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1st Educational Workshop of Simulation Lab, ETH, 1st Oct 2015

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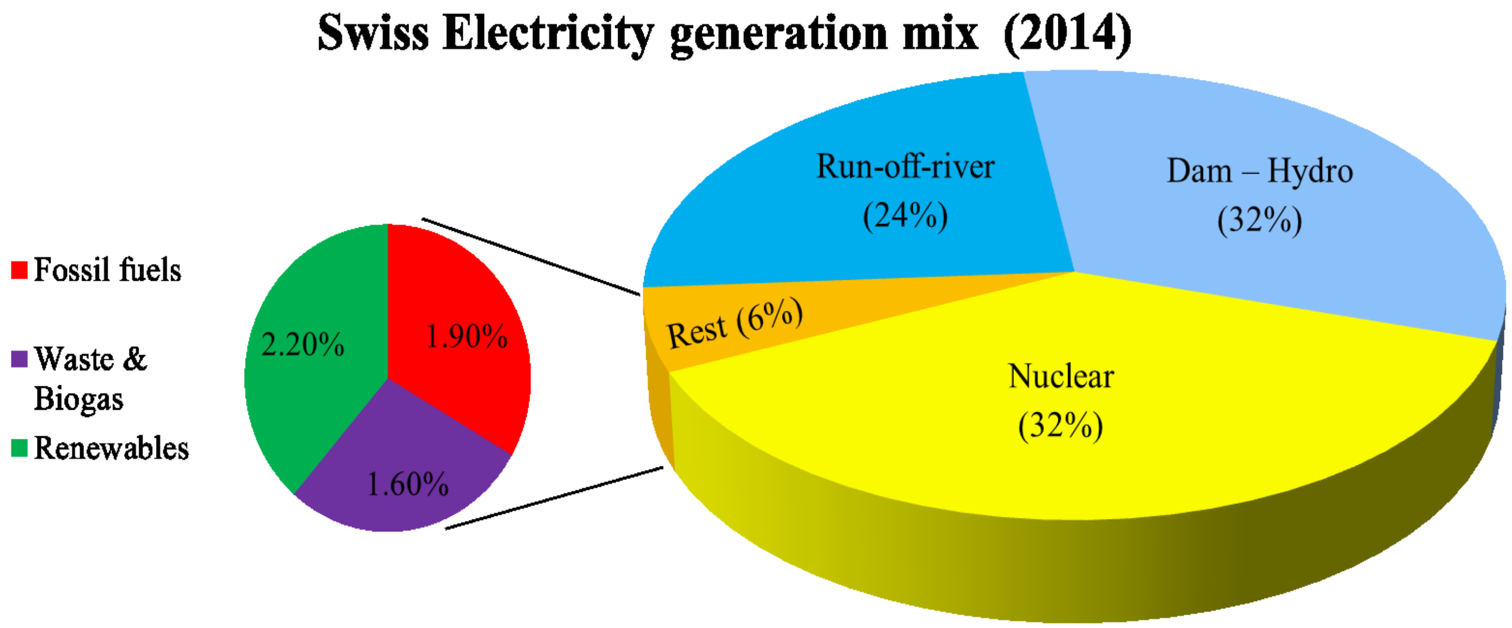
Long-term evolution of the Swiss electricity system under a European electricity market: Development and application of a cluster of TIMES electricity models

Outline

- Introduction – Background and Motivation
- CROSSTEM model
- TIMES modelling framework
- Scenarios & Key Assumptions
- Results
- Model limitations, issues and challenges
- Conclusions

Introduction

- Electricity accounts for one quarter of Swiss energy demand
- Large differences in seasonal output, seasonal demand.
- Creates seasonal dependence on electricity import.



Source: "Schweizerische Elektrizitätsstatistik 2013", BFE Bern

Future of Electricity system

Objectives

- ***Nuclear phase out*** – No replacement of existing Nuclear power plants at the end of their 50 year lifetime. Last power plant off grid by 2034.
- **Ambitious carbon reduction targets**

Difficult to predict the future

- Uncertainty regarding future electricity demand
- Uncertainty regarding future supply options
- Too long a timescale to make accurate predictions

Solution

- Energy System models

Future demand pathways

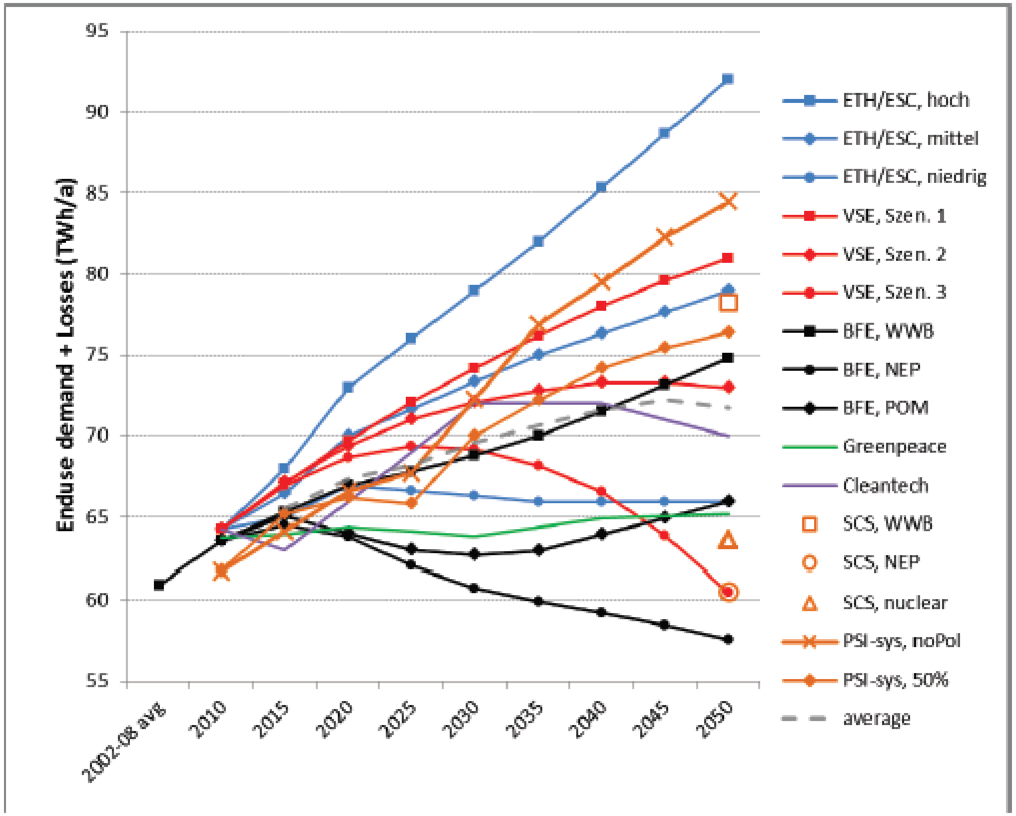


Figure 2: Electricity demand of the scenarios. Demand is after hydro-pumps, after import/export, and before losses. The demands of the SCS scenarios should be those of the BFE scenarios with same name, but seem to be different. The PSI-elc study (not shown) uses the demands of the BFE scenarios. Greenpeace: without electricity used for H_2-production

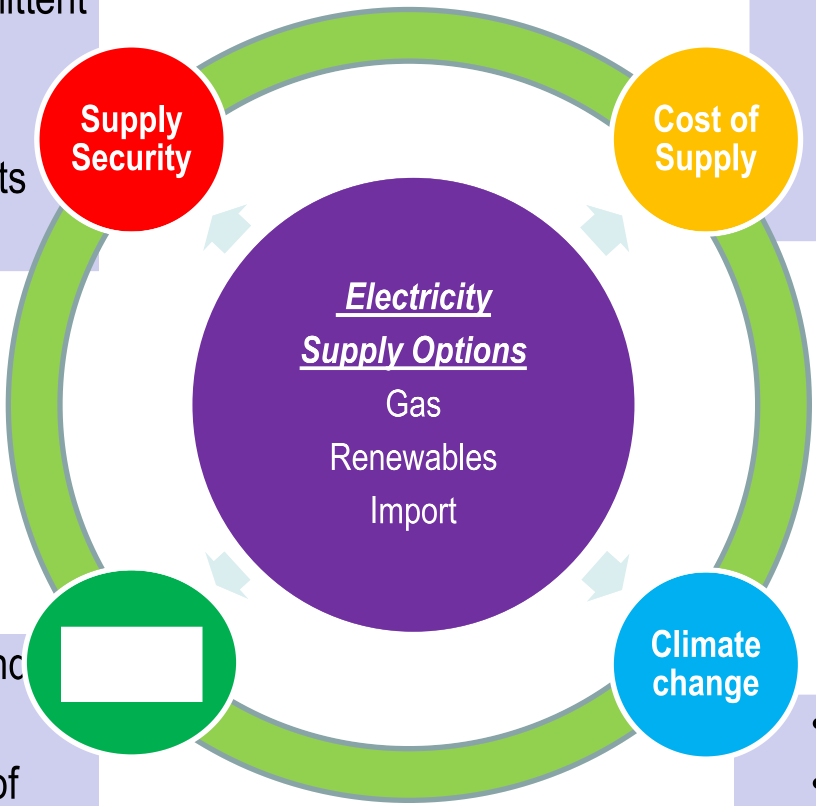
Source: M. Densing, "Review of Swiss Electricity Scenarios 2050", PSI (2014)

Forecasting future electricity system – Supply options

Developments in Europe

- Integration of intermittent Renewables
- Nuclear phase-out?
- CO_2 emission targets
- Gas imports

- Cost implications of renewable / low carbon policy
- Revenue from trade
- Evolution of fuel prices



- Balancing supply and demand
- Intermittent nature of renewables
- Electricity imports

- CO2 emission targets
- Expansion of Gas plants

Electricity supply mix – Switzerland (2050)

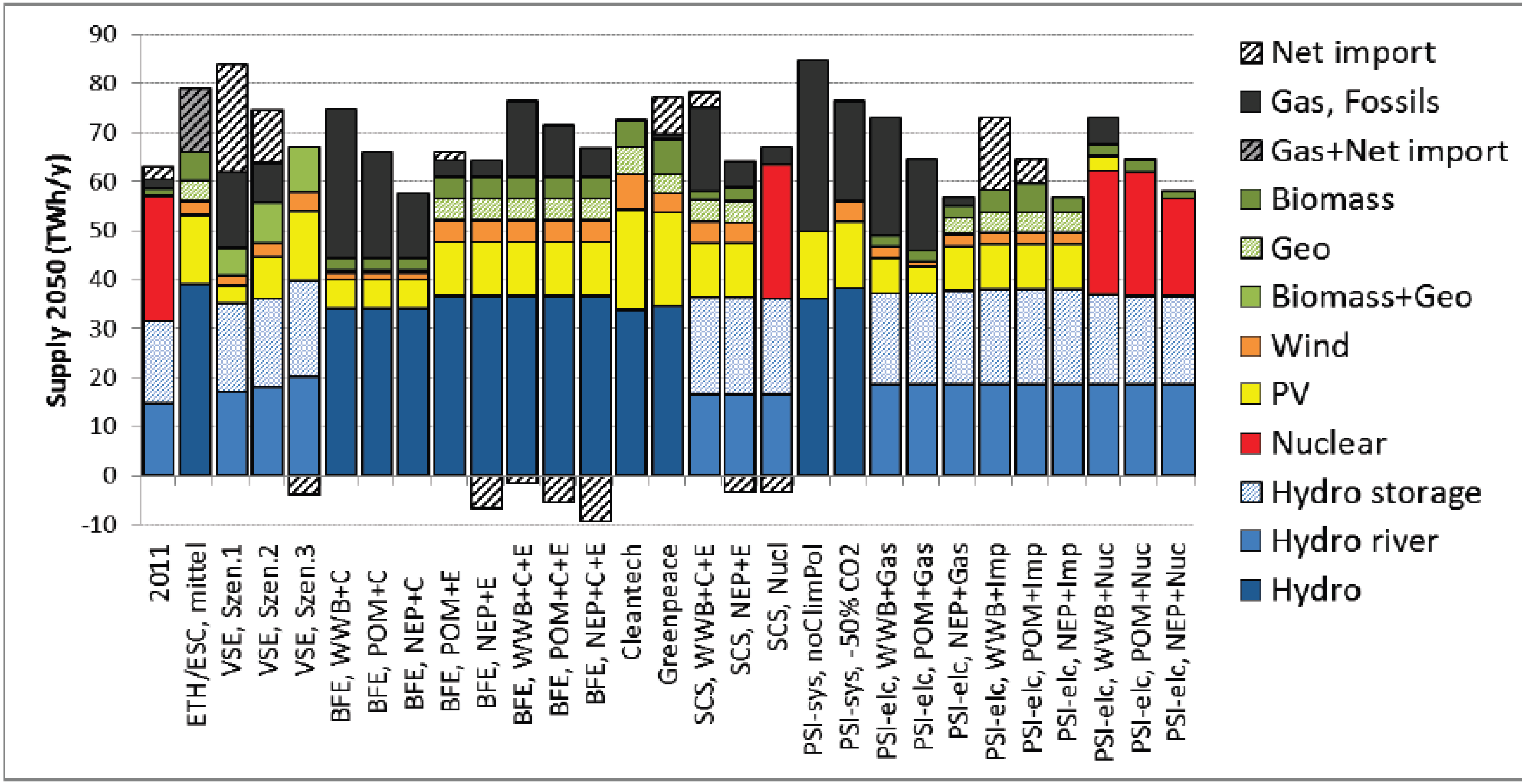


Figure 9: Yearly production mix in 2050.

Source: M. Densing, "Review of Swiss Electricity Scenarios 2050", PSI (2014)

Model Features

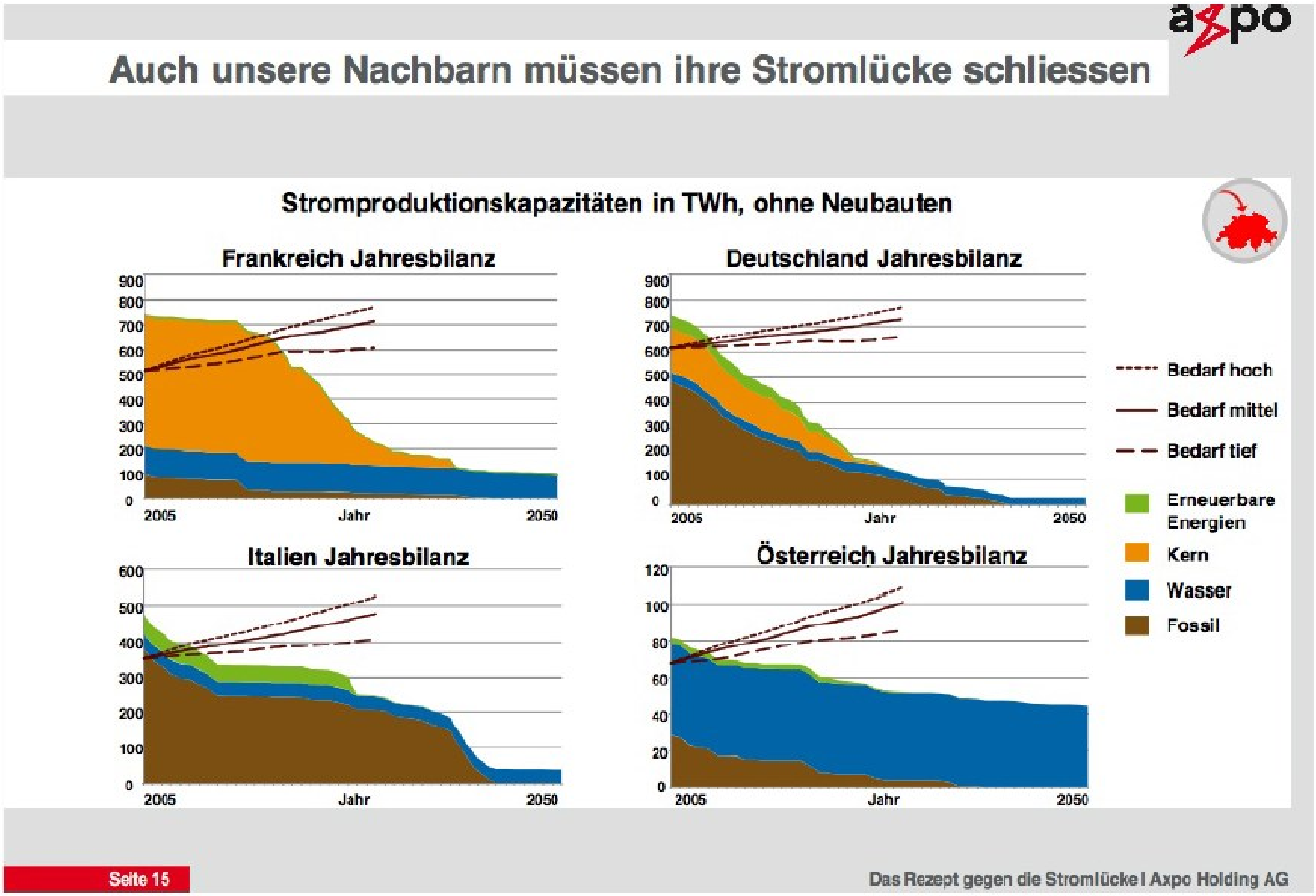
- Single region model
- Time horizon: 2000 – 2100
- An hourly timeslice
- Characterization of about 140 technologies and over 40 energy and emission commodities

Key Parameters

- Exogenous electricity demand for the future
- Range of primary energy resources
- **Exogenous** electricity import and export from four countries

R Kannan & H. Turton (2011) - ***Documentation on the development of the Swiss TIMES electricity model***
Available at *http://energyeconomics.web.psi.ch/Publications/Other_Reports/PSI-Bericht%2011-03.pdf*

Situation in neighbouring countries



Source: N. Zepf, "Das Rezept gegen die Stromlücke", AXPO (2003)

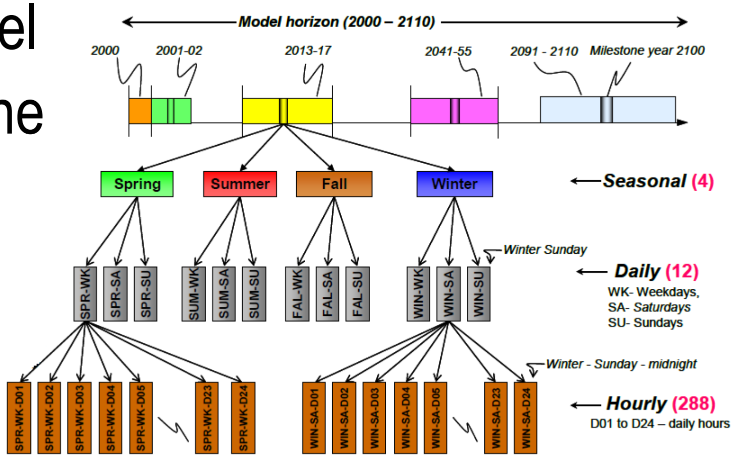
Why the need for a new model ?

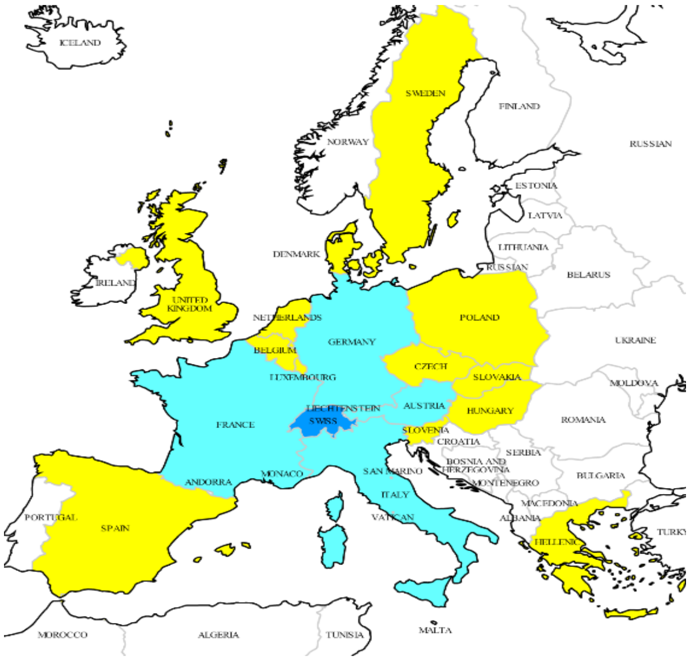
Objectives:

- Understand the developments in the neighbouring countries – Germany (DE), Austria (AT), France (FR) and Italy (IT).
- Quantify the extent to which these developments affect the Swiss electricity sector.

CROSSTEM Model

- **CROS**s border **S**wiss **T**IMES **E**lectricity **M**odel
- Extension of the STEM-E model to include the four neighbouring countries
- Time horizon: 2000 – 2050 in
- An hourly timeslice (288 timeslices)
- Detailed reference electricity system with resource supply, renewable potentials and demands for 5 countries
- Calibrated for electricity demand and supply data between 2000-2010
- **Endogenous** electricity import / export based on costs and technical characteristics





TIMES modelling framework

TIMES – **T**he **I**ntegrated **M**ARKAL / **E**FOM **S**ystem

- Technology rich, Perfect foresight, cost optimization framework
- Used to explore a range of parametric sensitivities under a “what-if” framework via exploratory scenario analysis.
- Integrated modelling of the entire energy system
- Prospective analysis on a long term horizon (20-50-100 yrs)
- Allows for representation of high level of temporal detail – load curves
- Enhanced Storage algorithm – modelling of pumped storage systems
- Optimal technology choice – based on costs, environmental criteria and other constraints.

MARKAL – **MARK**et **AL**location

EFOM – **E**nergy **F**low **O**ptimization **M**odel

The TIMES Objective Function – is the discounted sum of the annual costs minus revenues

$$NPV = \sum_{r=1}^{R} \sum_{y \in YEARS} (1 + d_{r,y})^{REFYR - y} \bullet ANNCOST(r,y)$$

where:

NPV	is the net present value of the total cost for all regions (the OBJ);
ANNCOST(r,y)	is the total annual cost in region r and year y;
$d_{r,y}$	is the general discount rate;
REFYR	is the reference year for discounting;
YEARS	is the set of years for which there are costs (in the horizon, plus past and before years EOH;
R	is the set of regions in the area of study

TIMES modelling framework

Demands and Parameters

- End-use demands
- Demand elasticity
- Energy (materials) prices
- Reserve supply curves
- Other parameters
  - Discount rate
  - Time period
  - Time slices

Technology database

- Techno-economic attributes

Environmental

- Emission coefficients
- Targets
- Taxes, subsidies
- Sectors' measures

TIMES

Output

- Technology Investments and annual activities
- Emission trajectories
- Adjusted demands for energy services
- Marginal prices of energy commodities
- Imports / Exports of energy and emission permits
- Total discounted system cost
- The least cost solution to satisfy energy service demands and constraints

ETSAP Training Course, IEA Paris, 12-14 June 2013

Alternative low carbon electricity pathways in Europe and knock-on effects on the Swiss electricity system

Scenario Overview

	CROSSTEM Scenarios
Least Cost	Baseline scenario No particular constraints in technology investment* EU-20-20-20 targets applied for emissions and renewable based generation
No Nuclear (noNUC)	Nuclear Phase-out scenario Nuclear phase-out in Switzerland by 2034 (50 year lifetime), in Germany by 2023, France to reduce nuclear share to 50% of total elc generation by 2025 and beyond All other conditions same as LC
Climate Target (CO2)	De-carbonization of power sector (95% CO_2 reduction by 2050 from 1990 levels) for all five countries together All other conditions same as noNUC.

* except where already part of policy: No nuclear investment in Italy (IT) and Austria (AT). No Coal investment in Switzerland (CH). Nuclear fleet can be replaced up to todays level.

Key assumptions

Input Assumptions

- **Electricity Demand** – EU Trends to 2050 (Reference scenario), BAU demands for CH (SES 2050)
- **Trade with “fringe regions”** – Historical limits applied
- **CO2 price** – European ETS prices implemented (SES 2050, Bfe)
- **Fuel Prices** – International fuel prices from WEO 2010.

Methodological Assumptions

- **Copper Plate regions** – No transmission and distribution infrastructure within each country. Interconnectors between regions.

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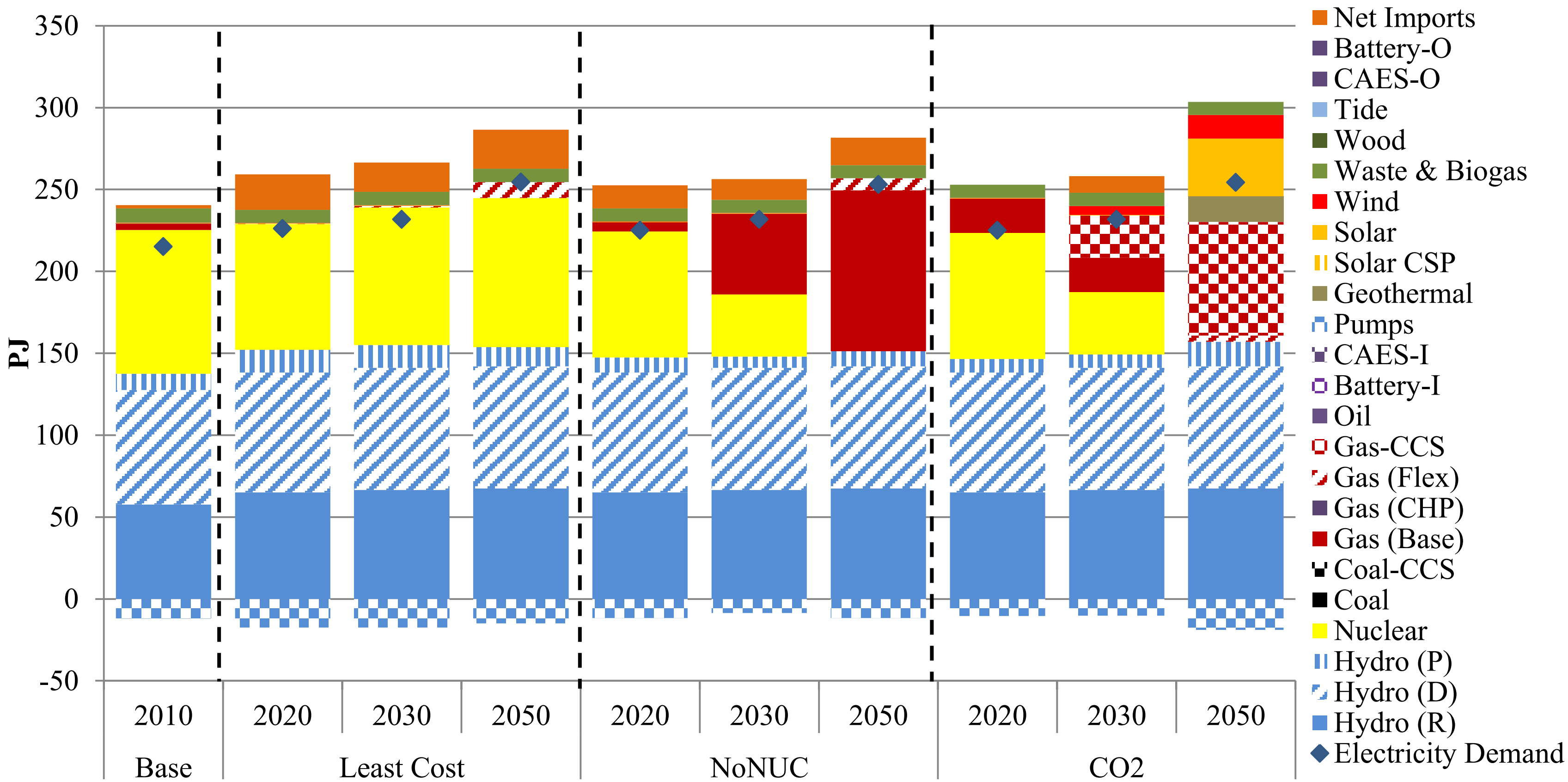
Results – Electricity generation mix

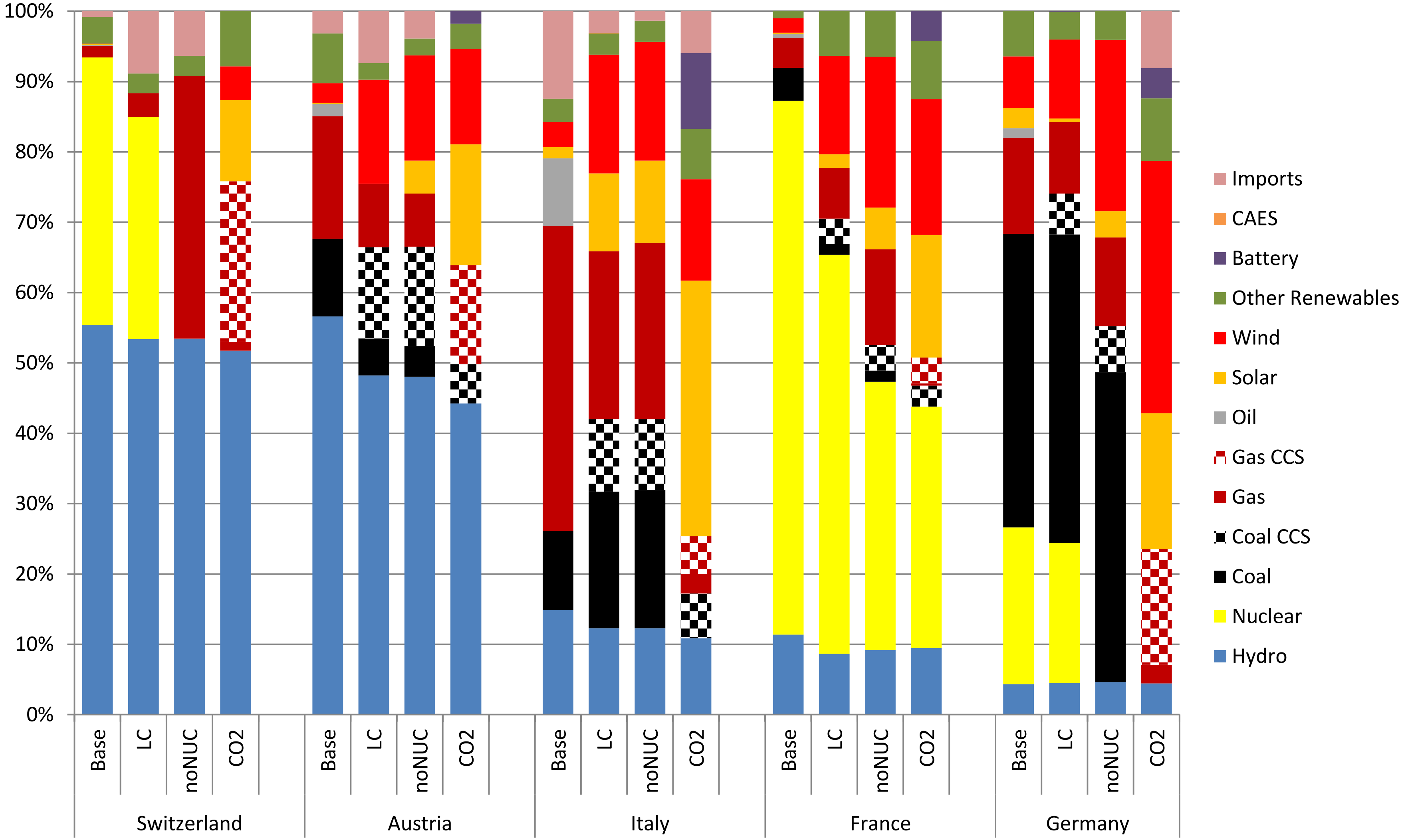
Switzerland – All CROSSTEM scenarios



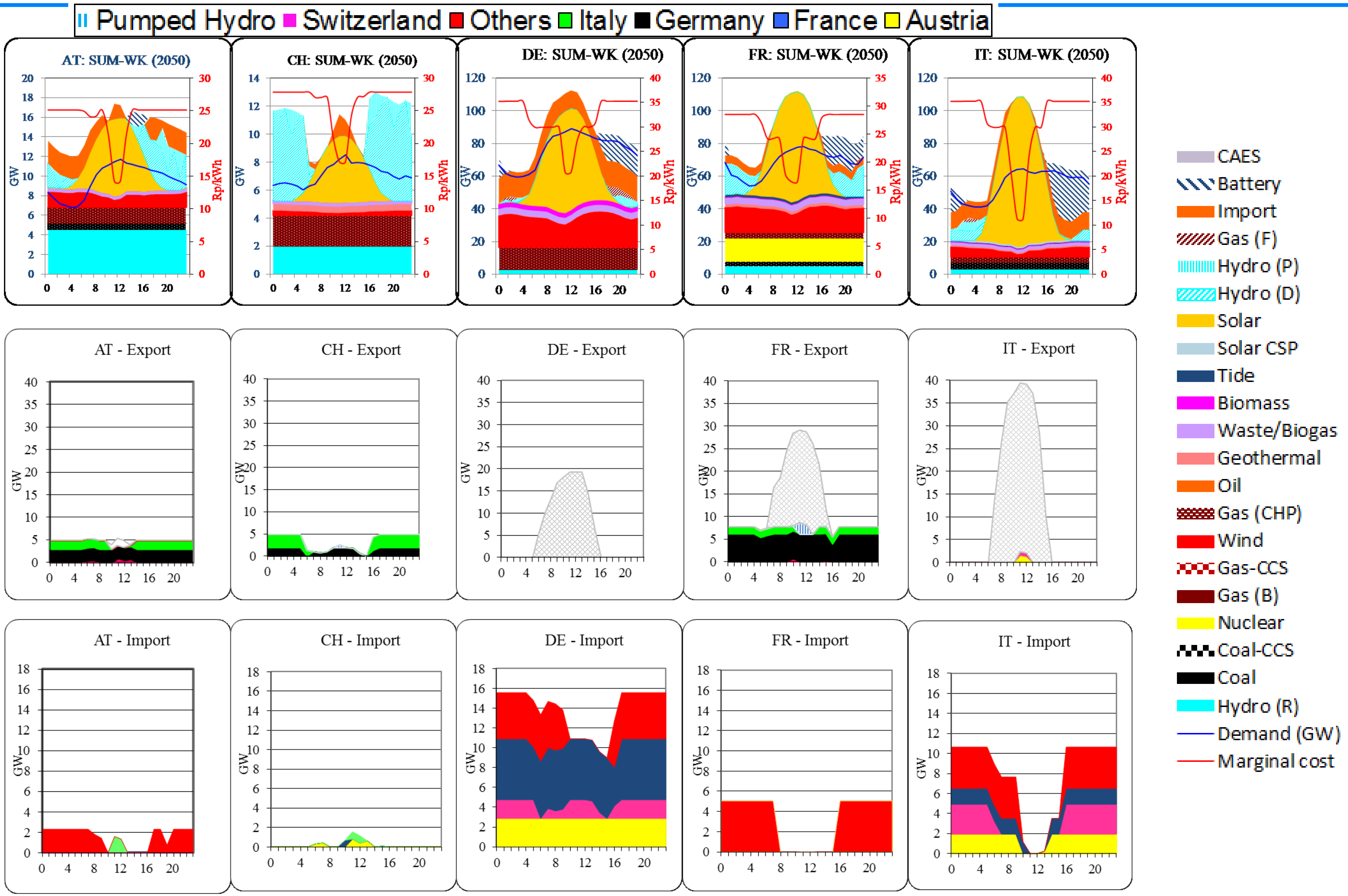
- noNUC – Nuclear power replaced by gas power; reduced imports as it is more expensive
- CO2 – Gas CCS + Geothermal for baseload; Net exporter by 2050 – Due to the availability of CCS storage

Results – Electricity generation mix

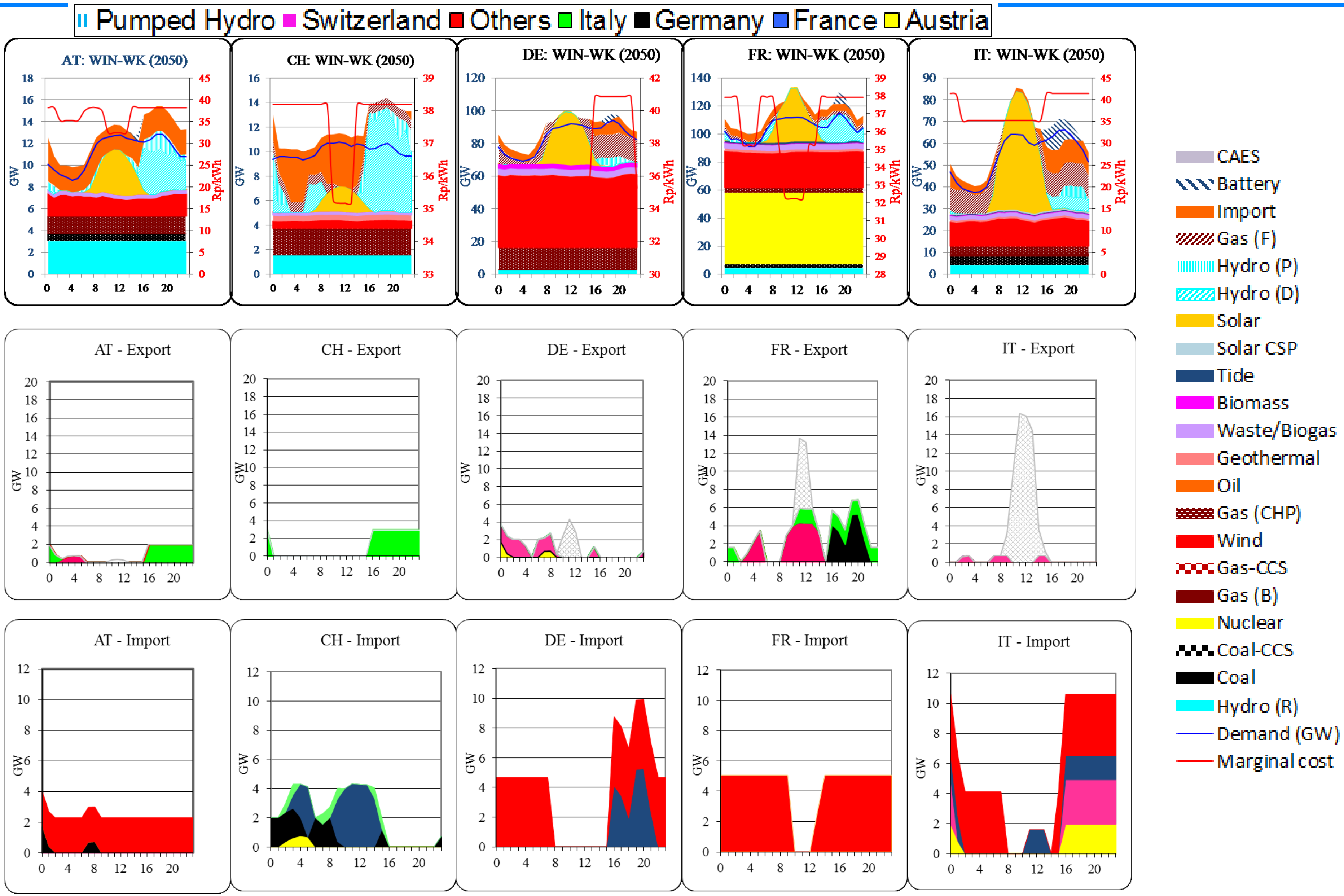
Electricity generation mix 2050



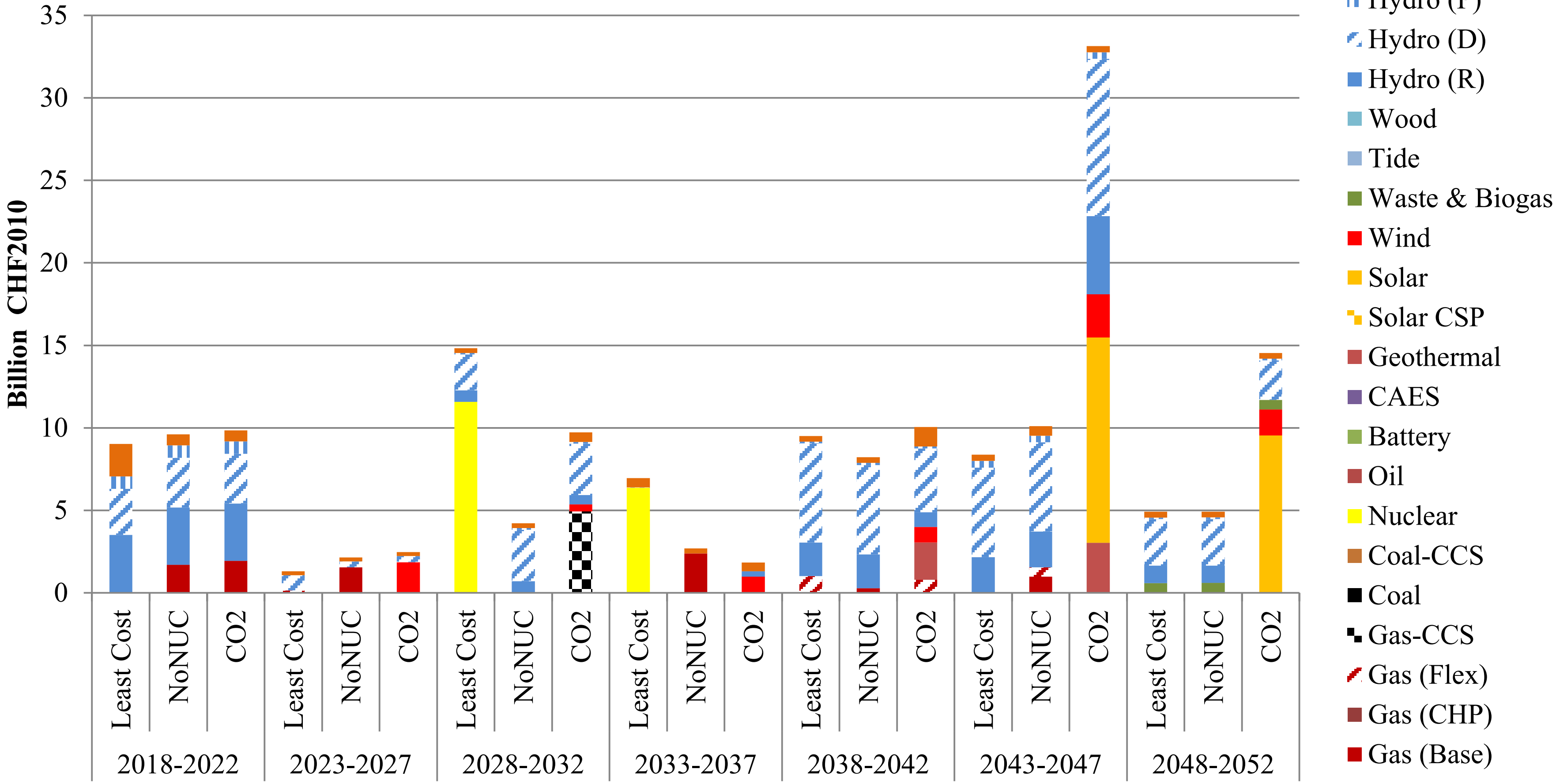
Load Curve – Summer Weekday 2050 (CO2)



Load Curve – Winter Weekday 2050 (CO2)

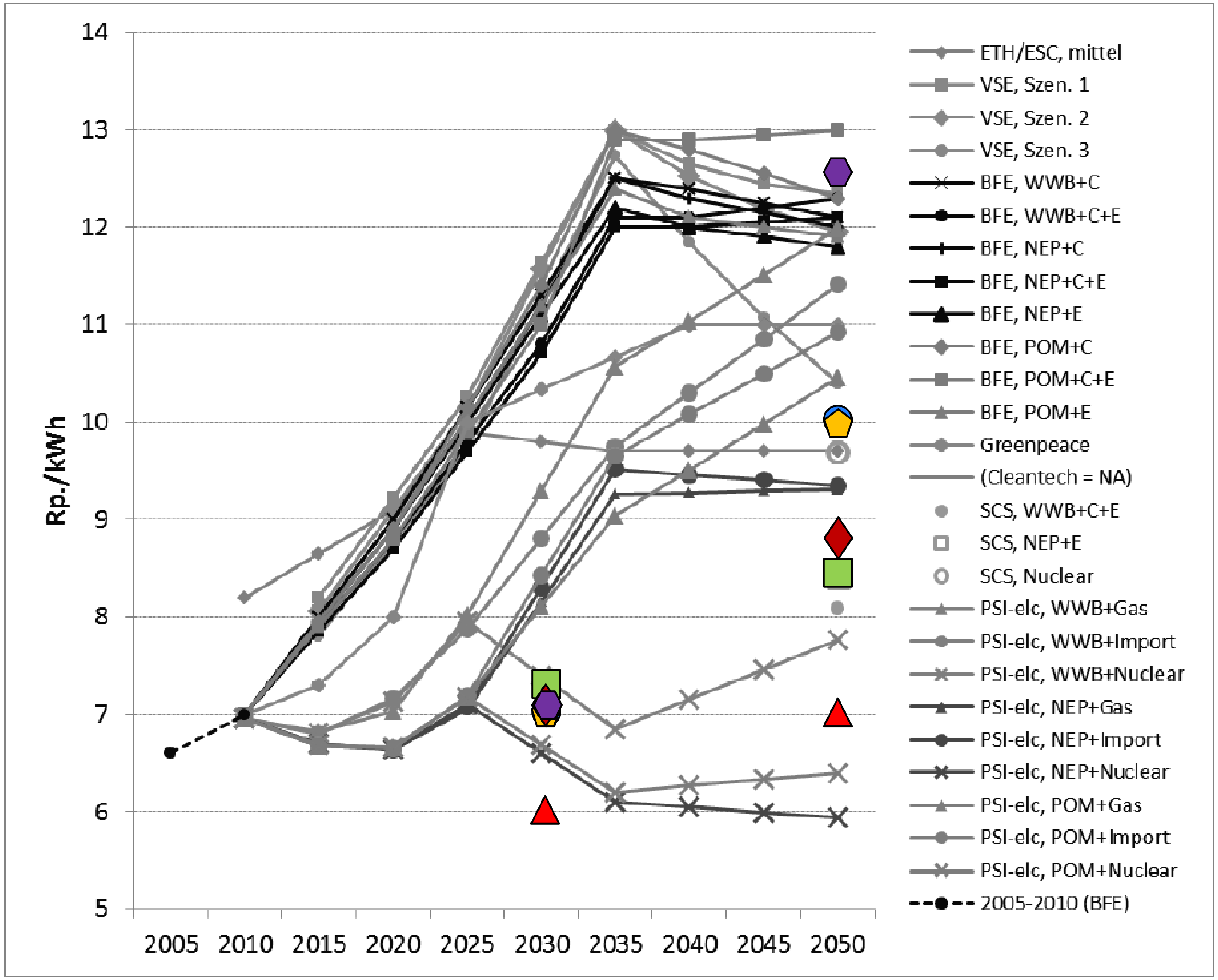


Capital Outlay per period



- Capital Investment highest for CO2 scenario, lowest for noNUC
- Total System Cost (excl Trade Cost/Revenue): LeastCost – 275 bio CHF, NoNUC – 305 bio CHF, CO2 – 332 bio CHF

Electricity generation Cost



Source: M. Densing, "Review of Swiss Electricity Scenarios 2050", PSI (2014)

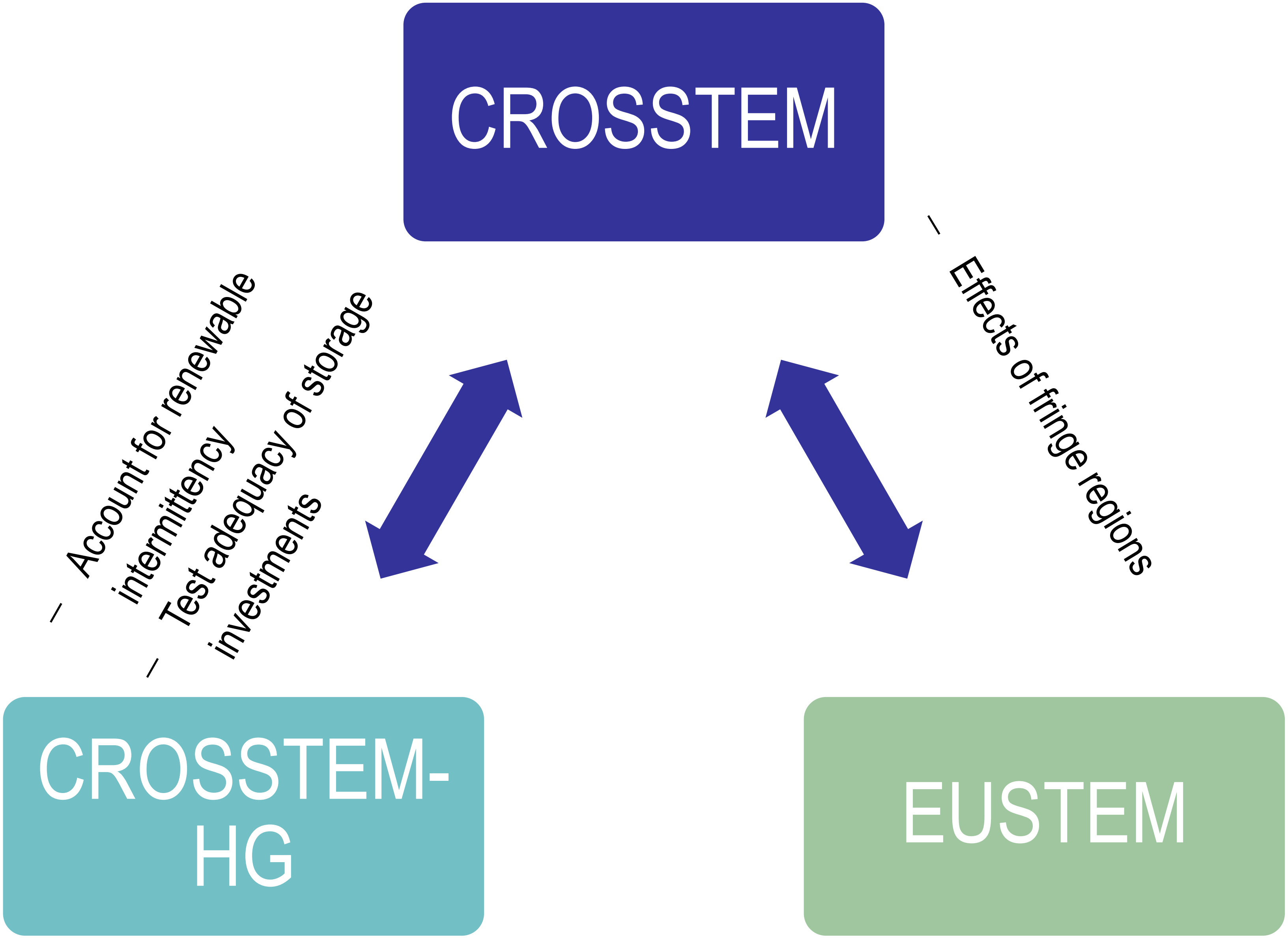
- noNUC
- CO2
- LC
- noNUC-CHSS
- CO2-SS
- CO2-LowCCS

Model Limitations

Limitations & Uncertainties

- CROSSTEM is not a pure dispatch model
- Modelling of representative days – Overall simplifications
- Trade with fringe regions – Inclusion of surrounding countries
- T&D infrastructure not explicitly modelled.
- CO2 transport across countries not modelled
- Model assumes perfect information, perfect foresight, well functioning markets and economically rational decisions – Optimal solution for 5 countries together, not for each country

The CROSSTEM Universe



Conclusions - CROSSTEM

- A new electricity system model for Switzerland with an emphasis on cross-border trade has been developed
- Various scenario explorations conducted to test robustness of model
- Feasibility of a low carbon electricity pathway has been demonstrated

Thank you for your attention !!!

Energy Economics Group

Laboratory for Energy Systems Analysis

General Energy Research department & Nuclear Energy and Safety Research Department