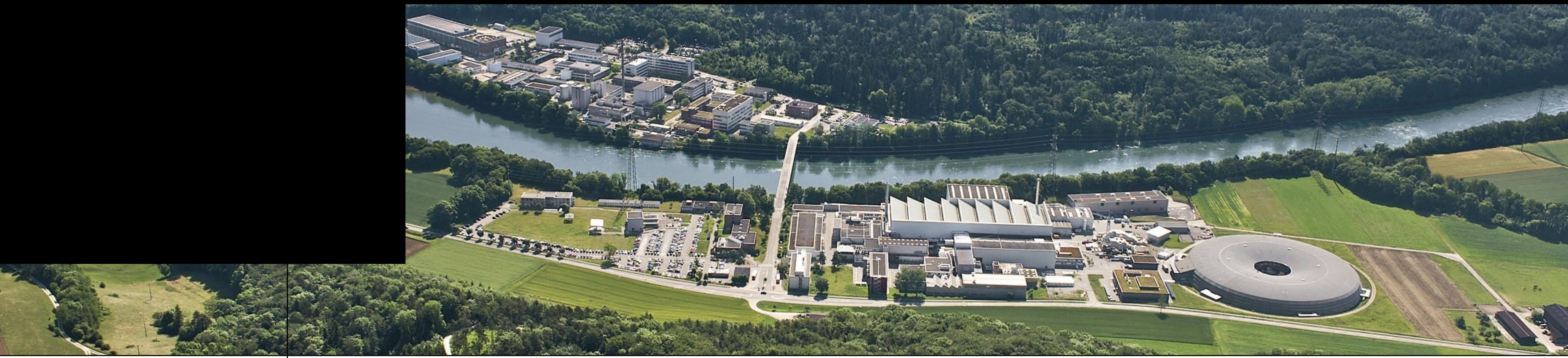


Wir schaffen Wissen – heute für morgen

Frontiers in Energy Research, ETH, 24th February 2015

Rajesh Mathew Pattupara

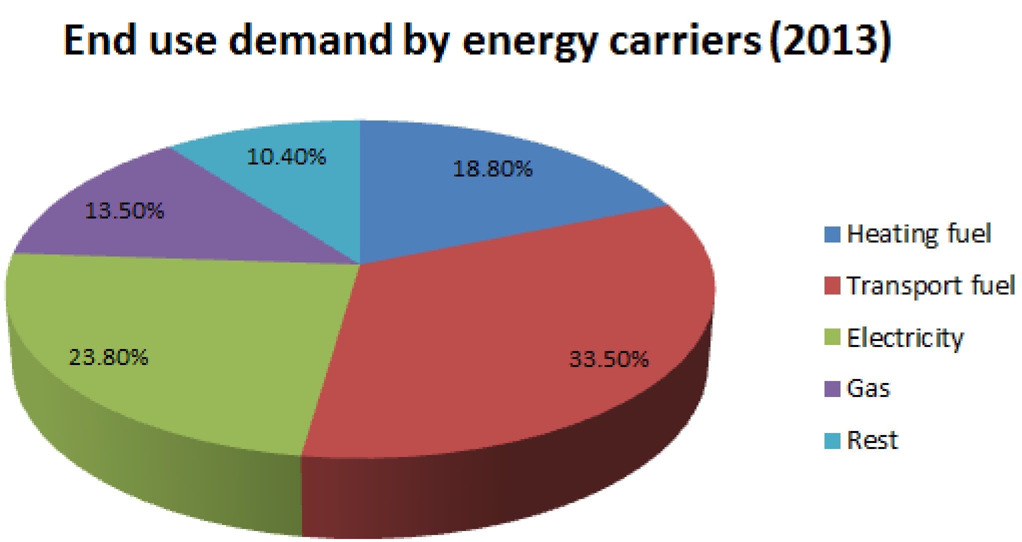
Development of the CROSSTEM model – A tool for analysing uncertainty in the evolution of the Swiss electricity system.

Outline

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

Introduction

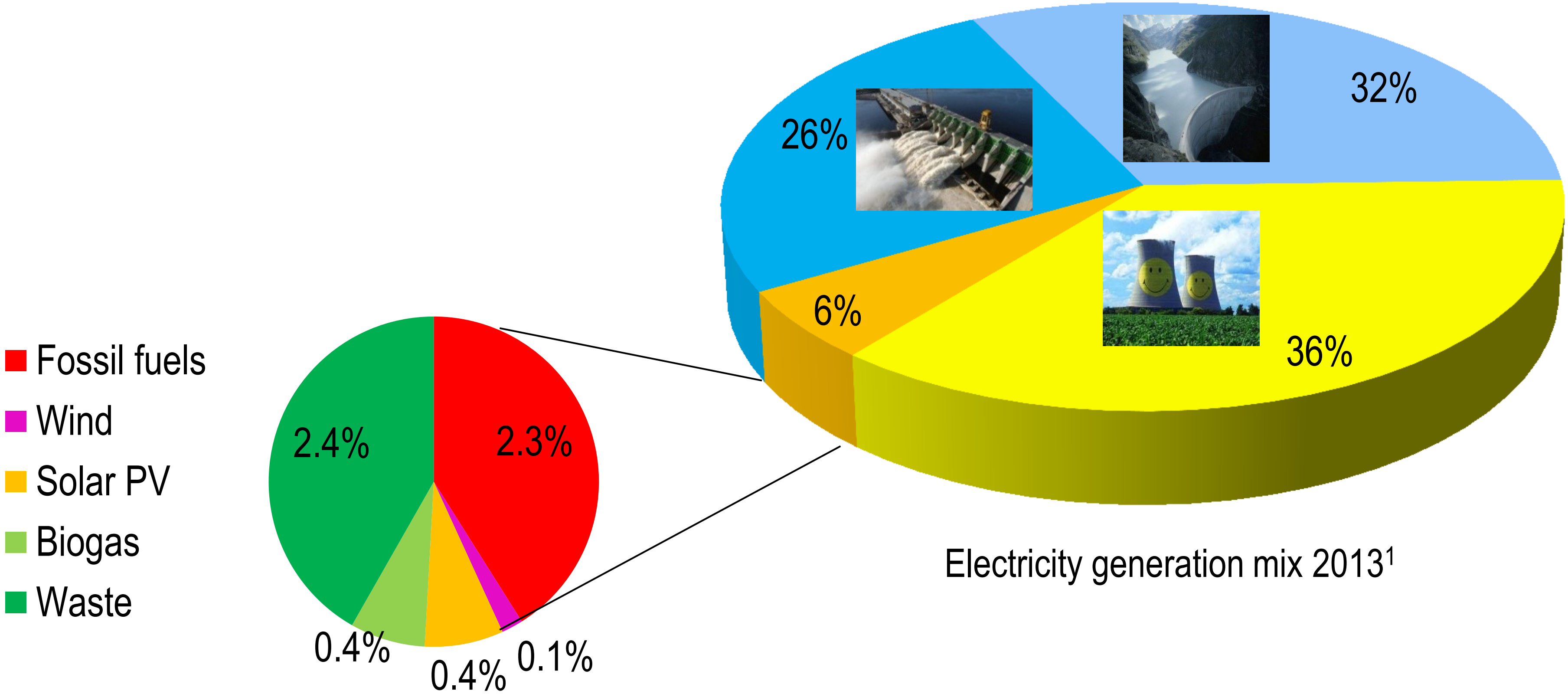
- Electricity accounts for one quarter of Swiss energy demand
- Important for energy security
- Source of revenue
- Clean source of energy



Source: "Schweizerische Gesamtenergiestatistik 2013", BFE Bern

Introduction

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

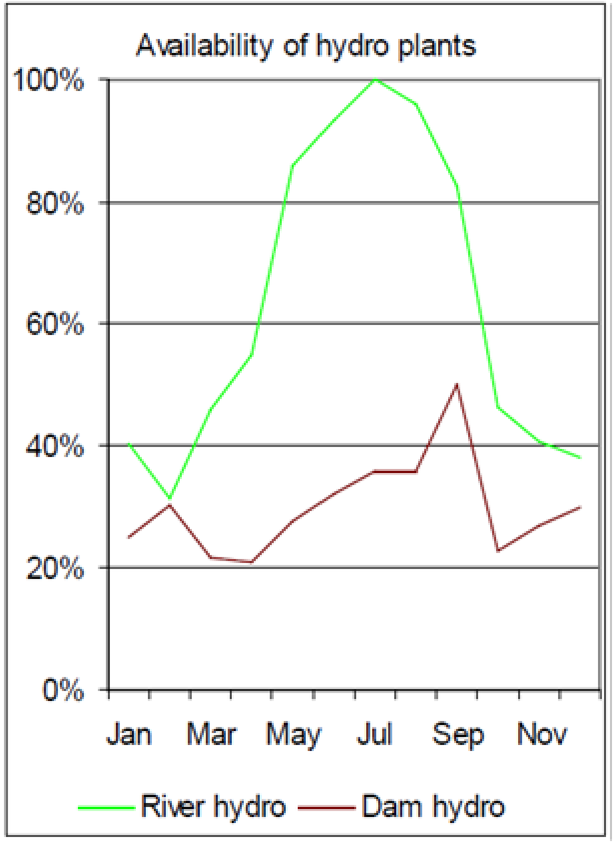


Electricity generation mix 2013[1]

Source: "Schweizerische Elektrizitätsstatistik 2013", BFE Bern

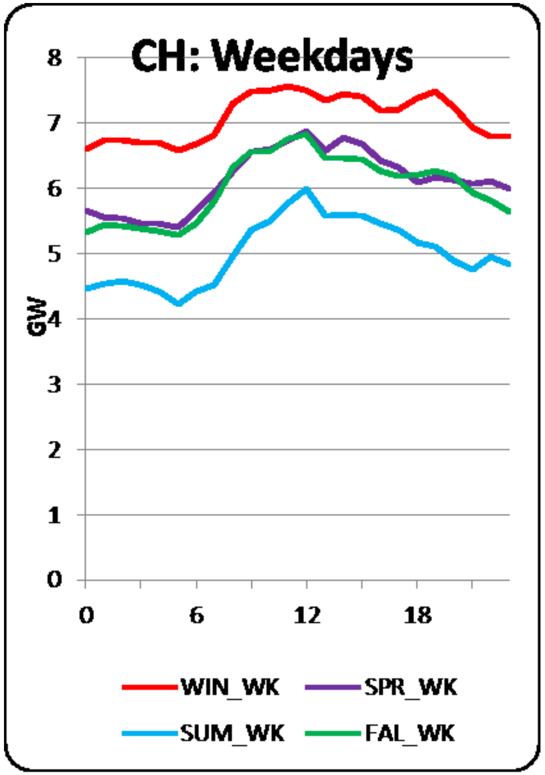
Seasonal demand – supply variation

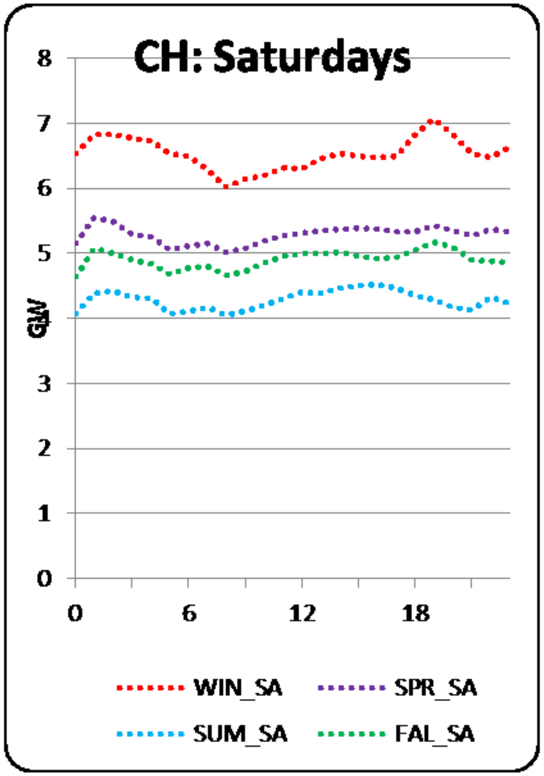
Hydro resource availability - Switzerland

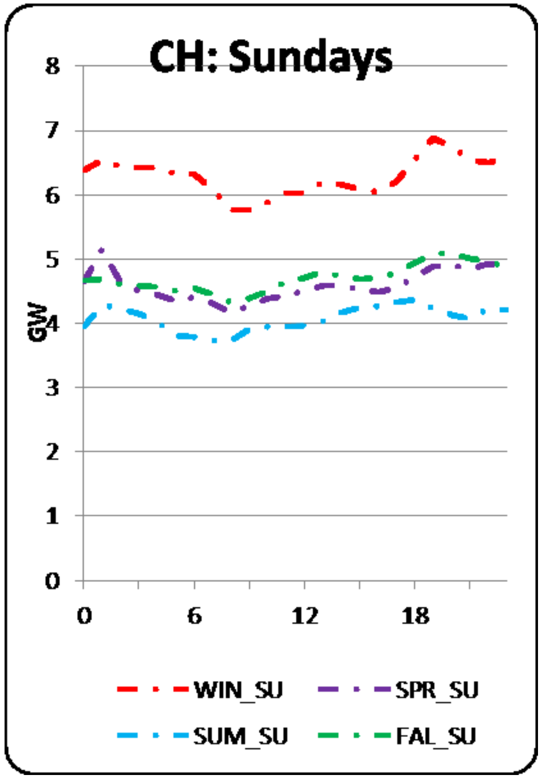


Source: "Documentation on the development of the STEM-E model", PSI (2011)

Electricity demand pattern - Switzerland



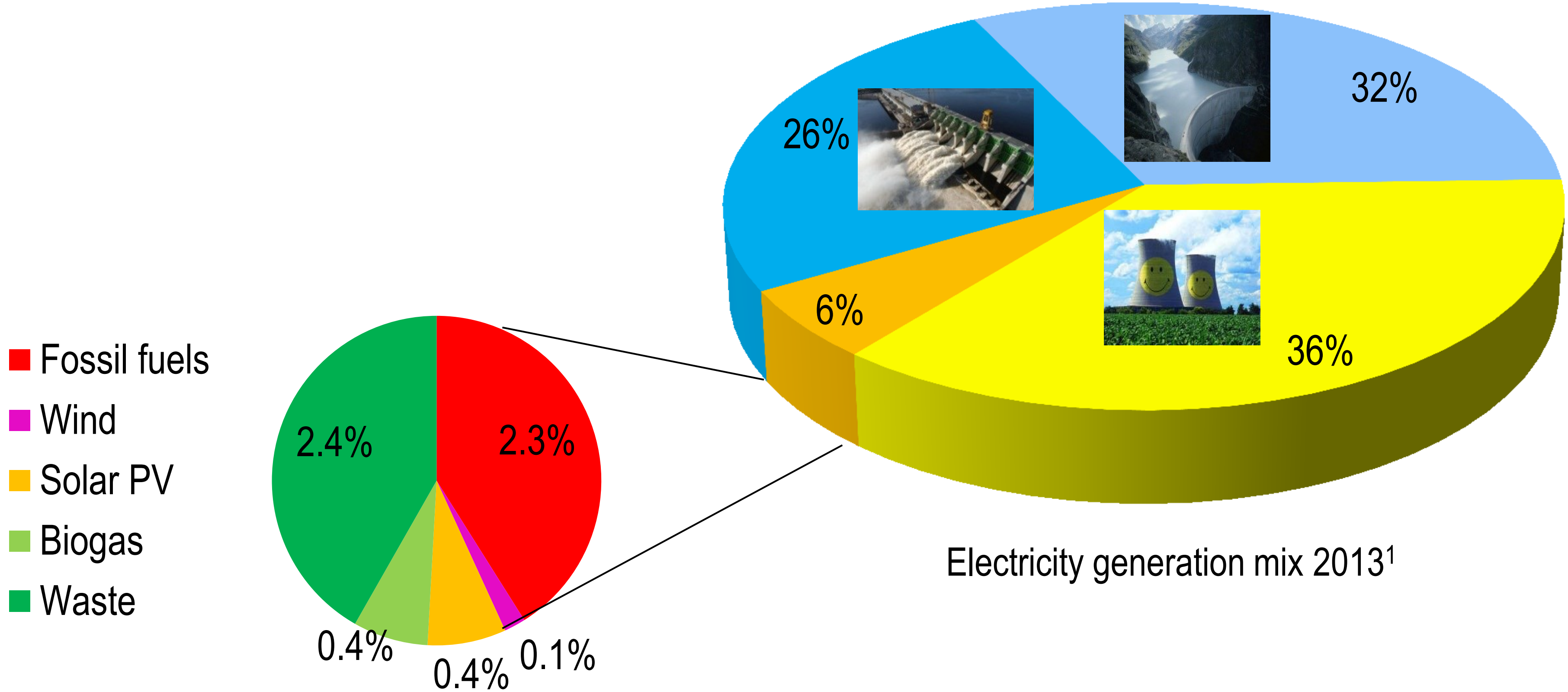




Source: Data provided by ENTSO-E

Current status of Electricity system

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



Electricity generation mix 2013[1]

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**

Problems

- ***Uncertainty regarding future electricity demand***
- ***Uncertainty regarding future supply options***

Future demand pathways

Population growth

Economic growth

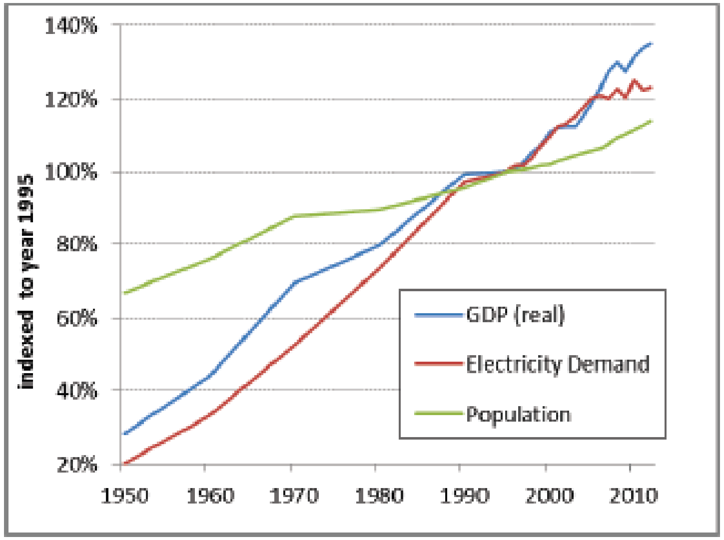


Figure 1: Historical growth of GDP, electricity demand and of population in Switzerland. Demand: after losses, no heating-days correction. Sources: BFE (energy), BFS (pop), SECO (GDP)

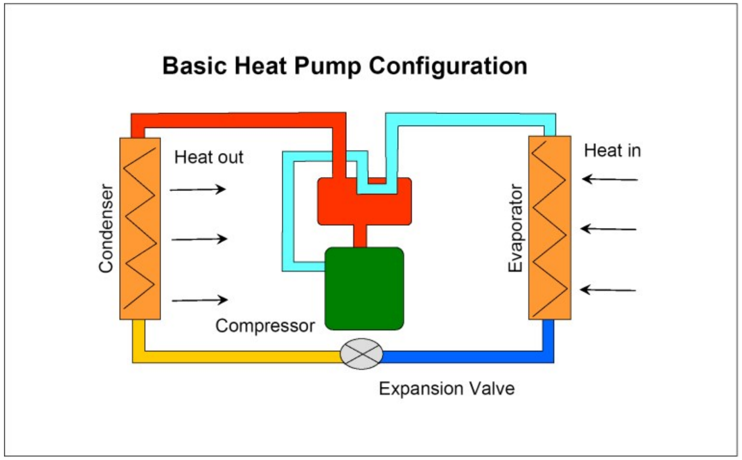
Source: M. Densing, "Review of Swiss Electricity Scenarios 2050", PSI (2014)

Future demand pathways

Population growth

Economic growth

Electric vehicles



Electric heating

Smart Technologies

Future demand pathways

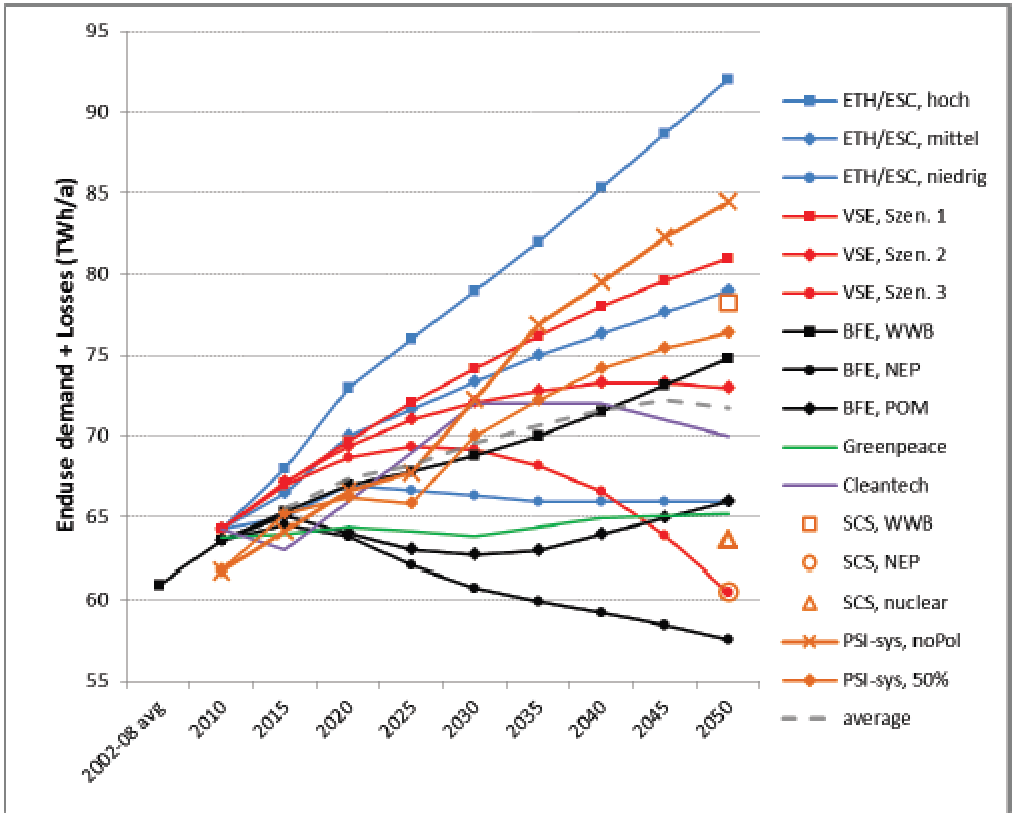


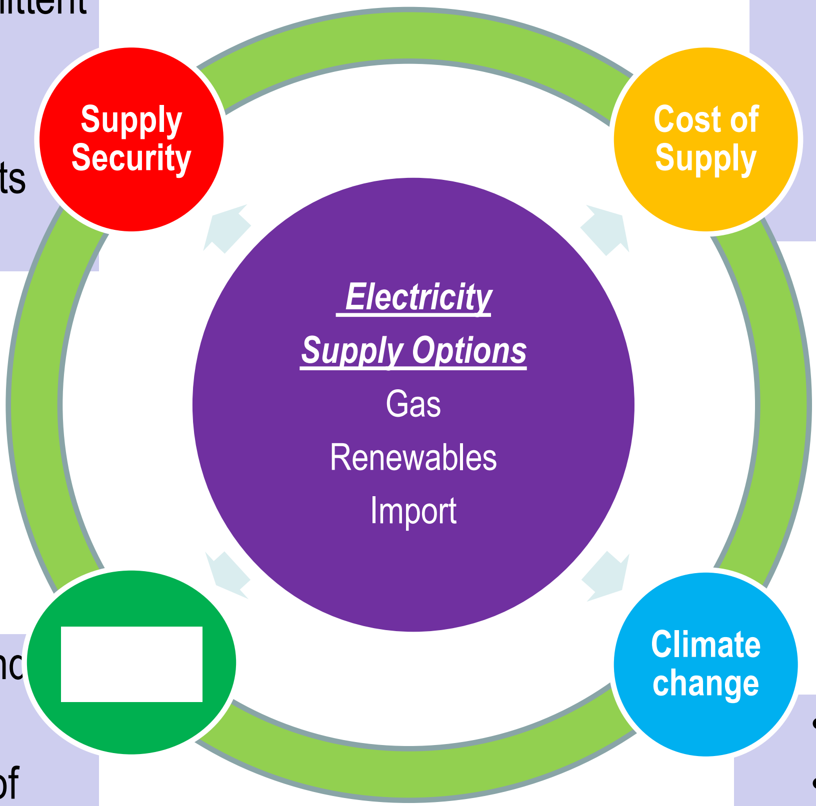
Figure 2: Electricity demand of the scenarios. Demand is after hydro-pumps, after import/export, and before losses. The demands of the SCS scenarios should be those of the BFE scenarios with same name, but seem to be different. The PSI-elc study (not shown) uses the demands of the BFE scenarios. Greenpeace: 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

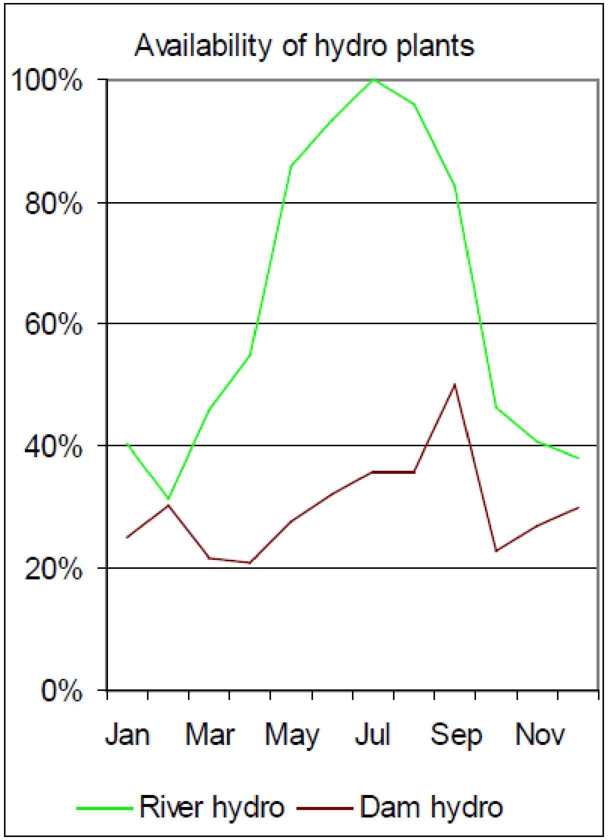


- Cost implications of renewable / low carbon policy
- Revenue from trade
- Evolution of fuel prices

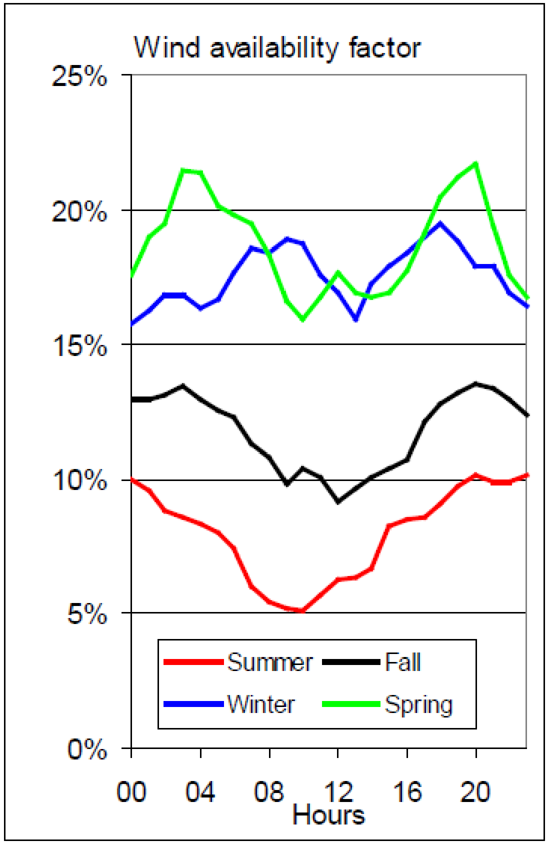
- Balancing supply and demand
- Intermittent nature of renewables
- Electricity imports

- CO2 emission targets
- Expansion of Gas plants

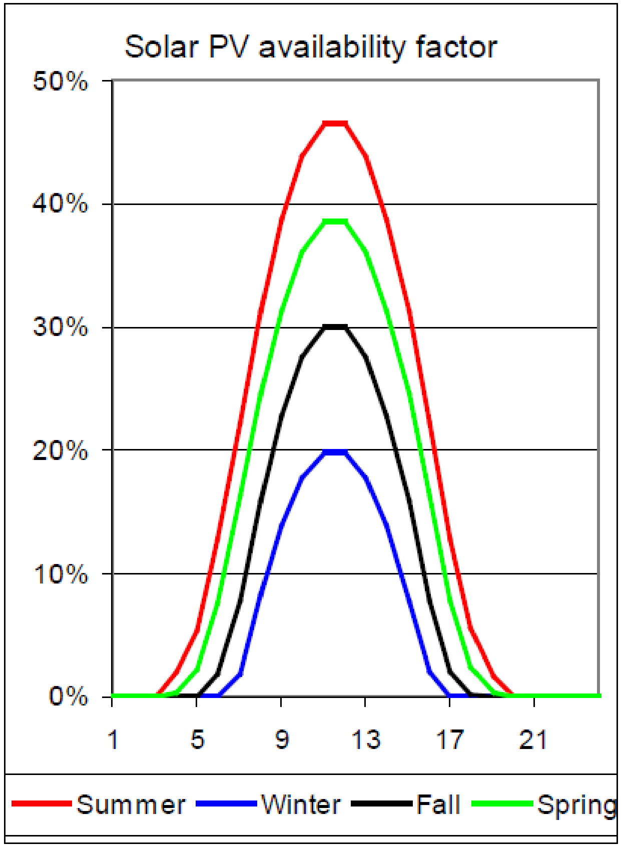
Intermittency of renewable sources of electricity



Hydro



Wind



Solar PV

Source: "Documentation on the development of the STEM-E model", PSI (2011)

Renewable resource potentials

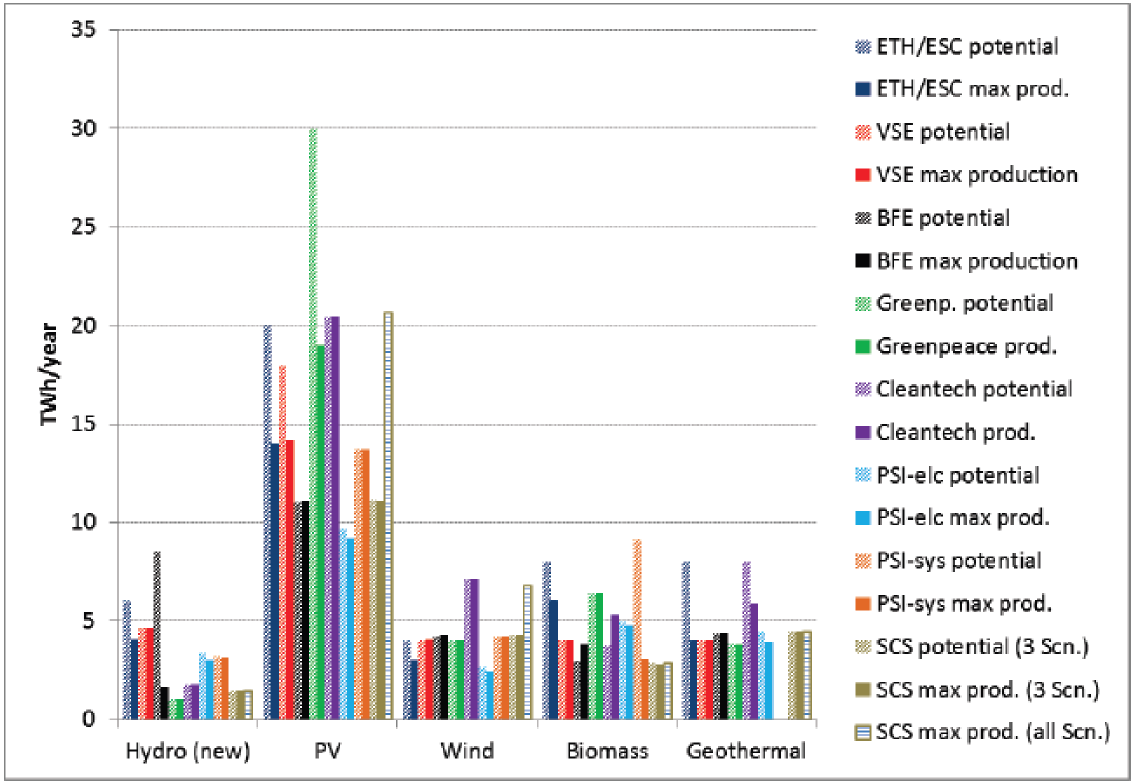


Figure 8: Assumed potentials of renewable generation, and maximal production in the studies. Hydro (new installations): with respect to 2010 production. ETH/ESC: "max. prod." is scenario "ETH, Mittel" (the only reported one). BFE: max. prod. occurs in supply variants "C+E" and "E". PSI-sys: biomass is with 33% efficiency in this chart, and is also for non-electricity use; geothermal not in study. PSI-elc: Biomass: 50% of potential of all biogas & waste (also for non-energy use). SCS: the max.prod. in the 3 scenarios that are considered in more detail in this review are reported separately

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

Forecasting future electricity system

Problems

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

Solution

- Energy System Models

Why Energy System Models?

- Purpose of models is to generate insights, not forecasting
- Long term strategic planning via *"what-if"* scenarios – Implication of changes to parts of the system under certain boundary conditions
- Assist policy makers to make decisions in order to fulfil given policy goals

Objective

- Optimization models (MARKAL, TIMES)
- Simulation models (NEMS, PRIMES)
- Power systems and electricity market models (WASP, PLEXOS)
- Qualitative and mixed method scenarios

Comparitive study: Pfenninger et.al, "Energy Systems modelling for 21st century energy challenges", London (2014)

Electricity supply mix – Switzerland (2050)

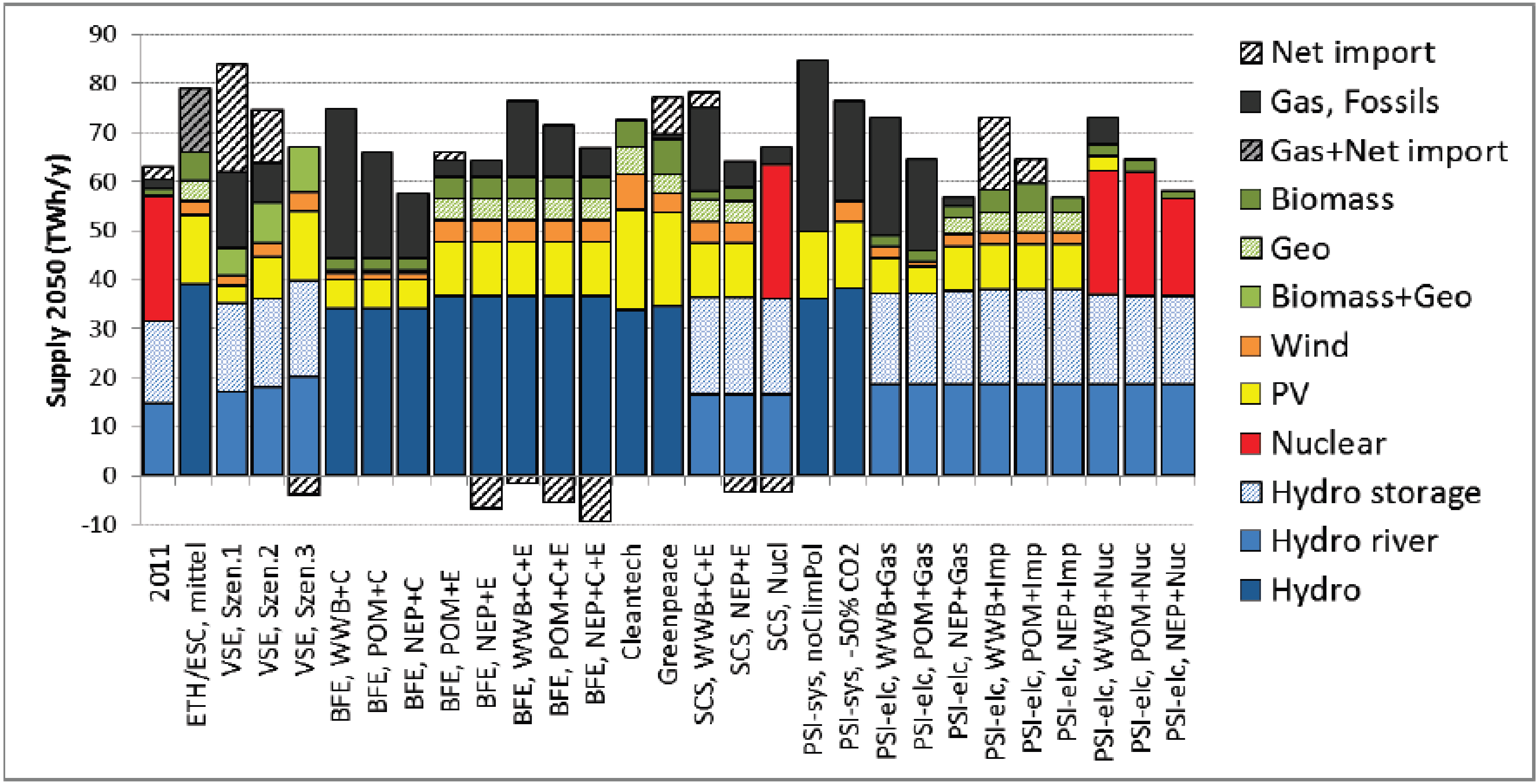
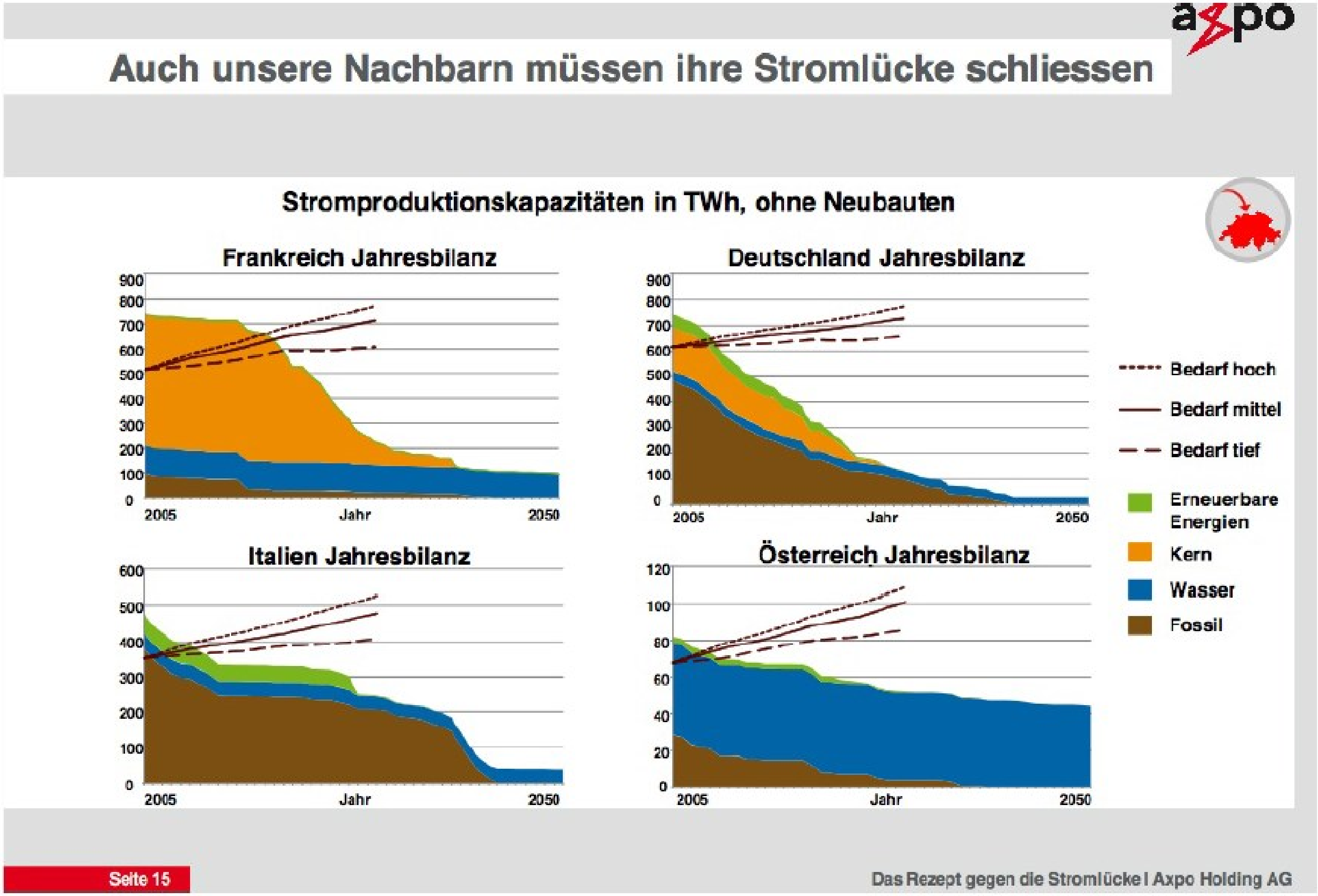


Figure 9: Yearly production mix in 2050.

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

Where do the imports come from?

Situation in neighbouring countries



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

STEM-E – Swiss TIMES Electricity Model

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*

Why the need for a new model ?

Variability influences electricity generation technology choice (investment) and operation:

- Cheapest baseload technology → not necessarily most economical for all demands
- Technologies with flexible output profile → attractive (e.g. dam/pump hydro, gas)
- Technologies with output profile matching demand profile → attractive (e.g. solar)

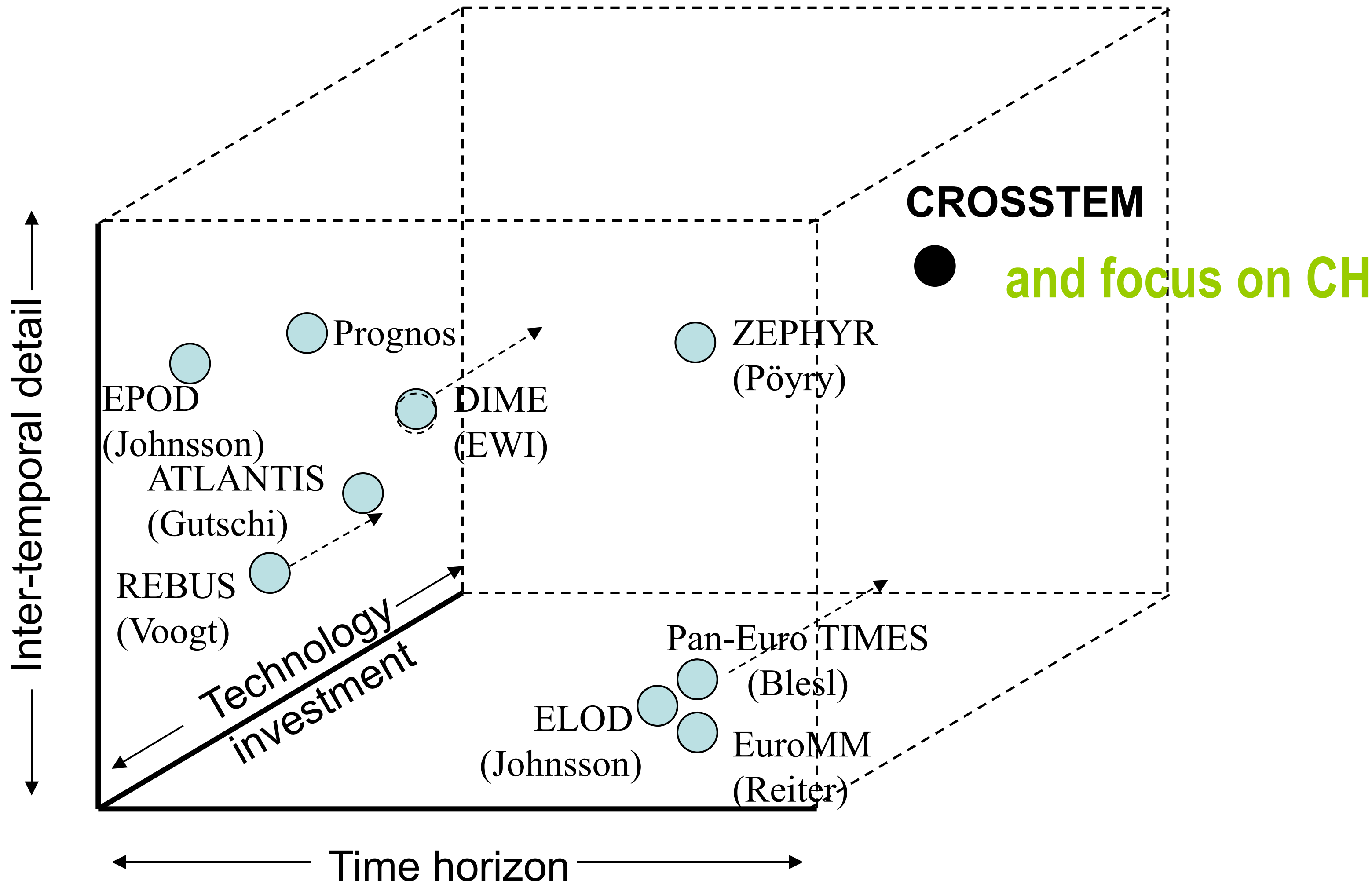
International trade influences this significantly:

- Cheapest baseload technology → attractive (excess can be exported)
- Flexible imports → attractive (instead of expensive flexible technologies)
- Technologies with output profile matching demand profile in neighbouring countries → attractive

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.

European electricity modelling approaches



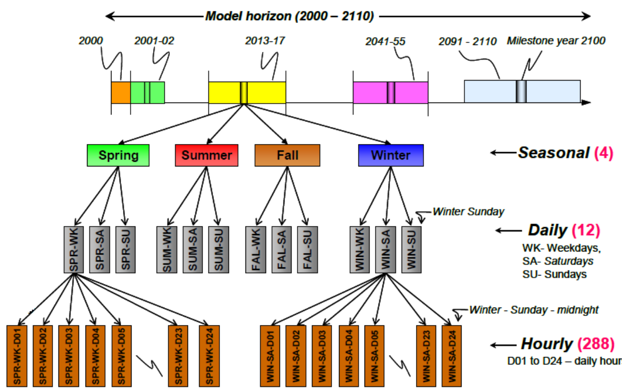
Representation of Switzerland highly aggregated

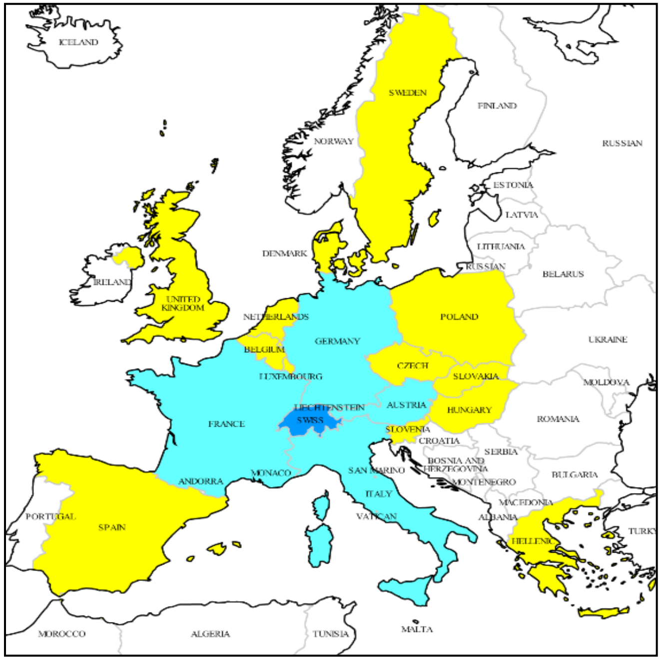
"ELECTRA Kick-off meeting - CROSSTEM", H. Turton & K. Ramachandran 19th July 2011

Voogt, 2001; Reiter, 2010; von Weizsäcker and Perner, 2001; Johnsson, 2011; Gutschi et al, 2009; Blesl, 2008; EWI, 2010; Prognos, 2010

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 – **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

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

Scenario Overview

	CROSSTEM Scenarios
Sc.1	Baseline scenario No particular constraints in technology investment* Trade constraints applied – net exporter (France, Germany) cannot become net importer (Italy, Austria) and vice versa → Also applied to Switzerland (analogous to self sufficiency) CO_2 prices for allowances in the ETS as in WWB (SES 2050)
Sc.2	De-carbonization of power sector (95% CO_2 reduction by 2050 from 1990 levels) for all five countries together All other conditions same as Sc.1 (including trade constraints)
Sc.3	No gas based generation in Switzerland Trade constraints relaxed for CH only (allowed to be a net importer) All other conditions same as Sc.2

* except where already part of policy: e.g., Nuclear phase-out in Switzerland (CH) and Germany (DE), no nuclear investment in Italy (IT) and Austria (AT). No Coal investment in Switzerland (CH).

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, with no trade loss.
- **Endogenous trade limits** – Based on historical trends. Net importers cannot become net exporters and vice versa.

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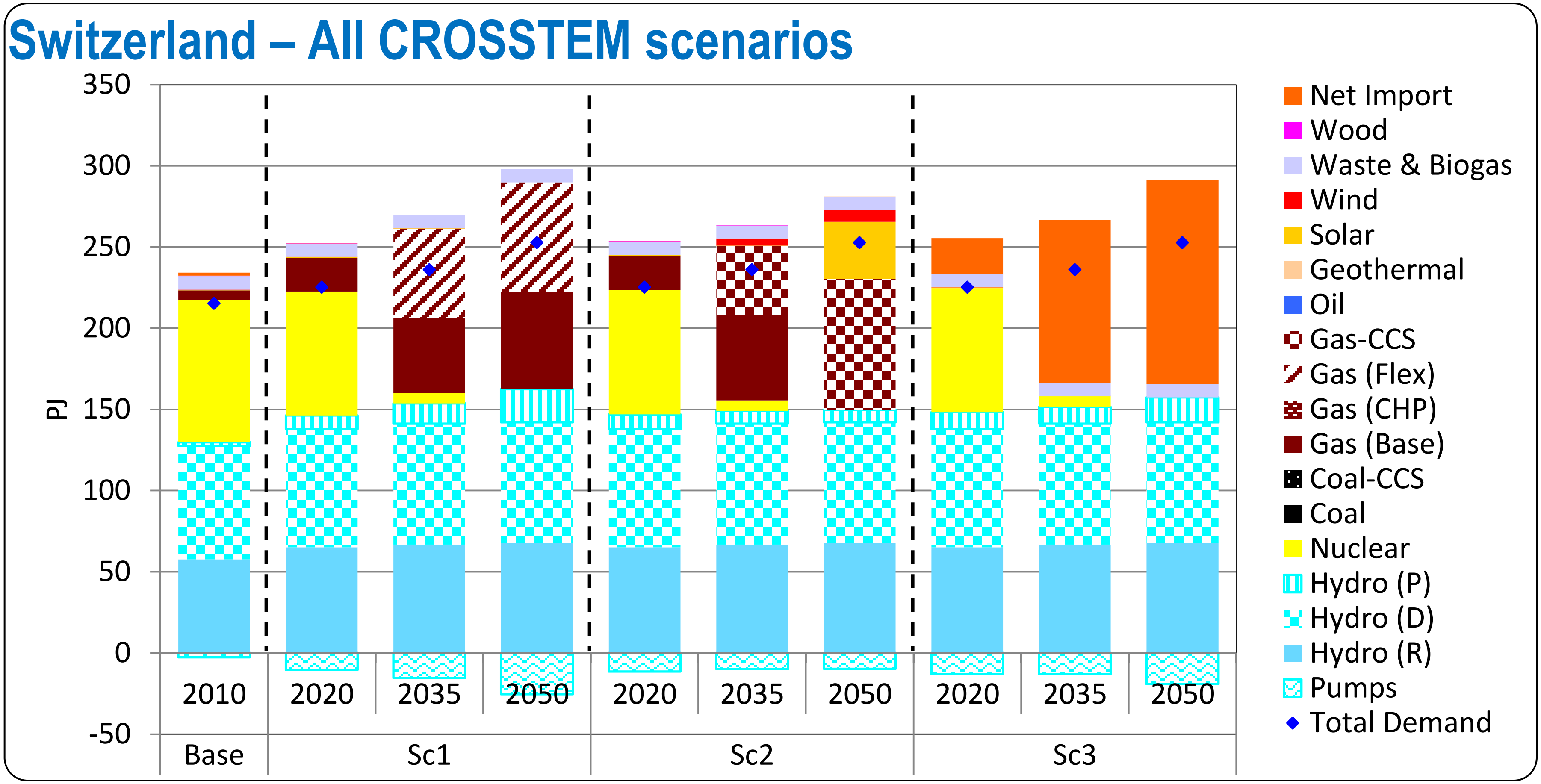
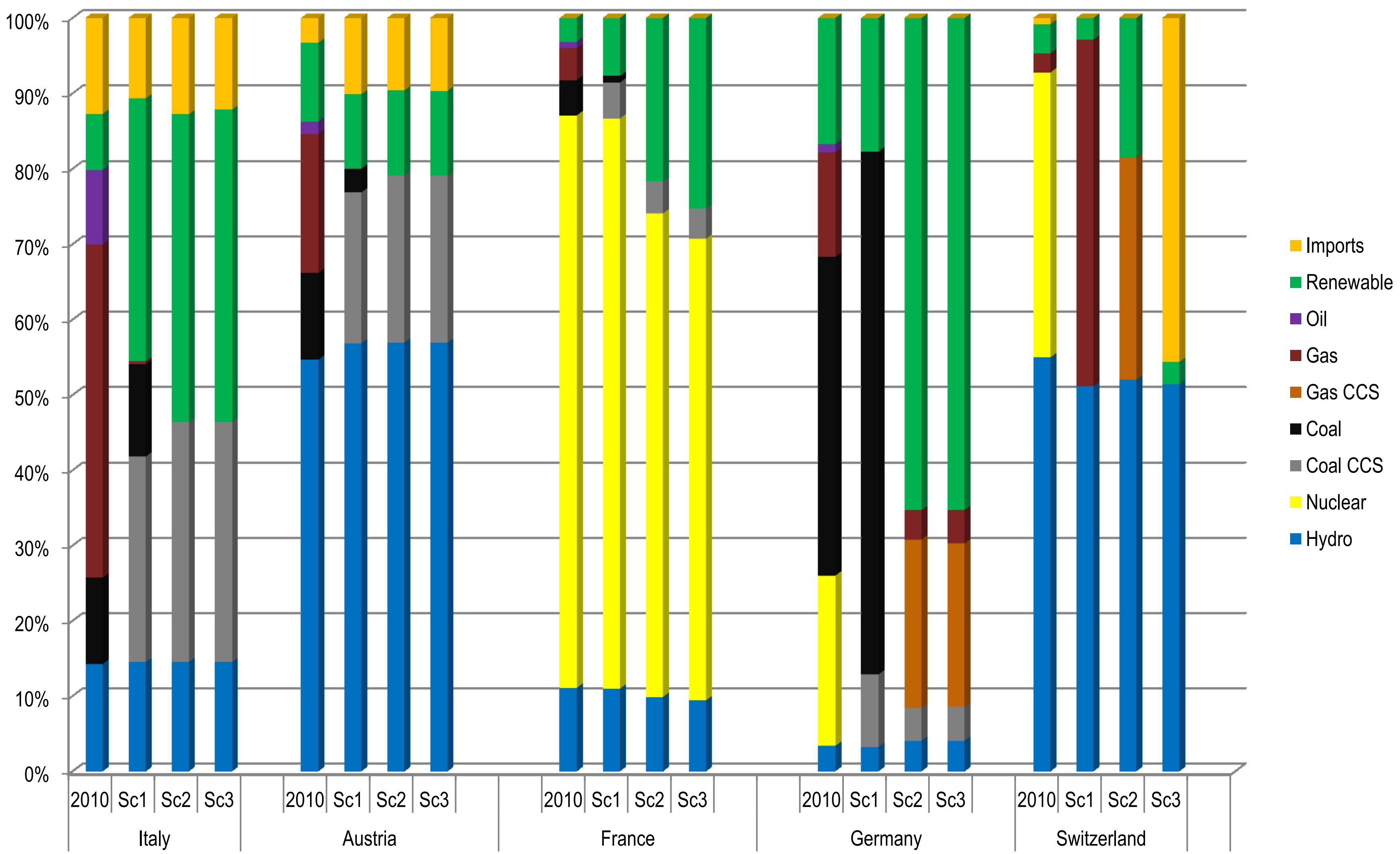
Results – Electricity generation mix



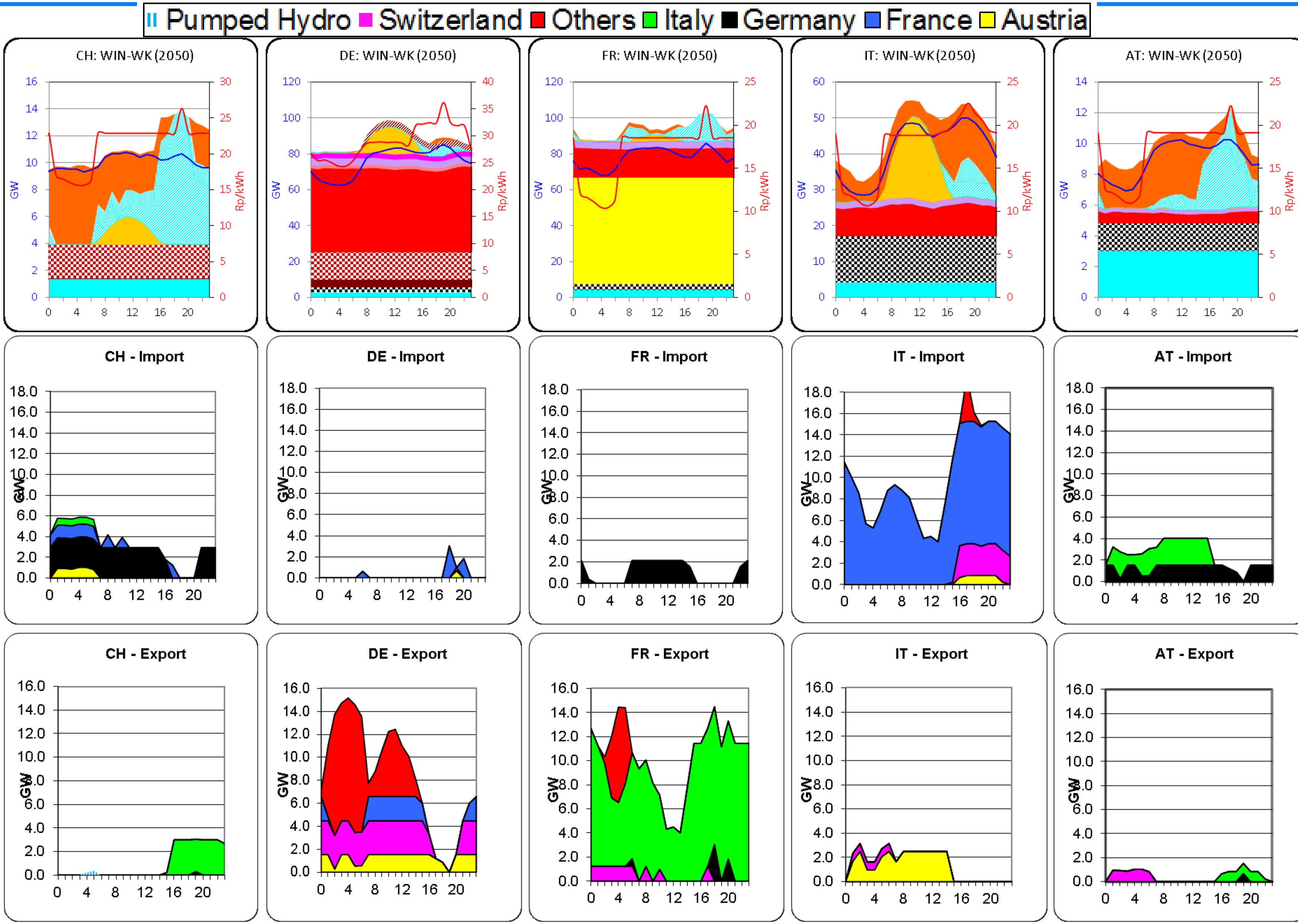
- Sc2 – Gas plants replaced by gas CCS + renewables, lower pump hydro (higher electricity price)
- Sc3 – Imports preferred to investments in renewables, Investments made elsewhere

Results – Electricity generation mix

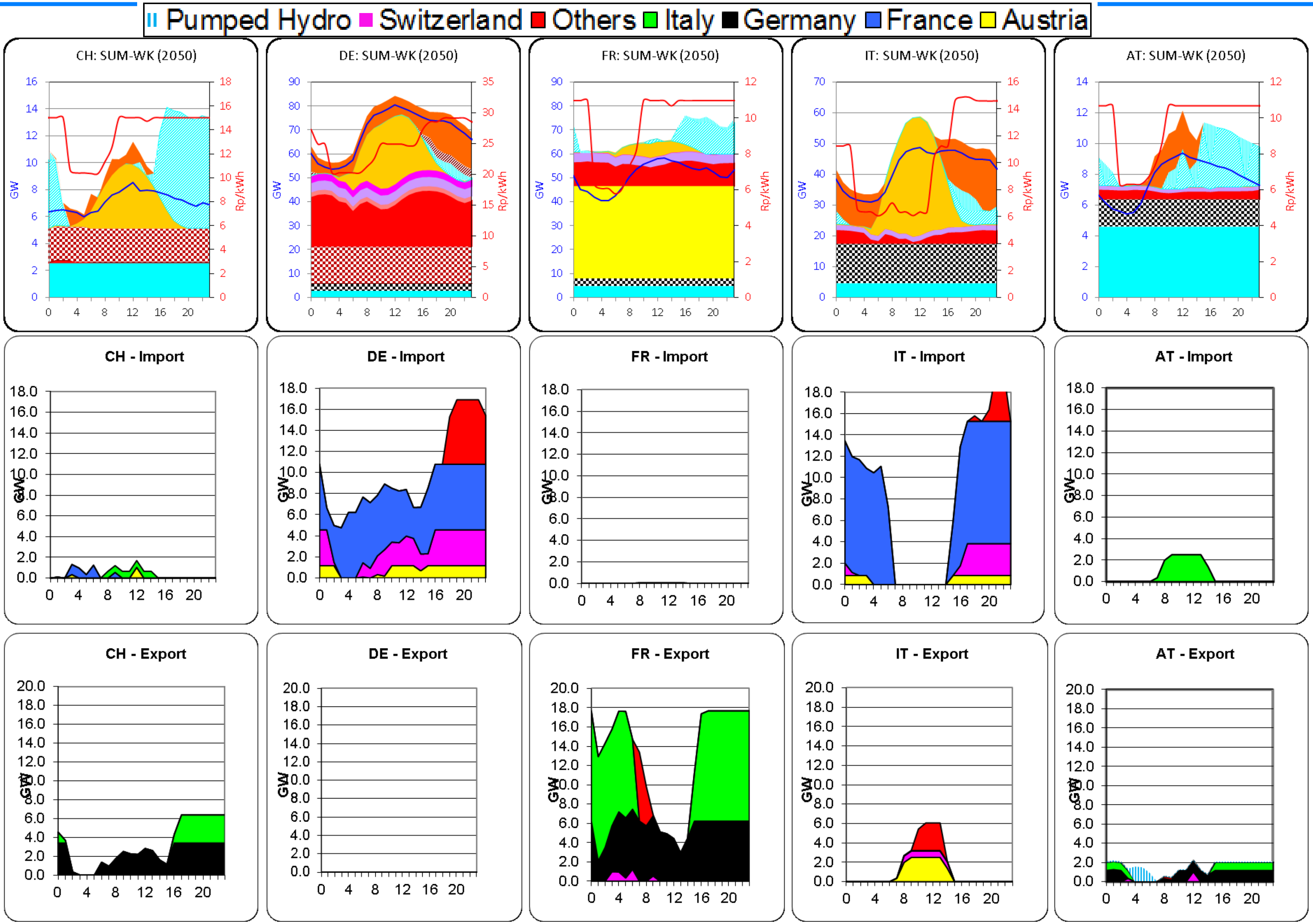
Electricity generation mix 2050



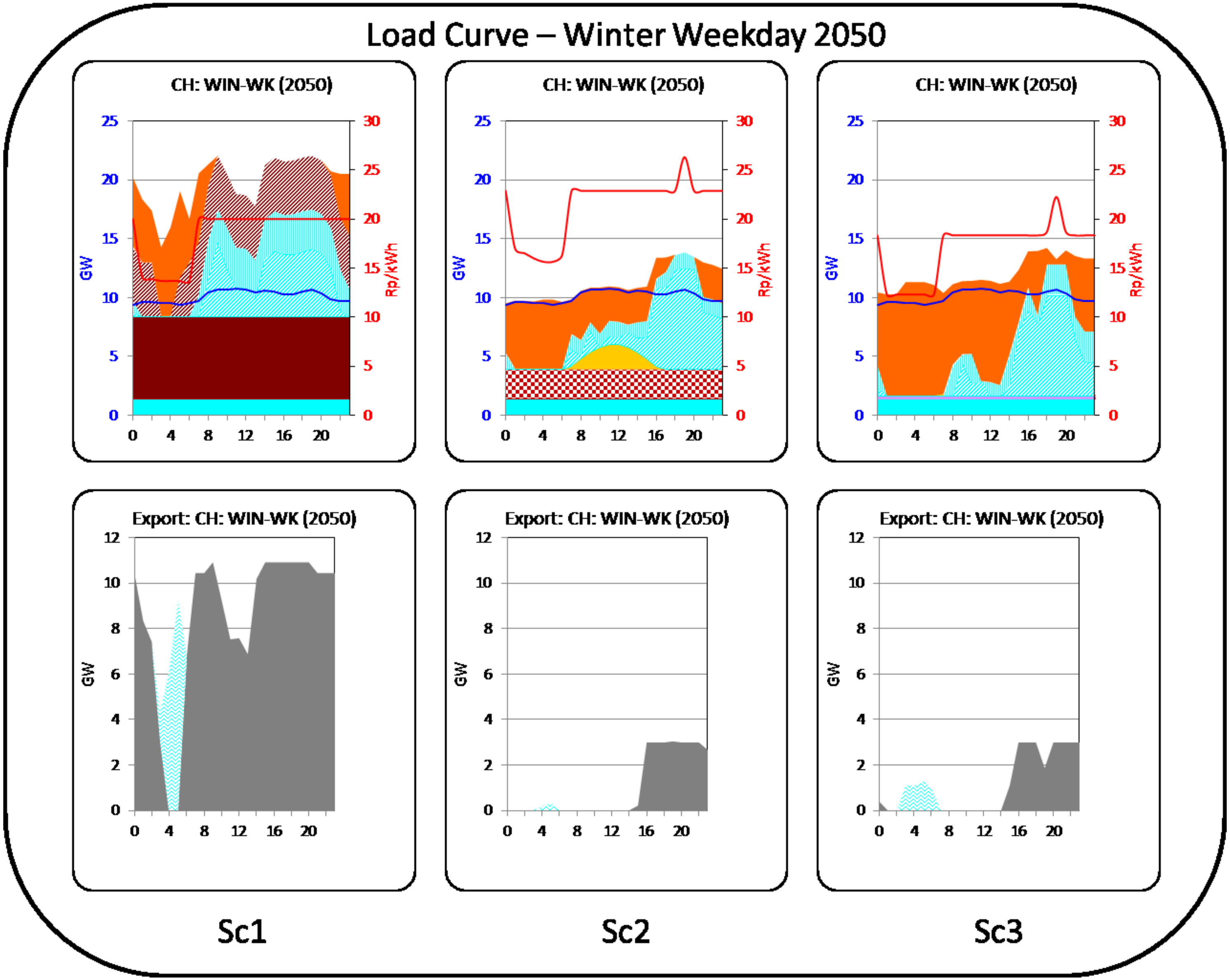
Load Curve – Winter Weekday 2050 (Sc2)



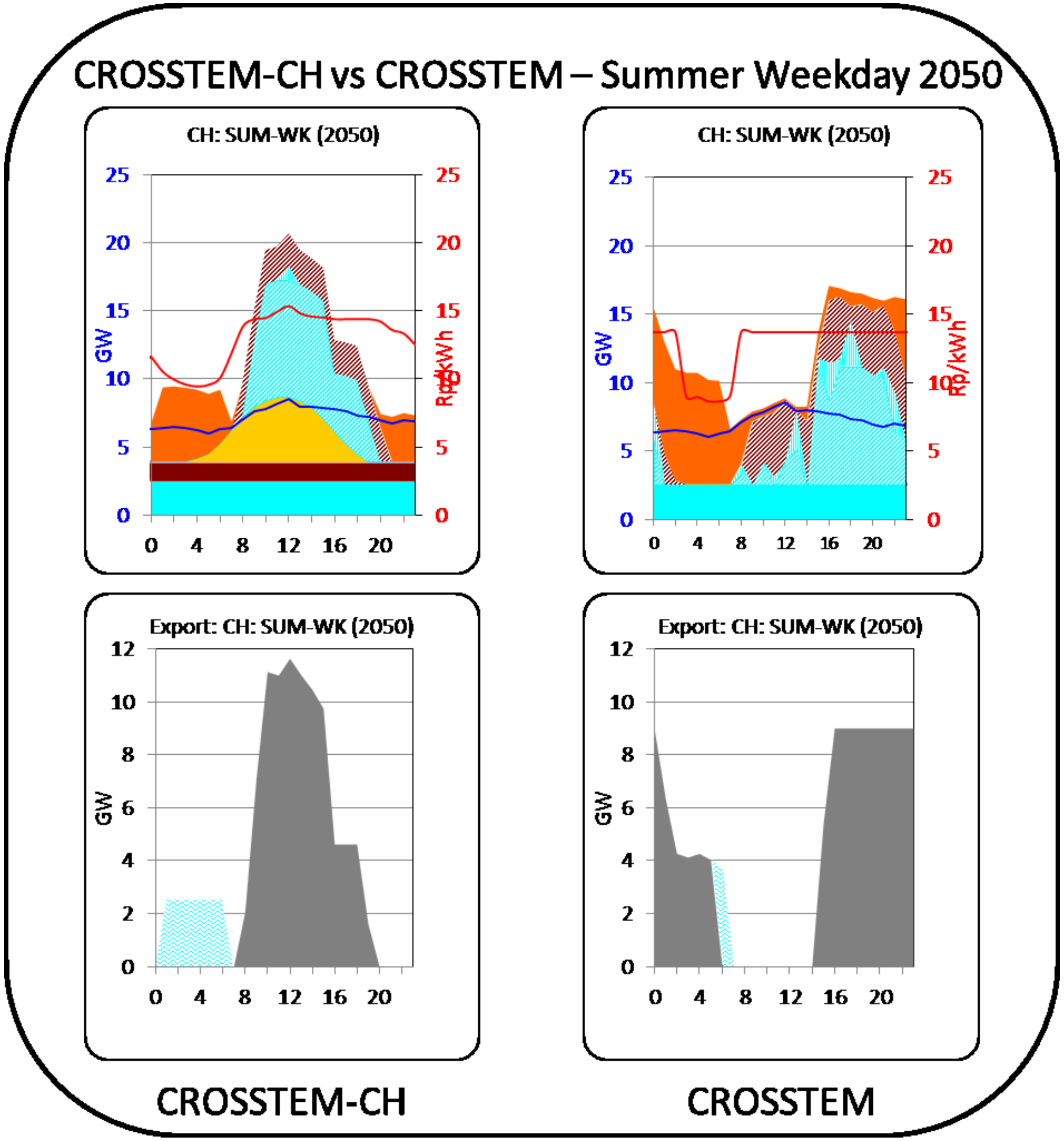
Load Curve – Summer Weekday 2050 (Sc2)



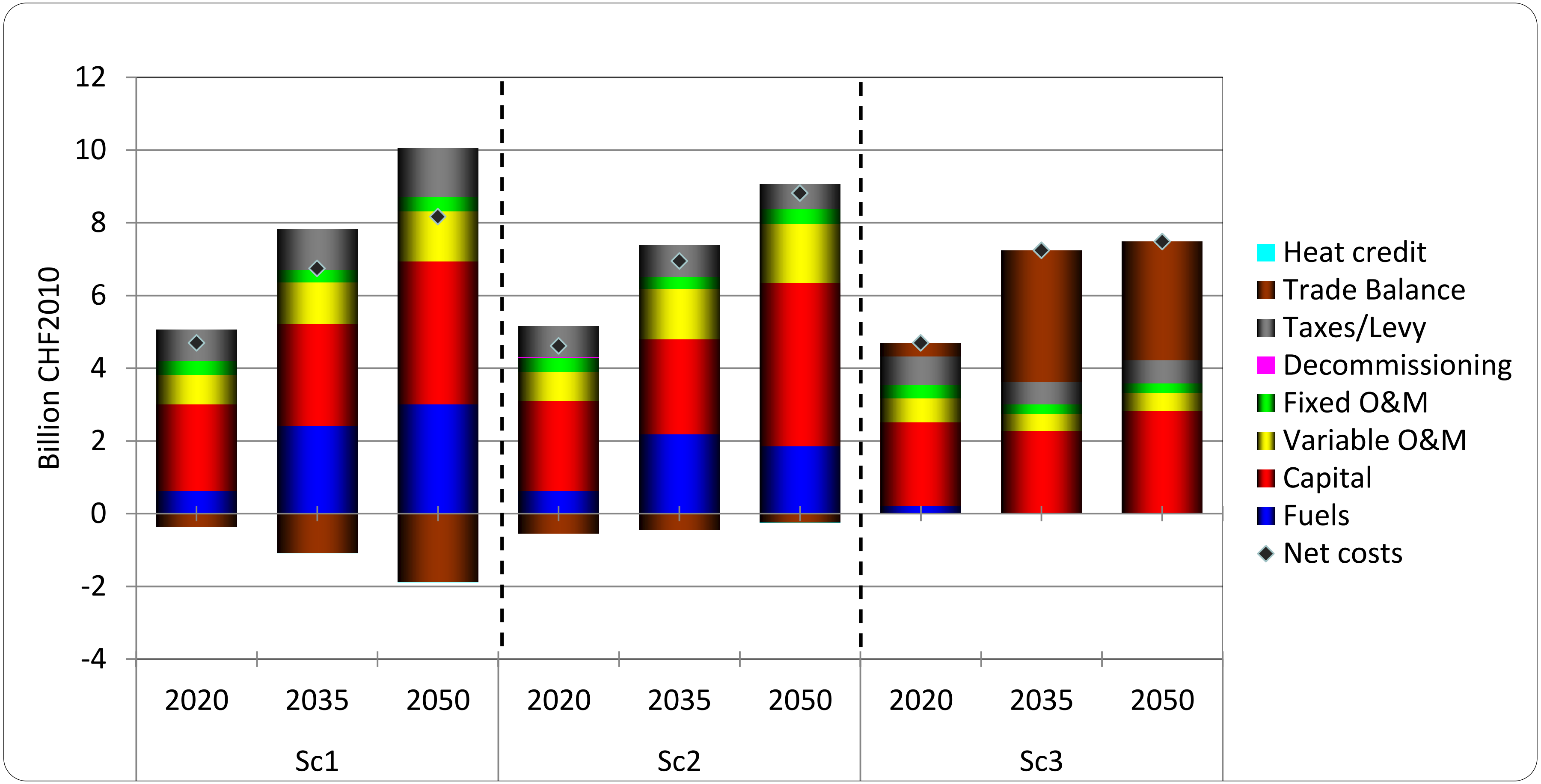
Results – Electricity generation schedules



STEM-E (CROSSTEM-CH) vs CROSSTEM



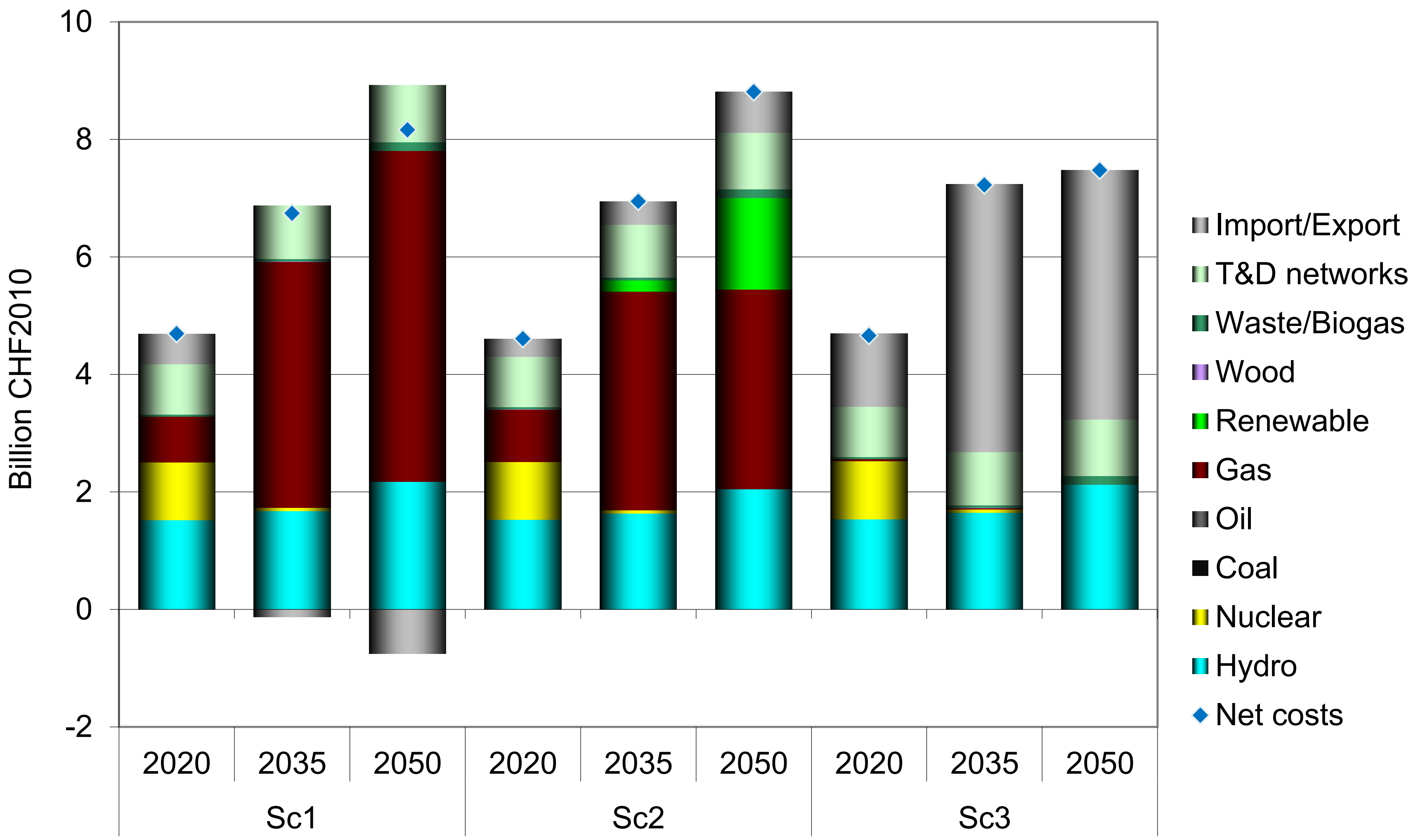
Total Electricity system costs



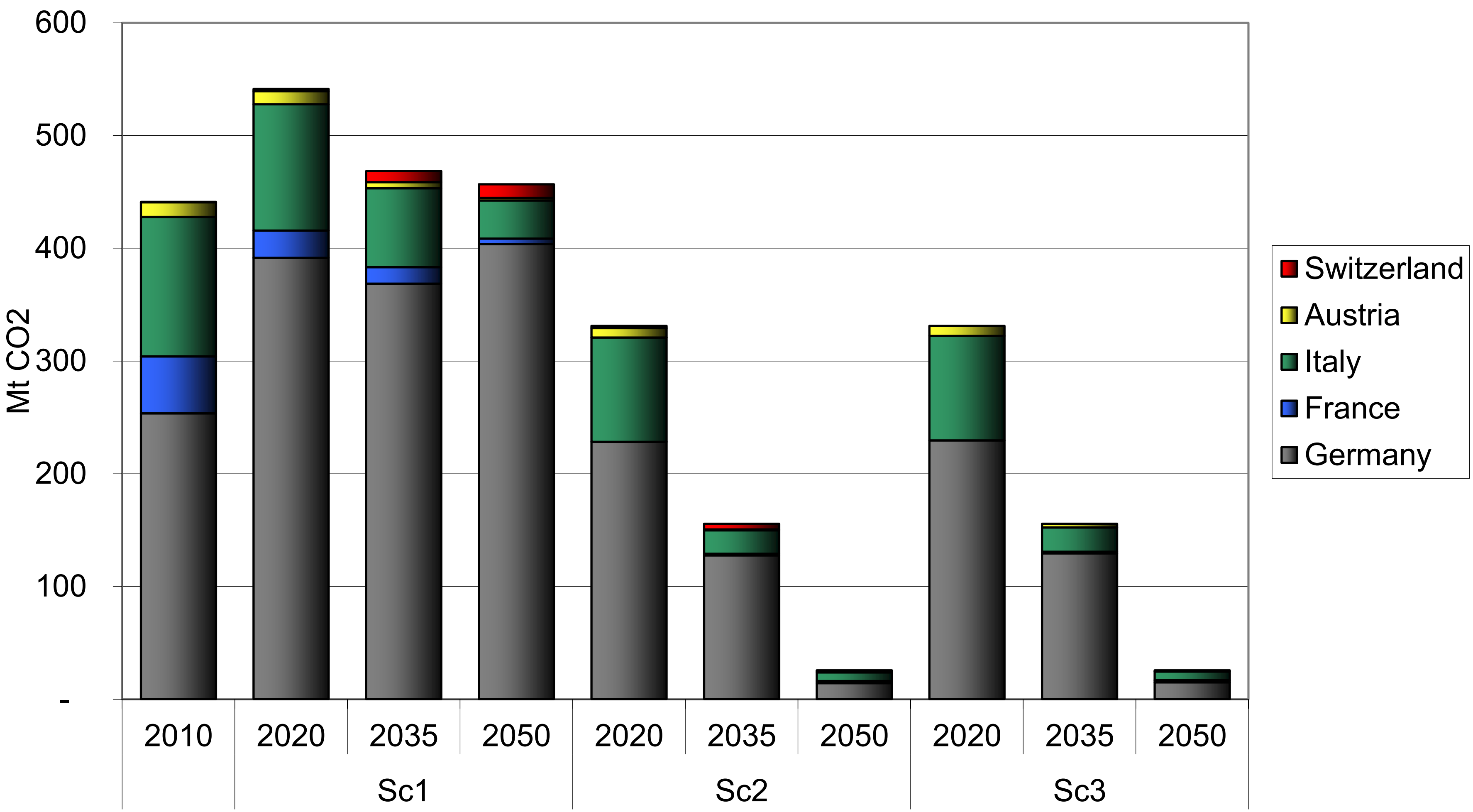
- In the near to medium term – Sc3 > Sc2 > Sc1
- In the long term – Sc2 > Sc1 > Sc3
- Why? The self sufficiency constraint in Sc1 and Sc2

Total Electricity system costs

Undiscounted electricity system costs (CH): Technology breakup



CO_2 emissions – Regional disaggregation



Conclusions

- 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
- Switzerland can remain self-sufficient even under stringent CO_2 emission targets but at a higher cost

Model Limitations

Limitations & Uncertainties

- CROSSTEM is not a pure dispatch model.
- Modelling of representative days – Overall simplifications
- T&D infrastructure not explicitly modelled.
- CO_2 transport across countries not modelled
- Trade with fringe regions – Inclusion of surrounding countries
- Model assumes perfect information, perfect foresight, well functioning markets and economically rational decisions – Optimal solution for 5 countries together, not for each country

Thank you for your attention !!!

Energy Economics Group

Laboratory for Energy Systems Analysis

General Energy Research department & Nuclear Energy and Safety Research Department