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Interdisciplinary assessment of renewable, nuclear and fossil power generation with and without carbon capture and storage in view of the new Swiss energy policy

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ABSTRACT

Swiss electricity generation is based on hydro and nuclear power, but current energy policy includes the nuclear phase-out by about 2035. This may lead to higher CO_2 emissions of the Swiss power supply due to domestic fossil power generation or electricity imports. For compliance with the Swiss CO_2 law, low carbon technologies such as renewable energies and Carbon Capture and Storage (CCS) gain importance. In order to support rational decision-making in this context, we compare various domestic and foreign renewable and non-renewable power supply options for Switzerland in 2035 based on environmental, economic, social and security of supply related indicators using multi-criteria decision analysis (MCDA). Our evaluation puts a focus on CCS technologies and uses (a) a novel approach that allows calculating the distribution of the MCDA results of all possible unique weighting profiles, and (b) two specific weighting profiles. The results show that domestic potentials for hydro and biogas power should be primarily exploited. Among the fossil and import options, natural gas plants with or without CCS and solar-thermal electricity imports are viable. Plants with CCS face a key trade-off: they may trigger social conflicts which must be weighed against the desired CO_2 emission reductions.

1. Introduction

1.1. Setting the scene

Swiss power generation is about 54% hydro and 41% nuclear power (SFOE, 2012a). Based on the 2011 decision of the Swiss Federal Council, Switzerland will gradually phase-out domestic nuclear power generation up to 2035 (SFOE, 2011).[1] Assuming a constant electricity demand, about 40% of the supply will have to be replaced by either additional domestic power generation or electricity imports in 2035[2]

At the same time, Switzerland has issued a law on carbon dioxide (CO_2) emissions with the goal of reducing domestic greenhouse gas (GHG) emissions 20% from the 1990 level by 2020 in order to contribute to the international efforts of limiting the global temperature rise to 2 °C above the pre-industrial level[3] (FOEN, 2016). With the nuclear phase-out, the CO_2-burden of the electricity supply mix is likely to increase, based on imported power and/or by domestic natural gas-fuelled plants (Kannan and Turton, 2012; SFOE, 2012b). Thus, low-carbon renewable energies and Carbon Capture and Storage (CCS) technologies are expected to gain importance in the coming decades to comply with the abovementioned CO_2 law. CCS is perceived as an important option for CO_2 emission reduction on a global level and at large scale (OECD/IEA, 2012). CCS technology allows capturing CO_2 emissions from point sources such as fossil power plants and industrial facilities and can be sub-divided into three steps: capture, transport and storage. For further information on CCS technologies, we refer to (IPCC, 2005).

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[1] There may be a referendum on the new Swiss energy policy and on the nuclear phase-out in particular.

[2] This assumes 50 years lifetime of the reactors. The safety-related life time is subject to continuous evaluation by the authorities and thus may be shorter or longer than 50 years. The economic lifetime is decided by the utilities operating the nuclear plants.

[3] By 2013, domestic GHG emissions have only been reduced by less than 2% compared to 1990 (FOEN, 2016).

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1.2. New Swiss energy strategy

The Swiss Federal Council is currently developing the new Swiss energy strategy covering the future decades until 2050 in light of the abovementioned nuclear phase-out and CO_2 law. In addition to these two boundary conditions, the main (and partially conflicting) goals of the new Swiss energy strategy are (Swiss Federal Council, 2013):

- increase energy efficiency,
- increase the share of renewable energies/decrease the use of non-renewable fuels,
- increase security of supply, and
- ensure an affordable electricity supply.

In order to define a sensible and sustainable energy strategy for Switzerland, the different parts of the energy sector, i.e. heat supply, mobility and electricity generation, must be thoroughly evaluated in view of the abovementioned goals. The strengths and weaknesses of power generation technologies must be assessed in detail.

1.3. Objectives and approach

The overall objective of this study is an interdisciplinary evaluation of the potential renewable and non-renewable power supply options for Switzerland in 2035 taking into account economic, environmental, social, and security of supply related aspects. We focus on the evaluation of a variety of CCS power plants based on the latest findings on their performance, analyse their benefits and drawbacks under the Swiss boundary conditions and seek the criterion preferences under which they perform well compared to the other power generation options. The assessment is carried out based on the functional unit of 1 kWh of electricity generated, and takes into account complete fuel and infrastructure supply chains for all the power plants addressed (i.e., applies the approach used in Life Cycle Assessment (LCA) in a consistent way).

Multi-Criteria Decision Analysis (MCDA) was chosen in order to reach the objectives in a structured, transparent and comprehensive way. This method allows for an integrated evaluation of technology performance based on both qualitative and quantitative indicators resulting in a ranking of alternative options. Thus, MCDA is a powerful tool to synthesize results covering a range of sustainability and energy security aspects. The methodology is explained in more detail in Section 2.

1.4. Literature review and progress by this analysis

MCDA is commonly used for interdisciplinary assessments of electricity generation (Table 1). However, considering the objectives of our evaluation, this previous work faces limitations as indicated by the characteristics in Table 1: only two of the studies explicitly addressed Switzerland, which is necessary for providing policy recommendations based on the location-specific performance of e.g. PV and wind power; several of the studies only considered a very small set of generation technologies and none of

Table 1
Overview of recent MCDA studies of power generation technologies.

	Region	Technologies	Indicators	MCDA algorithm[6]	Complete fuel chain included	Time frame	Weighting profiles[7]	Other comments
(Cartelle Barros et al., 2015)	generic	10	16	AHP	yes	n/a	6 artificial profiles	–
(Ahmad and Tahar, 2014)	Malaysia	4	12	AHP	yes	n/a	1 artificial profile	–
(Troldborg et al., 2014)	Scotland	11	9	PROMETHEE	yes	n/a	1 artificial profile	comparison of renewable energy technologies
(Maxim, 2014)	generic	14	10	WSA	no	n/a	stakeholder survey for profiles; 62 participants	–
(Scannapieco et al., 2014)	generic	7	23	AHP	yes	n/a	8 artificial profiles	–
(Stein, 2013)	USA	9	11	AHP	no	n/a	5 artificial profiles	–
(Streimikiene et al., 2012)	EU	33	13	MULTIMOORA TOPSIS	yes	n/a	4 artificial profiles	comparison of the two MCDA algorithms
(Suo et al., 2012)	generic	7	8	AOWA	no	n/a	3 artificial profiles	comparison to EOWA
(Chatzimouratidis and Pilavachi, 2012)	generic	10	12	PROMETHEE II	yes	n/a	13 artificial profiles	comparison to AHP method
(Eckle et al., 2011)	EU, world	5	13	WSA	no	2050	6 artificial profiles	comparison of scenarios, not technologies
(Cavallaro, 2010)	USA	7	10	Fuzzy TOPSIS	no	n/a	5 artificial profiles	–
(Roth et al., 2009)	Switzerland (Europe)	18	75	WSA	yes	current/2030	stakeholder survey for profiles; 85 participants	–
(Schenler et al., 2009)	Europe (France, Germany, Italy, Switzerland)	26	36	DA	yes	2025/2050	stakeholder surveys for criteria definition and profiles; >400 participants	comparison to WSA method

[6] AHP = Analytic hierarchy process, WSA = Weighted sum approach, MULTIMOORA = Multi-Objective Optimization by Ratio analysis plus Full Multiplicative Form, TOPSIS = Technique for Order Preference by Similarity to Ideal Solution, AOWA = Advanced Ordered Weighted Averaging, EOWA = Extended Ordered Weighted Averaging, PROMETHEE = Preference Ranking Organization Method for Enrichment Evaluations, DA = Dominating Alternative.

[7] In this context, *artificial* describes weighting profiles that are invented and assigned to a certain stakeholder group as opposed to real profiles that are derived from stakeholders directly.