Task 4.2

Title

Global observatory of electricity resources

Projects (presented on the following pages)

Transformation of the Energy-related Severe Accident Database (ENSAD) into an interactive, web-based GIS application
Poster see task 4.1
P. Burgherr, W. Kim, M. Spada, A. Kalinina, S. Hirschberg

Bi-level electricity market model (BEM)
M. Densing, E. Panos

Optimization of photovoltaic potential and its integration in Switzerland using genetic algorithm and optimal power flow
J. Dujardin, A. Kahl, B. Kruyt, M. Lehning

World Energy Scenarios 2016
T. Kober, E. Panos

A preliminary Spatial Multi-Criteria Decision Analysis for Deep Geothermal Systems in Switzerland
Poster see task 4.1
M. Spada, P. Burgherr

Marginal electricity supply mixes and their integration in version 3.4 of the ecoinvent database: results and sensitivity to key parameters
L. Vandepaer, K. Treyer, C. Mutel, C. Bauer, B. Amor

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Bi-level electricity market model (BEM)

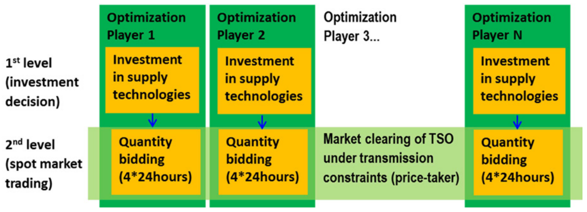
Martin Densing (martin.densing@psi.ch), *Evangelos Panos*
Energy Economics Group, Laboratory for Energy Systems Analysis, PSI

Motivation

- Goal: Decision-support for policy makers (ES2050 and beyond): Improved understanding of investment, production and trading decisions of producers on the European electricity market, especially for Switzerland
- Focus: Electricity producer-side (not consumer-side)
- Oligopolistic market modelling is required, because producers (in corpore, or single utilities) influence prices: E.g.
  - Producers withhold production, or limit investment to drive prices up deliberately, or are forced by technical or regulator's outages
  - Market power may be exerted only in some sub-markets having scarcity effects (e.g. during peak-hours)
- **Research questions:**
  - How can we capture the **volatility of the electricity price** with a numerical model that is also suitable for academic purposes (without infeasible parametrization efforts, e.g. modelling each plant separately and each day's idiosyncratic market/demand situation)
  - Can we understand **profit-oriented investment** behaviour?
- Partners (Projects also with **BFE-SFOE** and with **VSE**):
  - Chair of Quantitative Business Administration, UZH
  - Energy Economics, Uni Basel (Data harmonization)

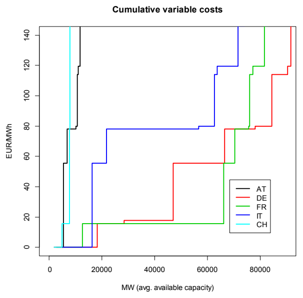
Method

- Multi-leader-follower game: Investment and subsequent production decision of several power producers
- Complements PSI's energy-system cost-optimization models
- Producers can influence prices by withholding investment or production capacity in certain load periods



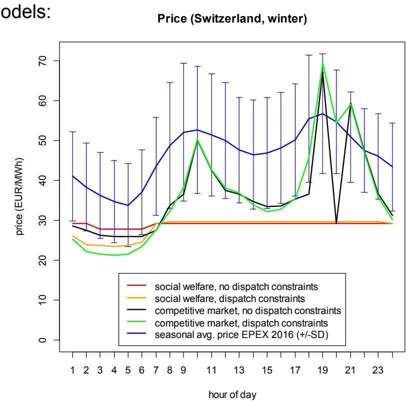
	Optimization Player 1	Optimization Player 2	Optimization Player 3...	Optimization Player N
1st level (investment decision)	Investment in supply technologies	Investment in supply technologies		Investment in supply technologies
2nd level (spot market trading)	Quantity bidding (4*24hours)	Quantity bidding (4*24hours)	Market clearing of TSO under transmission constraints (price-taker)	Quantity bidding (4*24hours)

- Bi-level Nash-Cournot Game for electricity market
- General framework model with several operation sub-modes: (i) Investment-decision and production-decision on same level (ii) Single scenario (deterministic) (iii) Social welfare maximization (price-taker, marginal cost perspective)
- Transmission constraints between players: DC (linear) flow model
- Wholesale consumers represented via demand-price elasticity on spot market. Additional in-elastic perfect-competition market (OTC)
- Hourly trading over a day in four seasons of a future representative year: (24*4 = 96 trading hours = load periods)
- **Base configuration**: **Players are countries, i.e. each player has country specific generation portfolio**
- Input: CAPEX & OPEX per technology, seasonal availability, merit-order curves (=cumulative variable costs) per country, etc.



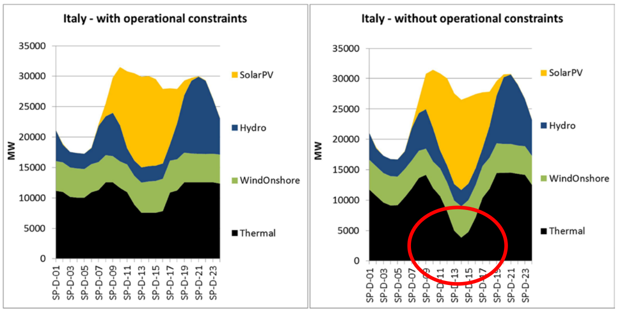
Results (Preliminary)

- Models with competitive market representation can explain price volatility better than (aggregated) social welfare maximization models:



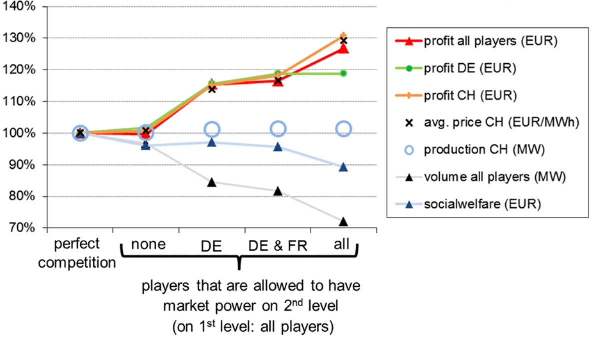
(single-level run)

- Representation of dispatch constraints on thermal generation is needed. Without such constraints, flexibility is overestimated, e.g. combined-cycle plants start freely without paying for start-up costs:



(Results from social welfare maximization, single-level run)

- Test of Bi-level game: What if the supply portfolio of the countries would acquire -in sequence- full Nash-Cournot market power:



Outlook

- Status of project: Model operational, first results are obtained
- Stochasticity, geographical expansion (EU), several investment steps

References

- Densing, M., Panos. E., Schmedders K. (2017). Stochastic bi-level electricity market modeling, *2nd Workshop of SET-Nav WP10 Modelling Forum*, ETHZ
- Densing, M., Panos, E., Schmedders, K. (2015). Decision making in electricity markets: Bi-level games and stochastic programming, ESC *Workshop*, ETHZ
https://www.psi.ch/eem/ConferencesTabelle/BilevelAndSP_MartinDensing_TALK.pdf
- Densing, M., Panos, E., Schmedders, K. (2015). Bilevel oligopolistic electricity market models: The case of Switzerland and surrounding countries**,** *OR2015,* Vienna

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Optimization of photovoltaic potential and its integration in Switzerland using genetic algorithm and optimal power flow

Jérôme Dujardin [1] , Annelen Kahl [1], Bert Kruyt [1,2], Michael Lehning [1,2]

[1] *EPFL, Lausanne, Switzerland*
[2] *WSL, SLF, Davos, Switzerland*

How to harvest solar energy effectively?

Given the natural resources? Given the transmission grid?

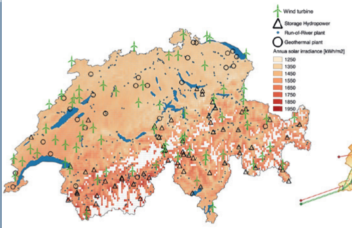


Fig.1. Annual solar irradiance and other electricity generation sources

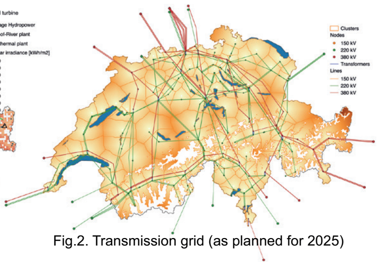


Fig.2. Transmission grid (as planned for 2025)

Hybrid deterministic / stochastic approach

1. Local photovoltaic (PV) configuration for **maximum yield**:
Differs from the classical setup (south at 39° tilt)

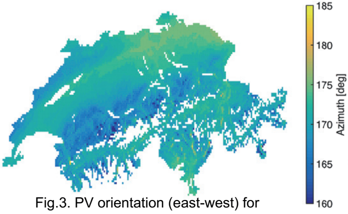


Fig.3. PV orientation (east-west) for maximum yield in each location

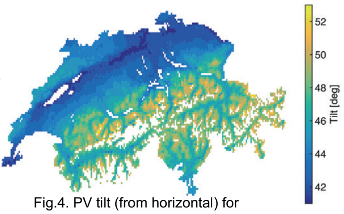


Fig.4. PV tilt (from horizontal) for maximum yield in each location

→ **Local settings** of PV panels are set, independently of the global configuration (locations within the country)

2. Local specificities of PV production:

- Annual yield
- Reduction of annual required import, due to higher winter production [1]
- Stability of annual production
- Stability of winter production

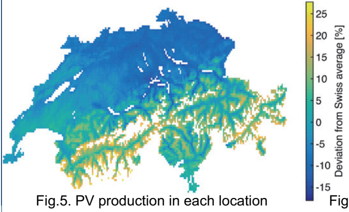


Fig.5. PV production in each location relative to the national average

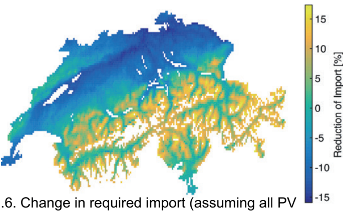


Fig.6. Change in required import (assuming all PV placed in a location) compared to the national average

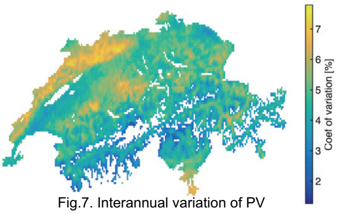


Fig.7. Interannual variation of PV production in each location

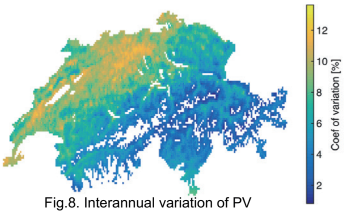


Fig.8. Interannual variation of PV winter production in each location

→ Multi-**objective function** for the genetic algorithm
→ Selection of the best locations within the clusters

3. Maximum PV coverage in each pixel based on CORINE land surface cover type.

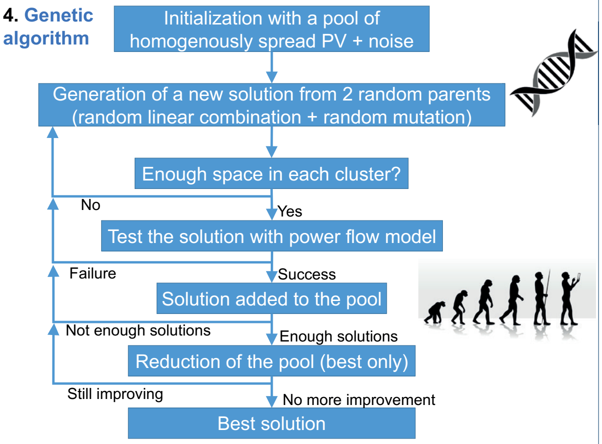
Land type	Urban	Industry	Pasture	Agriculture	Open
Max coverage	10%	10%	5%	5%	5%

Constrained to altitudes below 2500m

→ Amounts to 670 km2 (~10 times the required PV area)
→ Leaves freedom to the genetic algorithm

→ **Constraints** on the solutions found by the genetic algorithm (upper limit of PV installed in each cluster)
→ Selection of the available locations within the clusters

4. Genetic algorithm



Initialization with a pool of homogenously spread PV + noise

Generation of a new solution from 2 random parents (random linear combination + random mutation)

Enough space in each cluster?

No

Yes

Test the solution with power flow model

Failure

Success

Solution added to the pool

Not enough solutions

Enough solutions

Reduction of the pool (best only)

Still improving

No more improvement

Best solution

Results

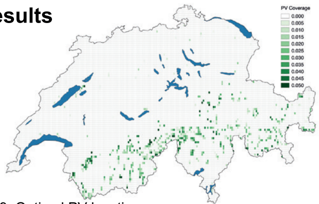


Fig.9. Optimal PV location

Optimization converges to a PV placement scenario that:

- **Increases the yield** (+18%) *
- **Reduces the interannual variations** (-37% yearly, -64% in winter) *

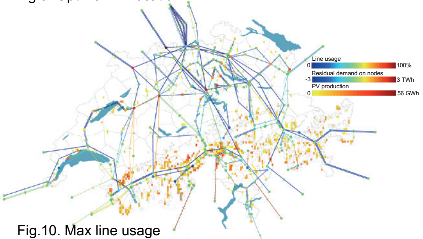


Fig.10. Max line usage

- **Never exceeds** the line capacity

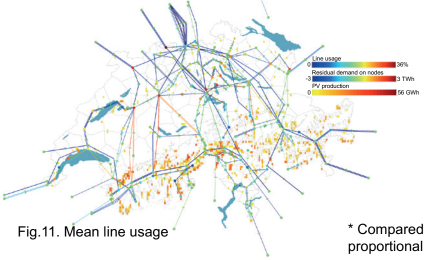


Fig.11. Mean line usage

- **Reduces the required import** (-17%) *

* Compared to a PV placement scenario proportional to population density

Perspectives

- Improvements on the definition of potential PV area by using more GIS products (access from road, complexity of the terrain).
- Increase resolution of topographic shading for better irradiance computation in **complex terrain**.
- Apply optimization strategies to **wind energy** as well.

References

[1] National energy balance model from:
J Dujardin et al. Interplay between photovoltaic, wind energy and storage hydropower in a fully renewable Switzerland. Energy, vol135, p513-525, 2017

Data

- PV production time series based on satellite-derived irradiance (MeteoSwiss)
- Wind production time series based on wind speed measurements (MeteoSwiss)
- Demand time series from Swissgrid (publicly available on their website)
- Run-of-the-river montlhy production and reservoirs' inflow from the Swiss Federal Office of Energy (SFOE) and PREVAH model (WSL)
- Storage / pumped hydropower characteristics from WASTA database (SFOE)

Acknowledgments

Stuart Bartlett, Pedro Manso, Massimiliano Zappa, Fabrizio Sossan

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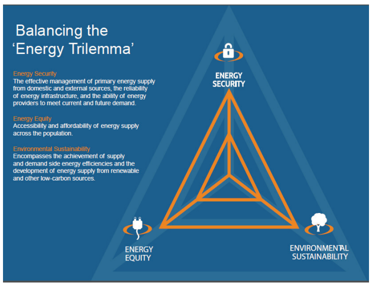
World Energy Scenarios 2016

Tom Kober, Evangelos Panos

Energy Economics Group, Paul Scherrer Institute

Objectives of the study



Balancing the 'Energy Trilemma'

Energy Security
The effective management of primary energy supply from domestic and external sources, the reliability of energy infrastructure, and the ability of energy providers to meet current and future demand.

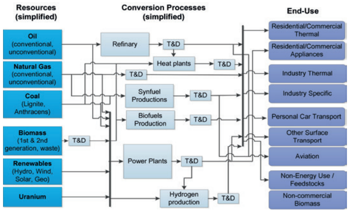
Energy Equity
Accessibility and affordability of energy supply across the population.

Environmental Sustainability
Encompasses the achievement of supply and demand side energy efficiencies and the development of energy supply from renewable and other low-carbon sources.

In partnership with the World Energy Council and Accenture, the Energy Economics Group in LEA PSI, quantified and analysed three scenarios (named **Modern Jazz, Unfinished Symphony** and **Hard Rock)** exploring alternative development pathways for the global energy system out to 2060.

The **Modern Jazz scenario** describes a market driven world oriented towards economic and affordable access to energy. The **Unfinished Symphony scenario** characterizes a more government driven world with coordinated international action to mitigate climate change. The **Hard Rock scenario** represents a rather fragmented world with low global cooperation and with priority on local energy security and exploitation of local energy resources.

The GMM global energy systems model

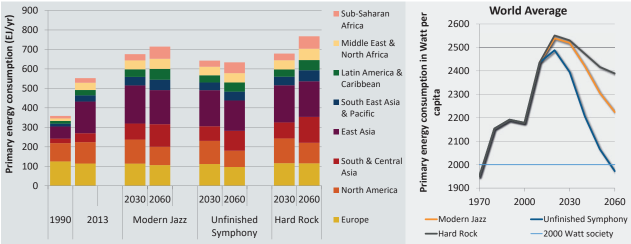


The scenario analysis was carried out by PSI using a **global MARKAL model**. This optimisation tool represents around 400 different energy technologies (e.g. power plants, heating devices, vehicles, etc.) and determines the least-cost configuration of the global **energy system for 15 world regions**, under specific boundary conditions.

Selected results for the key elements of the **Energy Trilemma** are presented below.

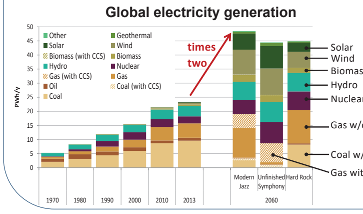
Results

Dampened world primary energy growth and a peaking in per capita energy before 2030 due to unprecedented efficiencies created by new technologies and tightening policies



Demand for electricity to double to 2060, meeting this demand with cleaner energy sources requires substantial infrastructure investments and system integration to deliver benefits to all consumers

Global electricity generation

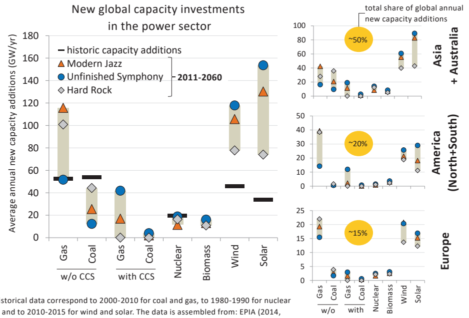


Global cumulative power generation investments (2011-2060) billion USD2010, undiscounted

	Modern Jazz	Unfinished Symphony	Hard Rock
Coal	2500	1600	4200
Oil	300	300	400
Gas	9800	8100	7600
Nuclear	2300	3500	3200
Hydropower	2800	3400	2700
Biomass	2500	3300	2300
Wind	12200	12900	8800
Solar	7700	10200	6600
Others	900	1300	60
Total	**41000**	**44600**	**36400**

Results (cont.)

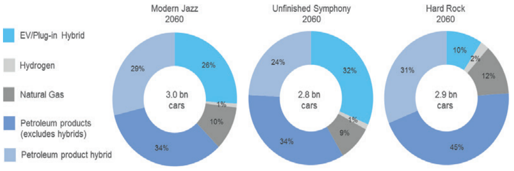
Wind and solar continue to grow at an unprecedented rate and create new opportunities and challenges for energy systems



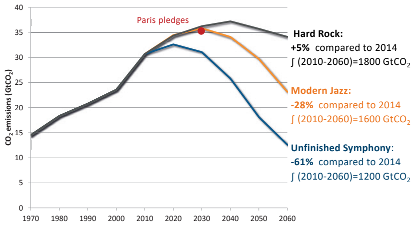
N.B.: Historical data correspond to 2000-2010 for coal and gas, to 1980-1990 for nuclear energy, and to 2010-2015 for wind and solar. The data is assembled from: EPIA (2014, 2016), GWEC (2016), IEA-PVPS (2016), IEA-CCS (2012) and Platt's (2013).

Transitioning global transport forms one of the hardest obstacles to overcome in order to decarbonise future energy systems

Global car fleet in 2060



2°C climate target will require an exceptional and enduring effort, far beyond already pledged commitments, and with high carbon prices



Performance of scenarios in view of the Energy Trilemma

Global cooperation, sustainable economic growth, and technology innovation are needed to balance the Energy Trilemma

	Modern Jazz	Unfinished Symphony	Hard Rock
Energy Security	• Higher energy production • Greater trading and diversity of international fossil energy suppliers	• Wider diversity of energy resource types • Government-promoted investment in Infrastructure	• More domestic production • Lower capacity for funding infrastructure • Lower trade
Energy Equity	• Energy Access for all by 2060	• 0 – 0.5 bn people still lack access to energy	• 0.5 –1 bn people still lack access to energy
Environmental Sustainability	• Surpass Carbon budget in early 2040s • Emissions fall 28% below 2014 volumes in 2060	• Surpass carbon budget in before 2060 • Emissions fall 61% below 2014 volumes in 2060	• Surpass carbon budget in early 2040s • Emissions are 5% above 2014 volumes in 2060

The challenge is to maintain the current integrity of energy systems worldwide while steering towards a new transformed future. This requires new policies and strategies, and consideration of novel and risky investments. The decisions taken in the next 10 years will have profound effects on the development of the energy sector. To this end, the WEC/PSI scenarios provide support to the robust development of medium to long-term strategies, government policies, investment and disinvestment decisions.

References

World Energy Scenarios 2016 – The Grand Transition

https://www.worldenergy.org/publications/2016/world-energy-scenarios-2016-the-grand-transition/

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Marginal electricity supply mixes and their integration in version 3.4 of the ecoinvent database : results and sensitivity to key parameters

Laurent Vandepaer[12], Karin Treyer[2], Chris Mutel[2], Christian Bauer[2] and Ben Amor[1]
[1]Université de Sherbrooke, Civil Engineering Department, Sherbrooke, Quebec, Canada, [2]Laboratory for Energy Systems Analysis, Paul Scherrer Institute, CH-5232 Villigen PSI, Switzerland

Introduction & objectives

- ➢ Marginal electricity supply mixes provided in previous versions of the ecoinvent database were based on historical data and limited by database features. This did not allow to capture accurately the consequences of additional demand for electricity given the complex nature of power markets.
- ➢ Objectives:
  - Provide long-term and consistent marginal electricity supply mixes based on energy scenarios to take into account future market trends and constraints.
  - Perform several sensitivity analyses to understand the influence of the key parameters and methodological choices on the mix composition and their corresponding environmental impacts.

Methodology

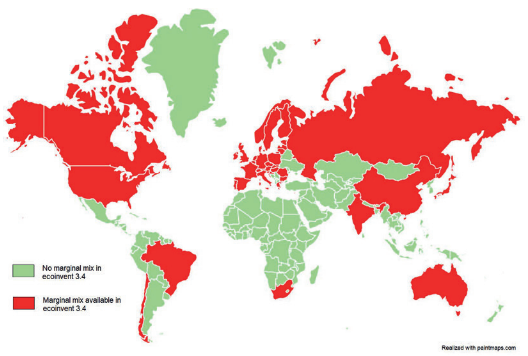
- ➢ The calculation method used to determine the marginal electricity supply mixes originates from (Schmidt et al. 2011; Muñoz 2015) :

$$Share_{i,TH} = 100 \cdot \frac{P_{i,TH} - P_{i,ref}}{\sum_i^n \left(P_{i,TH} - P_{i,ref}\right)}$$

Where:
i: electricity producing technology
TH: the year chosen as time horizon
ref: the year chosen as a reference for the time of the decision
P: the quantity of electricity generated at time "TH" or "Ref" by technology i
n: includes all unconstrained electricity producing technologies with an increased production at TH with respect to ref
Share i: the percentage that supplier i contribute to the marginal mix

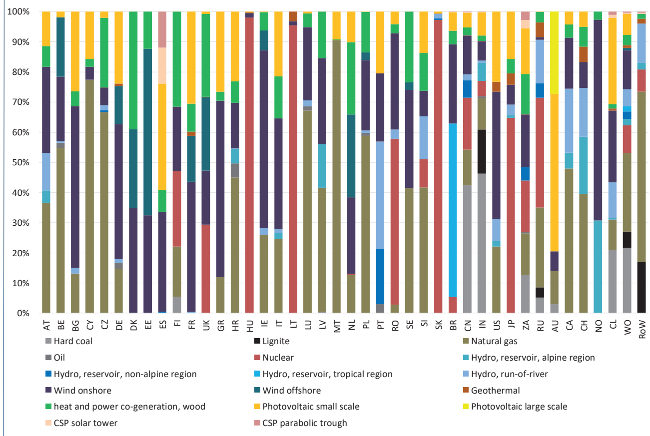
- ➢ The reference year is 2015 and time horizon is 2030.
- ➢ Public energy projections realized by national or supra-national official agencies are used as a source of data (e.g. European Commission, International Energy Agency, Energy Information Administration).
- ➢ Additional processes are created for missing activities.

Geographical coverage



- ➢ The long-term marginal electricity supply mixes of 40 countries are updated and integrated in version 3.4 of the ecoinvent database. These markets correspond to ~76.5 % of the global electricity production in 2015 (~76.9% in 2030).

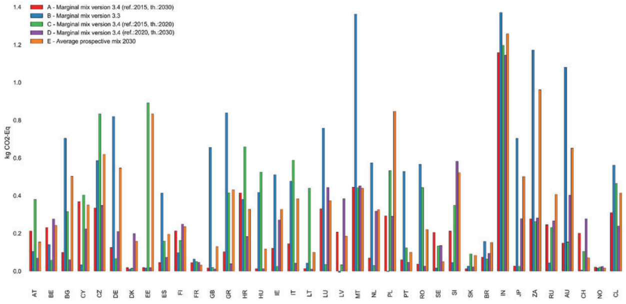
Marginal mixes composition



- ➢ The marginal mixes are composed on average by 29% fossil fuel power , 14% nuclear and 58% renewables

Meta-sensitivity analyses

- ➢ Different approaches to define the marginal mixes are tested : original v 3.3 approach, time horizon = 2020, reference year = 2020, average mix 2030.
- ➢ This compares the global warming potential (IPCC 2013, GWP 100a) of every activity of ecoinvent v.3.3 updated with v.3.4 marginal mixes to versions of ecoinvent v3.3 generated with the different approaches.



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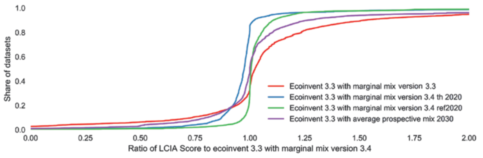

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Schmidt JH, Thrane M, Merciai S, Dalgaard R (2011) Inventory of country specific electricity in LCA - consequential and attributional scenarios. Aalborg