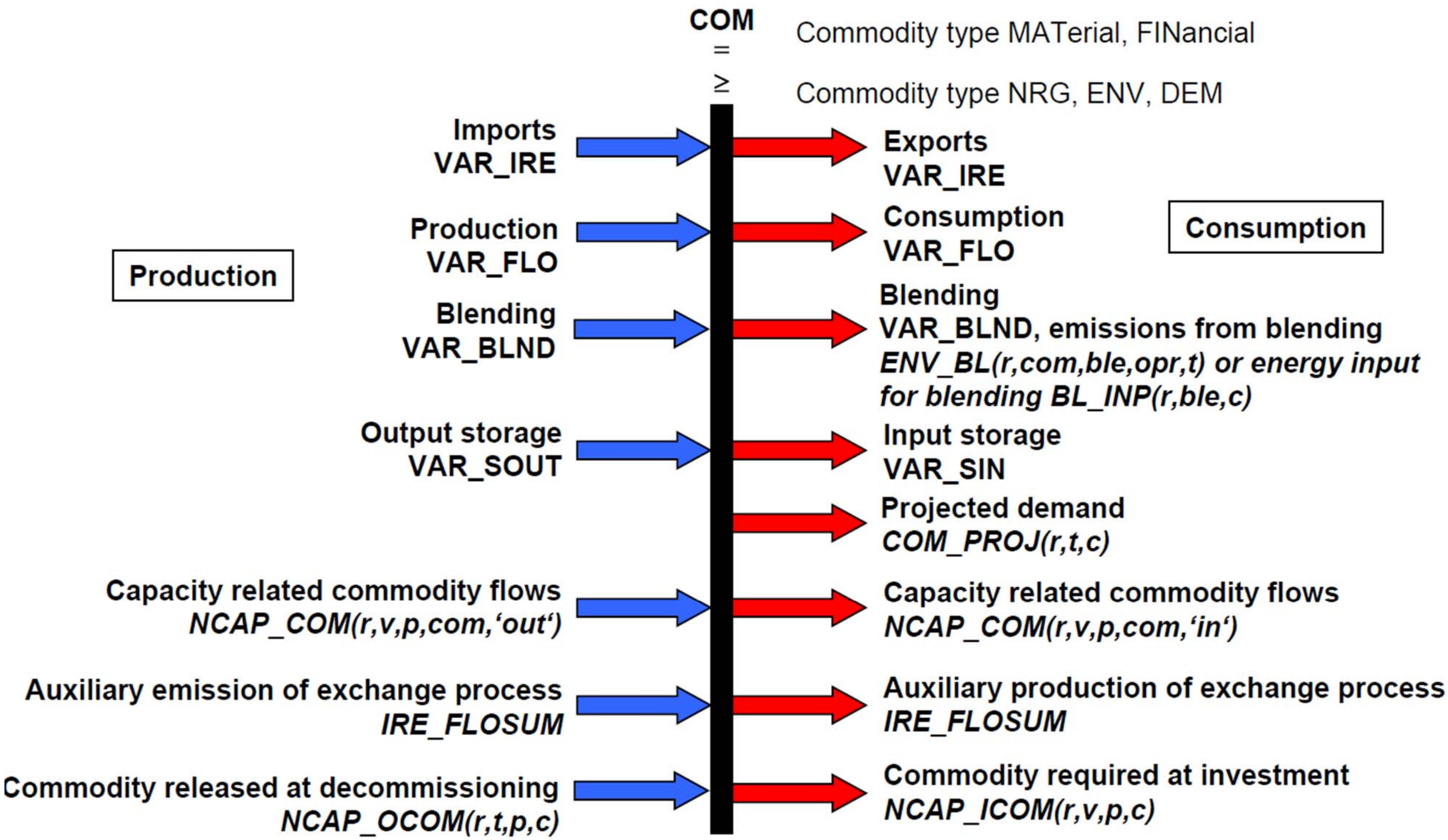
  i. VAR_BLND(r,t,ble,opr): amount of blending stock opr needed for the production of blending product ble

TIMES Equations

Basic equations

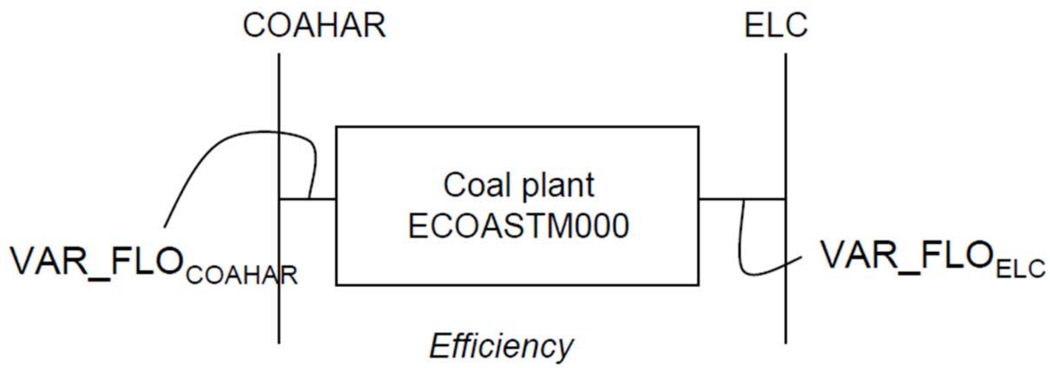
- *EQ(l)_COMBAL* $_{r,t,c,s}$ — Commodity balance
- *EQ_ACTFLO* $_{r,v,t,p,s}$ — Definition of activity variable
- *EQ_CAPACT* $_{r,v,t,p,s}$ — Utilization constraint
- *EQ_PTRANS* $_{r,v,t,p,cg1,cg2,s}$ — Transformation equation
- *EQ(l)_INSHR/OUTSHR* $_{r,t,p,c,cg,s}$ — Share constraints on in/output side of process
- *EQ_OBJ* — Objective function

Commodity Balance Equation



Process Transformation Equation

- Transformation equations establishes relationship between the flows of two commodity groups.
- Example 1: Efficiency of coal plant ECOASTM000



$$FLO\_FUNC_{r,t,ECOASTM000,COAHAR,ELC,s} = 0.33$$

Transformation equation

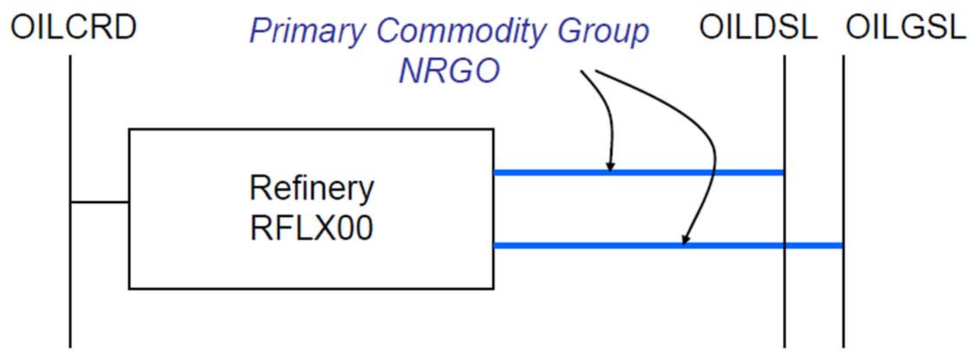
$$EQ\_PTRANS_{r,v,t,ECOASTM000,COAHAR,ELC,s}$$

$$FLO\_FUNC_{r,t,ECOASTM000,COAHAR,ELC,s} \times VAR\_FLO_{r,v,t,ECOASTM000,COAHAR,s} = VAR\_FLO_{r,v,t,ECOASTM000,ELC,s}$$

Process — *1st commodity group* — *2nd commodity group*

Definition of the Activity Variable

- Activity of a process equals the sum of the flows specified in the Primary Commodity Group (PRC_ACTUNT).
- Activity variable is created on the timeslice level specified by PRC_TSL.



$$EQ\_ACTFLO_{r,v,t,RFLX00,s}$$

$$=$$

$$VAR\_ACT_{r,v,t,RFLX00,s} = VAR\_FLO_{r,v,t,RFLX00,OILDSL,s} + VAR\_FLO_{r,v,t,RFLX00,OILGSL,s}$$

Capacity Utilization Equation

EQ(l)_CAPACT $_{r,v,t,p,s}$

VAR_ACT(r,v,t,p,s) ≤ = Available capacity of process p in period t and timeslice s

timeslice s member of PRC_TSL

Capacity:

- Past investments before model horizon: NCAP_PASTI
- New investments from previous periods
- New investments in actual period t

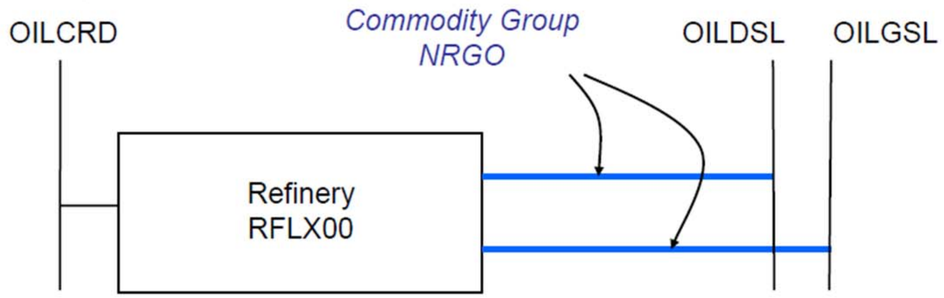
Three availabilities:

- NCAP_AFA(r,v,p,l) : Annual availability
- NCAP_AFS(r,v,p,s,l) : Seasonal availability
- NCAP_AF(r,v,p,s,l) : Availability in timeslices

which can be combined.

Flow Share Equations

- Possibility to limit the share of a commodity flow within a commodity group on the input or output side of a process.
- Example



$$FLO\_SHAR_{r,t,FRLX00,NRGO,OILDSL,s,UP} = 0.3$$

Process — Commodity group defining the total flow — Commodity

- Fixed, upper or lower bounds may be specified.
- Commodity group must not necessarily compromise all output/input flows, one can identify a subgroup as commodity group.

EQ(l)_IN/OUTSHR

$$\frac{\sum_{v} VAR\_FLO_{r,v,t,RFLX00,OILDSL,s}}{\sum_{v}\left(VAR\_FLO_{r,v,t,RFLX00,OILDSL,s} + VAR\_FLO_{r,v,t,RFLX00,OILGSL,s}\right)} \leq FLO\_SHAR_{r,t,RFLX00,NRGO,OILDSL,s,UP}$$

Objective Function

- Discounted sum of the annual costs minus revenues:

  \+ Investment costs

  \+ Costs for sunk material during construction time

  \+ Variable costs

  \+ Fix operating and maintenance costs

  \+ Surveillance costs

  \+ Decommissioning costs

  \+ Taxes

  \- Subsidies

  \- Recuperation of sunk material

  \- Salvage value

- Cost documentation of investments made before the first model year
- Technical and economic lifetime
- Investment and decommissioning lead-times
- General and technology specific discount rate

Basic variables and parameters

Reserve Margin

Firm Capacity

Load Curves

Demand

Peak Availability

Generation

Existing Capacity

Load hours
Ramp rate

Tech Life

New Capacity

Total Capacity

Emissions

Efficiency

Emission Factors

Inv Cost
Lead Time
Build Rates

FOM cost

Fuel Input

Res Supp Curves

Other features

- Grid balancing
  - DC load flow equations
- Residual load approach
  - using deterministic variation parameters that are statistically calibrated outside the model
  - Minimum limits on thermal generation
- Foresight and uncertainty
  - Easy to control the span of optimization window
  - Multi-stage stochastic

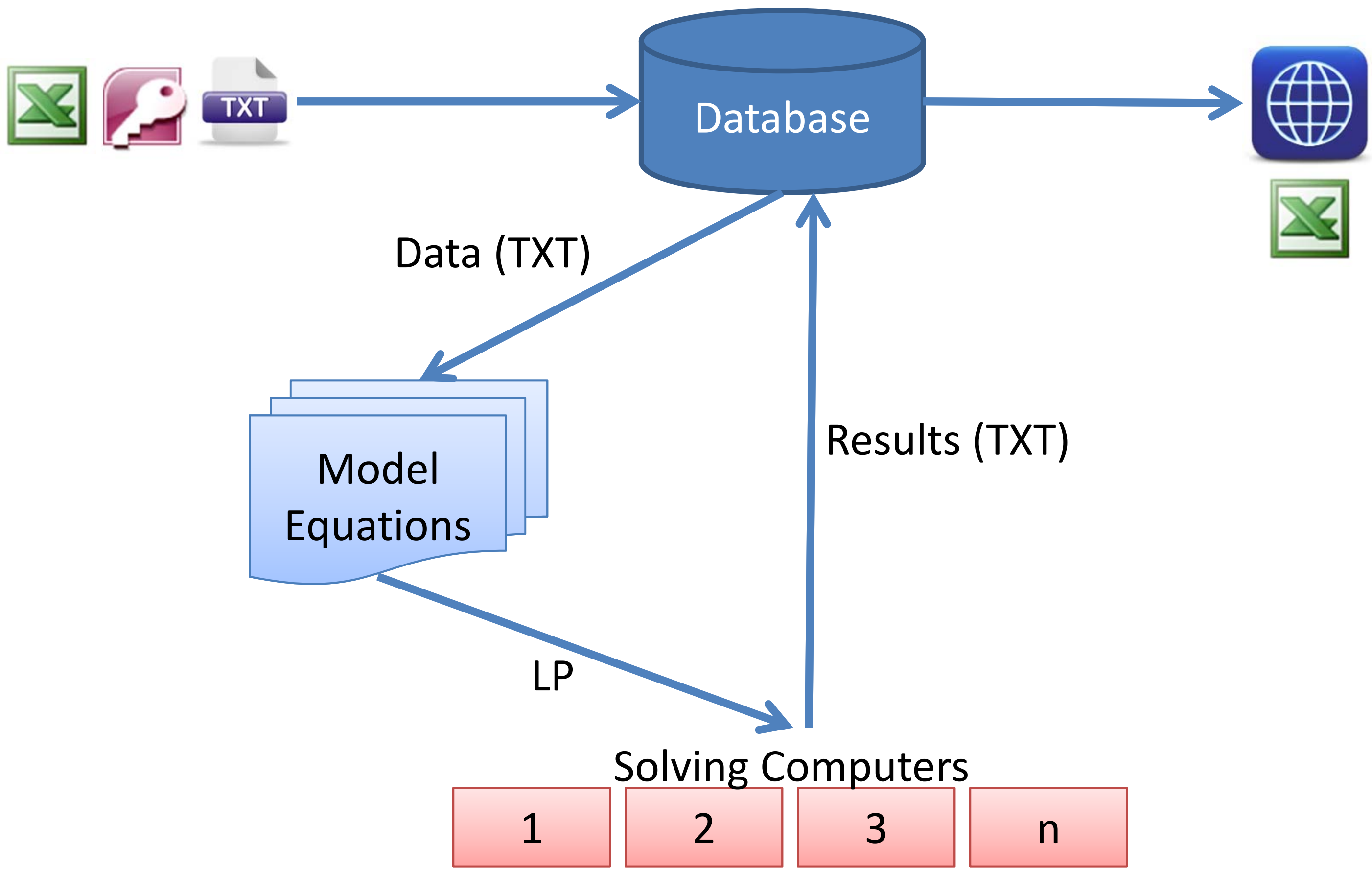
Key factors that improve insights

- Sufficient well-grounded detail to realistically represent availability of and access to resource and technology options
  - Geographical sensitivity
  - Installation level representation converts a famous liability of LP into an asset
- Ability to make a large number of runs
- Detailed model + many runs => need for sophisticated results analysis tools

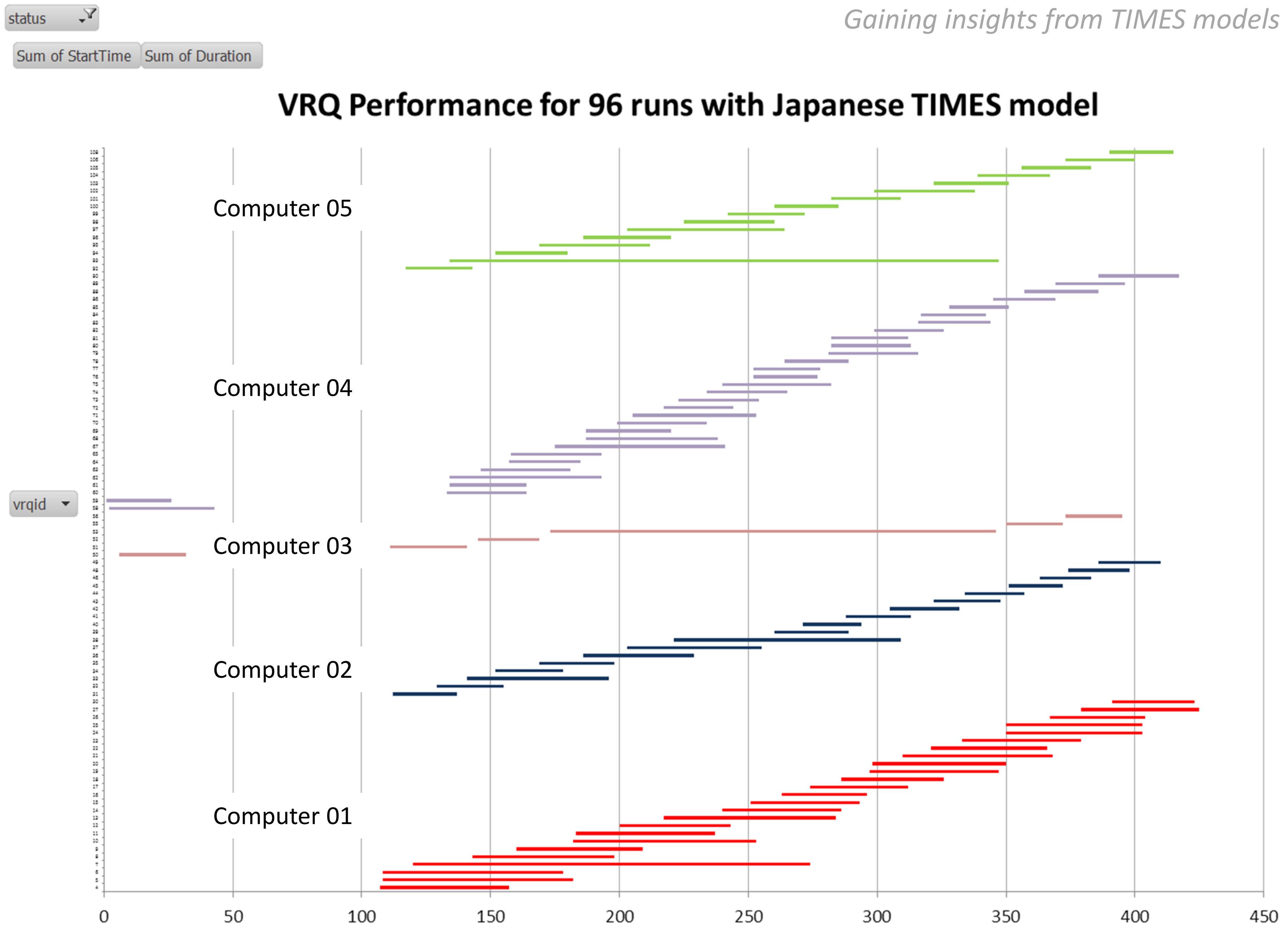
Key factors addressed

- VEDA allows rule-based specs for rapid building of large models
- Special features to create large number of scenario specs based on a mix of dimensions
- Runs management system (VRQ) that allows multiple computers to perform multiple runs (simultaneously), as per their own resource availability
- VEDAViz and VEDA BE used for results analysis

Large VEDA-TIMES Models

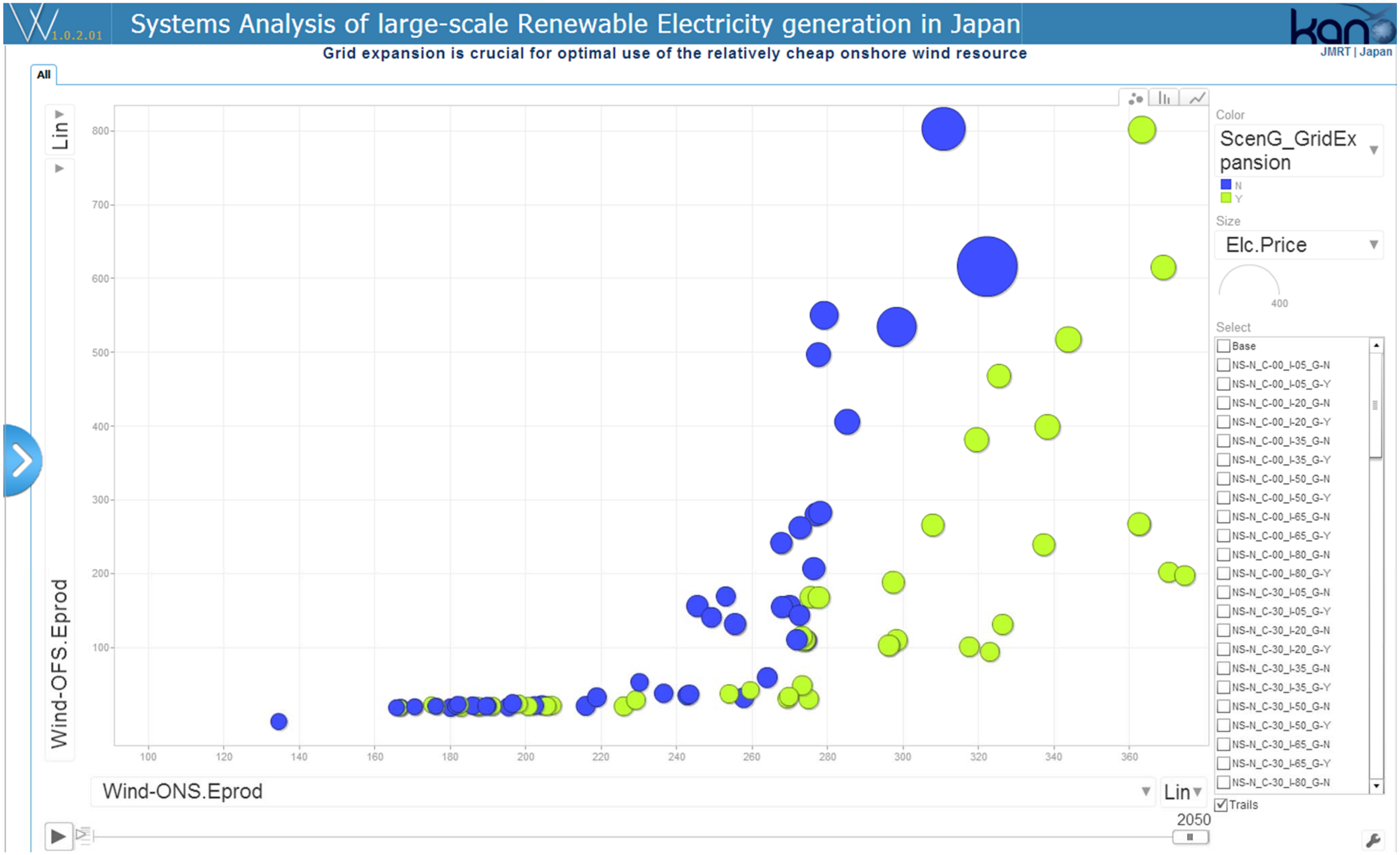


VRQ Performance for 96 runs with Japanese TIMES model



Japan example: Policy formulation

Relationships rather than Numbers



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http://vedaviz.com/Index.aspx?vid=162237

Portals can be used to widen engagement

Energy Security and Clean Air scenarios for Indian Power Sector:
http://vedaviz.com/Portal/Playground.aspx?p=IMRT23Dec14&g=a24c44

Global electricity scenarios from TIAM-World(EMF27):
http://vedaviz.com/Portal/Playground.aspx?p=FEMF27Sep27&g=ec12b8

Self-sufficiency/Climate/Costs tradeoffs for Japan:
http://vedaviz.com/Portal/Playground.aspx?p=JMRT-PO01Oct13&g=77f822

IEM based on Country-level data

- Existing, under construction and planned (firm) units (Platts)
  - Easy to maintain
- Efficiency by vintage
  - Age-dependent costs and efficiency with endogenous retirement
- Fuel consumption for electricity generation
  - Determine utilization for base-year calibration
- Electricity demand
  - GDP elasticity for future projection
- Load curves
- Solar/wind/biomass resource
- Fossil supply
  - Trade links (regional)
- International electricity trade links

Data-model independence

- Technology granularity
  - Unit-level Vs model plants (by vintage-fuel)
- Regional representation
  - Country level Vs aggregated regions
  - Regional runs
- Model horizon
  - Full flexibility in number and lengths of periods
- Break into pieces and run in parallel

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Possible uses

- National policies
  - Detailed characterization will help accuracy
- Resource potential and demand/load curve detail will help realism
- Model policy objectives for clean air, energy security and carbon abatement