Stadt Zürich
Amt für Hochbauten

04 | 2013

Life Cycle Assessment of Electricity Mixes according to the Energy Strategy 2050

Schlussbericht

Fachstelle Nachhaltiges Bauen

IMPRESSUM

Auftraggeberin:
Stadt Zürich,
Amt für Hochbauten,
Fachstelle Nachhaltiges Bauen
Amtshaus III, Lindenhofstrasse 21
8021 Zürich

Bearbeitung:
Franziska Wyss, Rolf Frischknecht (treeze Ltd. Uster)
wyss@treeze.ch

Projektleitung:
Dr. Heinrich Gugerli
Fachstelle Nachhaltiges Bauen,
Amt für Hochbauten

Projektteam:
Franziska Wyss, Rolf Frischknecht (treeze Ltd., Uster)
Dr. Heinrich Gugerli (Stadt Zürich, AHB)

Zürich, April 2013

Abbreviations and Glossary

a	annum (year)
CCS	Carbon Capture and Storage
CED	Cumulative Energy Demand
CH	Switzerland
CO_2	Carbon dioxide
GLO	Global average
GWP	Global warming potential
J	Joule
KBOB	Swiss Federal Office for Construction and Logistics (Koordination der Bau- und Liegenschaftsorgane des Bundes)
LCA	life cycle assessment
LCI	life cycle inventory analysis
LCIA	life cycle impact assessment
NEP	scenario 'new energy policies'
POM	scenario 'political measures'
RER	Europe
SIA	Swiss society of engineers and architects
TWh	Terawatt hour
UBP	eco-points (German: Umweltbelastungspunkte)
WWB	Scenario ‚business as usual'

Zusammenfassung

Im Jahr 2011 wurde in der Schweiz der Atomausstieg beschlossen. Im Rahmen einer nachhaltigen und „grünen" Zukunftsgestaltung wurden verschiedene Möglichkeiten einer zukünftigen Energie- und Stromversorgung diskutiert. In diesem Zusammenhang entwickelte der Bundesrat die Energiestrategie 2050, in welcher drei unterschiedliche Szenarien für mögliche zukünftige Energie-Situationen aufgezeigt werden. Die Szenarien sind ‚Weiter wie bisher' (WWB), ‚Neue Energiepolitik' (NEP) und ‚Politische Massnahmen' (POM). Die Szenarien unterscheiden sich in den politischen Rahmenbedinungen, der Entwicklung der Stromnachfrage, den Produktionsvolumina und den Technologien, welche für die Stromgewinnung eingesetzt werden.

Dieser Bericht untersucht die Umweltauswirkungen von drei schweizer Strommixen im Jahr 2050, gemäss den Szenarien der Energiestrategie 2050. Die funktionelle Einheit ist 1 MJ Strom (Niederspannung), welcher an schweizer Kunden geliefert wird. Zur Abschätzung der Umweltauswirkungen werden die Indikatoren ‚Treibhauspotential' (GWP), ‚kumulierter Energieaufwand' (CED) und die Gesamtumweltbelastung anhand der Methode der ökologischen Knappheit 2006 (MoeK) herangezogen.

Die Stromproduktion wurde mit heutigen Technologien modelliert. Die Anteile pro Technologie entsprechen denjenigen der Energiestrategie und des Jahres 2050. Einerseits wurde die inländische Stromproduktion untersucht, andererseits wurde auch der Stromhandel, wie er heute stattfindet, mitberücksichtigt. Die gehandelten Volumina basieren auf den heute gehandelten Strommengen. Die Modellierung des Stromhandels basiert auf Informationen über den Europäischen Strommix im Jahr 2050. Für die drei Szenarien WWB, NEP und POM wurden passende europäische Strommixe gewählt. In den Szenarien NEP und POM wurde davon ausgegangen, dass europäische Steinkohle- und Erdgaskraftwerke mit CO_2-Abscheidung und Speicherung (CCS) ausgerüstet sind.

Tab. Z. 1 zeigt eine Übersicht über alle drei Szenarien und die untersuchten Umweltindikatoren für die Strommixe im Jahr 2050. Zudem ist ein Vergleich mit den Umweltauswirkungen der heutigen schweizerischen und europäischen Strommixe aufgeführt. Fig. Z. 1 bis Fig. Z. 3 zeigen einen graphischen Vergleich der Umweltauswirkungen der Strommixe.

Der Strommix des Szenarios NEP weist die tiefsten Umweltauswirkungen bezüglich kumuliertem Energieaufwand und Gesamtumweltbelastungen auf. Verglichen damit hat der Strommix des Szenarios POM ein leicht tieferes Treibhauspotential. NEP verfolgt eine strikte Energiepolitik zur Förderung von erneuerbaren Energieträgern. Aufgrund dessen weist NEP den höchsten Anteil an erneuerbaren Energiequellen auf. Der Anteil an fossilen Energieträgern ist deutlich tiefer als im Strommix des WWB Szenarios aber höher als im Strommix des Szenario POM. Im Szenario POM werden rund 9 % der Stromnachfrage durch Importe abgedeckt. Das Treibhauspotential des Strommix des POM-Szenarios ist wegen der Verwendung von CCS-Technologien und Atomkraft im Importstrom und wegen des geringeren fossilen Anteils geringer als bei NEP. Da im

NEP Szenario kein Strom aus dem Ausland importiert wird, hat der Strommix keinen Anteil an Strom aus europäischer Atomkraft oder Kohlekraft.

Tab. Z. 1 Zusammenfassung der Umweltauswirkungen der Strommixe gemäss den Szenarien der Energiestrategie 2050, mit und ohne Strommhandel, Bezugsgrösse: 1 MJ Strom Niederspannung

Strommix	Primärenergie, total MJ Öl-eq/MJ	Primärenergie, nicht-erneuerbar (fossil und nuklear) MJ Öl-eq/MJ	Primärenergie nicht-erneuerbar - fossil MJ Öl-eq/MJ	Primärenergie nicht-erneuerbar - nuklear MJ Öl-eq/MJ	Primärenergie erneuerbar MJ Öl-eq/MJ	Primärenergie Abfall/Abwärme MJ Öl-eq/MJ	Kohlendioxid, fossil g CO_2-eq/MJ	Treibhauspotential g CO_2-eq/MJ	Gesamtumweltbelastung eco-pt/MJ
WWB, Variante C	1.67	0.96	0.94	0.02	0.72	0.00	54.2	59.2	39.5
NEP, Variante C+E	1.38	0.28	0.26	0.02	1.09	0.00	17.0	21.2	26.6
POM, Variante E	1.40	0.29	0.23	0.06	1.11	0.00	12.8	16.9	26.8
WWB inkl. Handel, Variante C	2.20	1.61	1.28	0.32	0.59	0.00	86.9	93.7	76.9
NEP inkl. Handel, Variante C+E	1.58	0.41	0.39	0.02	1.18	0.00	23.4	27.5	32.7
POM, inkl. Handel, Variante E	1.92	1.06	0.69	0.38	0.86	0.00	16.8	21.8	45.1
CH-Produktionsmix[1]	2.41	1.76	0.10 [2]	1.65 [2]	0.65 [2]	-	0.007 [2]	8.3	75.7
CH-Liefermix[1]	3.05	2.63	0.51 [2]	2.13 [2]	0.42 [2]	0.02 [2]	0.038 [2]	41.3	125
UCTE-Mix[1]	3.54	3.32	2.01 [2]	1.32 [2]	0.22 [2]	-	0.156 [2]	165.0	177

1 Daten aus der KBOB Empfehlung 2009/1, Stand Juli 2012 (KBOB et al. 2012)

2 Daten aus Frischknecht et al. (2011)

Im Szenario WWB wird die Nutzung von erneuerbaren Energieträgern nicht gross geschrieben. Die Stromgewinnung aus fossilen Energieträgern beeinflusst die Umweltindikatoren GWP und CED stark. Somit sind die Umweltbelastungen (alle Indikatoren) von Strom im WWB Szenario am höchsten.

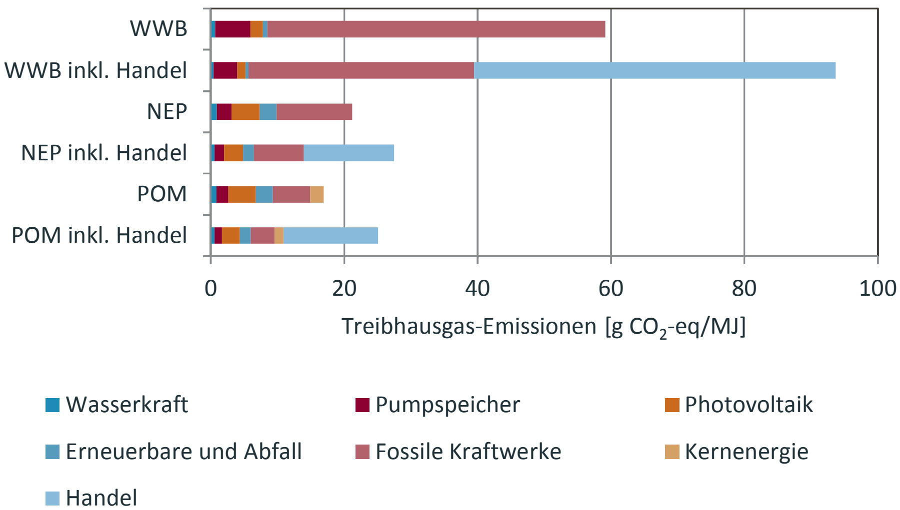

Fig. Z. 1 Treibhausgas-Emissionen der Strommixe im Jahr 2050, mit und ohne Stromhandel

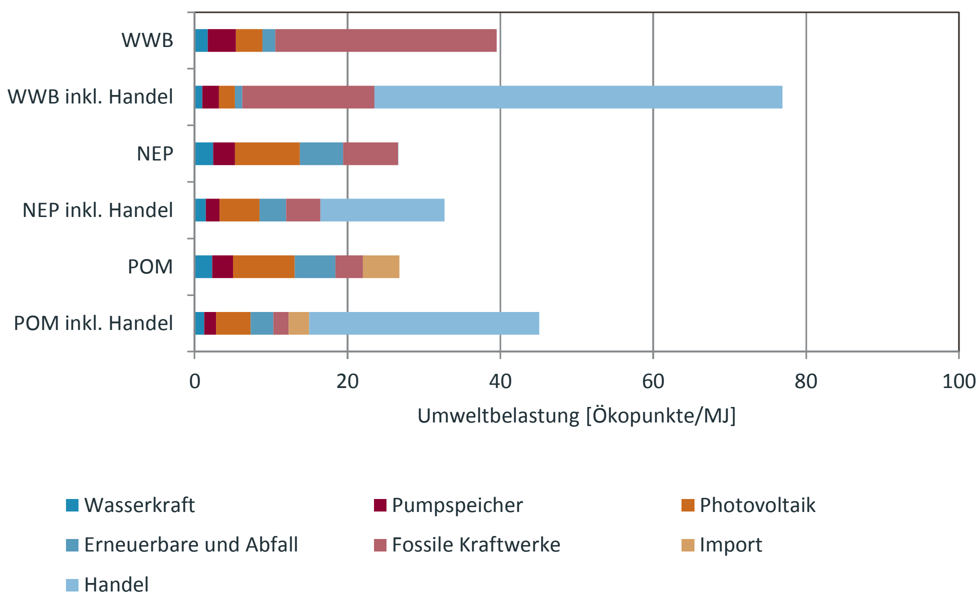

Fig. Z. 2 Gesamtumweltbelastung (gemäss der Methode der ökologischen Knappheit 2006) der Strommixe im Jahr 2050, mit und ohne Stromhandel

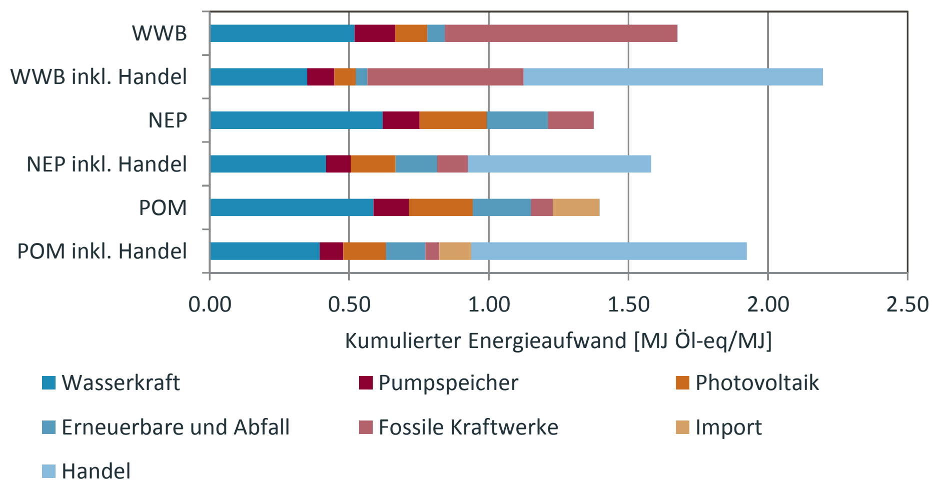

Fig. Z. 3 Kumulierter Energieaufwand der Strommixe im Jahr 2050, mit und ohne Stromhandel

Die Umweltauswirkungen der untersuchten, potentiellen Strommixe im Jahr 2050 sind deutlich tiefer als diejenigen des Strommix im Jahr 2012 (Produktions- als auch Liefermix). Einzige Ausnahme bilden die Treibhausgas-Emissionen des heutigen Produktionsmixes. Der heutige Produktionsmix der Schweiz verursacht tiefere Treibhausgas-Emissionen als alle drei untersuchten zukünftigen Strommixe, da ein Grossteil der heutigen Stromgewinnung in der Schweiz auf Wasserkraft und Atomkraft beruht. Gleichzeitig ist der Atomstrom der Hauptgrund für die hohen Werte bei den Gesamtumweltbelastungen. Der Strommix des UCTE-Netzverbundes verursacht die höchsten Treibhausgas-Emissionen und auch die höchste Gesamtumweltbelastung. Verglichen mit dem heutigen Strommix ist er Anteil der nicht-erneuerbaren Energieträger im Jahr 2050 um 45 bis 84 % gesunken (abhängig vom jeweiligen Szenario).

Die Szenarien der Energiestrategie 2050 sind reine Versorgungsszenarien. Wird in den drei Szenarien eine Stromhandelstätigkeit im heutigen Umfang unterstellt, so steigt die Umweltbelastung der Strommixe in allen untersuchten Szenarien. Insbesondere wird das deutlich beim Strommix des Szenario WWB, da dieser einen hohen Anteil an fossilen Energieträgern ohne CCS-Technologien aufweist. Der Strommix inklusive Stromhandel des Szenario POM weist die tieferen Treibhausgas-Emissionen auf als der NEP Strommix inklusive Stromhandel. Dies rührt daher, dass POM neben dem Stromhandel über einen nicht unwesentlichen Anteil an Importstrom verfügt, welcher auf Grund von erneuerbaren Energieträgern und fossilen Kraftwerken mit CCS-Technologien tiefe CO_2-Belastungen haben.

Summary

In 2011 the exit from nuclear power was declared. In regard for a sustainable and 'green' future, Switzerland outlined different options for prospective energy strategies and securitiy of energy supply. In this context the Swiss Federation elaborated the Energy Strategy 2050, in which three different scenarios for possible future energy situations were designed. The scenarios are 'business as usual' (WWB), 'new energy policies' (NEP) and 'political measures' (POM). The scenarios differ in energy policies, electricity demand, production volumes and the technological mix for achieving security of energy supply.

This study analyzes environmental impacts of three electricity mixes in 2050, according to the scenarios. The analysis is conducted for the year 2050 and for Switzerland. The functional unit of this study is 1 MJ of electricity consumed in Switzerland (low voltage). The environmental impact categories 'global warming potential' (GWP), 'cumulative energy demand' (CED) and ecological scarcity 2006 were assessed.

The electricity production was modelled with present technologies. However the shares per production technology comply with the year 2050 (in accordance with the scenarios from the Energy Strategy 2050). Two data-sets are generated: one regards only domestic production and one includes electricity trade according to present trade volumes. Electricity import and trade is modeled based on scenario information about the European electricity mix in 2050. For the three scenarios WWB, NEP and POM dedicated and consistent European mixes were chosen. Within the scenarios NEP and POM, European coal and natural gas fired power plants are equipped with carbon capture and storage (CCS). Tab. Z. 2 shows a comparison of all three scenarios and the indicators analyzed for the electricity mixes in 2050 as well as the environmental impacts of the present electricity mix in Switzerland and Europe. Fig. Z. 4 to Fig. Z. 6 compare the environmental impacts of the electricity mixes with and without trade graphically.

Tab. Z. 2 Summary of the cumulative results of electricity mixes according to the scenarios in the Energy Strategy 2050, per MJ electricity, low voltage

Electricity mix	Primary energy total MJ oil-eq/MJ	Primary energy non-renewable (fossil and nuclear) MJ oil-eq/MJ	Primary energy non-renewable - fossil MJ oil-eq/MJ	Primary energy non-renewable - nuclear MJ oil-eq/MJ	Primary energy renewable MJ oil-eq/MJ	Primary energy waste/ wasteheat MJ oil-eq/MJ	Carbon dioxide fossil g CO_2-eq/MJ	Global warming potential g CO_2-eq/MJ	Ecological scarcity eco-pt/ MJ
WWB, option C	1.67	0.96	0.94	0.02	0.72	0.00	54.2	59.2	39.5
NEP, option C+E	1.38	0.28	0.26	0.02	1.09	0.00	17.0	21.2	26.6
POM, option E	1.40	0.29	0.23	0.06	1.11	0.00	12.8	16.9	26.8
WWB incl. trade, option C	2.20	1.61	1.28	0.32	0.59	0.00	86.9	93.7	76.9
NEP incl. trade, option C+E	1.58	0.41	0.39	0.02	1.18	0.00	23.4	27.5	32.7
POM, incl. trade, option E	1.92	1.06	0.69	0.38	0.86	0.00	16.8	21.8	45.1
CH-Production mix[1]	2.41	1.76	0.10 [2]	1.65 [2]	0.65 [2]	-	0.007 [2]	8.3	75.7
CH-Supply mix[1]	3.05	2.63	0.51 [2]	2.13 [2]	0.42 [2]	0.02 [2]	0.038 [2]	41.3	125
UCTE-Mix[1]	3.54	3.32	2.01 [2]	1.32 [2]	0.22 [2]	-	0.156 [2]	165.0	177

[1] data from the KBOB recommendation 2009/1, July 2012 (KBOB et al. 2012)

[2] data from Frischknecht & Itten (2011)

The electricity mix of the scenario NEP has the lowest environmental impacts regarding CED and ecological scarcity. Within the NEP scenario a strict policy for renewable energy is proclaimed. Hence the electricity mix of the NEP scenario has the highest share of renewable energy sources and only little fossil fuels. As there is no import, there is no electricity from european nuclear or coal power. The electricity mix of the POM scenario has a slightly lower share of renewable energy sources compared with the electricity mix of the NEP scenario. It contains hardly any fossil fuel based electricity. Furthermore about 9 % of the electricity is imported. European fossil fuel based power plants are equipped with CCS-technologies. In consequence the electricity mix of the scenario POM causes slightly lower greenhouse gas emissions compared to the electricity mix of the NEP scenario.

The use of fossil fuels has a large impact on the indicators GWP and CED. Hence the electricity mix of the scenario WWB, which has no particular emphasis on renewable electricity, causes higher environmental impacts (all indicators) than the electricity mix of the NEP or POM scenarios.

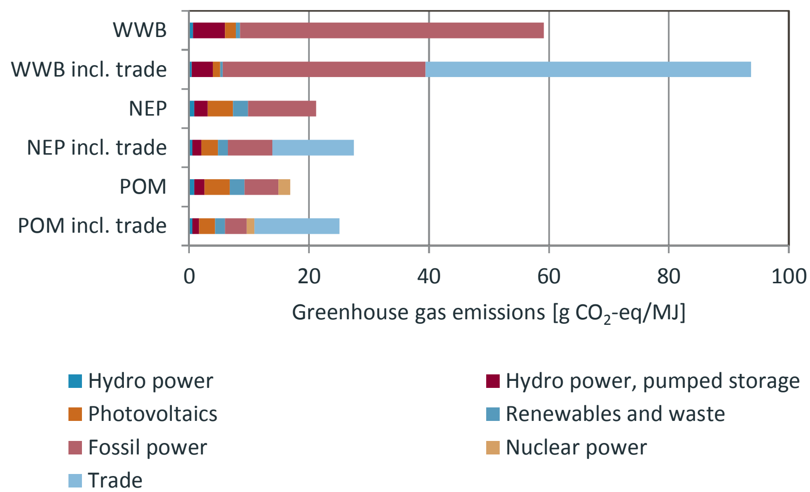

Fig. Z. 4 Greenhouse gas emissions of the electricity mixes, with and without trade

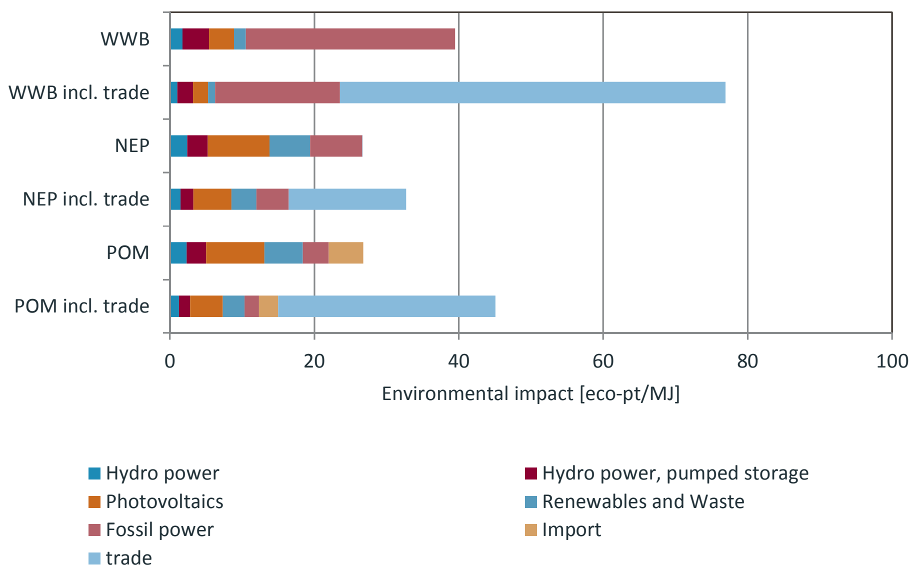

Fig. Z. 5 Environmental impacts of of the electricity mixes, with and without trade, ecological scarcity method 2006

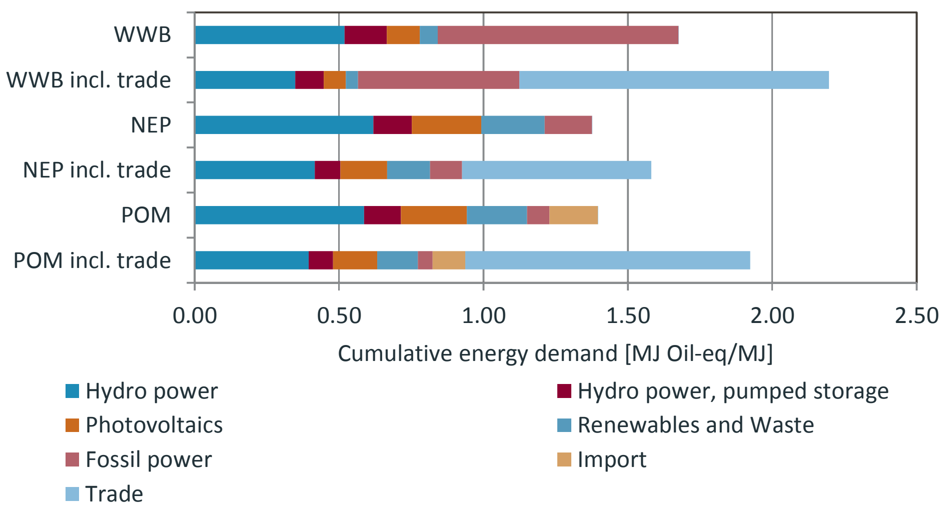

Fig. Z. 6 Cumulative energy demand of the electricity mixes, with and without trade

The environmental impacts of the aspired electricity mixes in the year 2050 are clearly lower than those in Switzerland in 2009 (production mix as well as supply mix). However the current production mix causes lower greenhouse gas emissions than any of the three future electricity mixes, due to todays share of domestic electricity production from hydroelectric and nuclear power. At the same time, nuclear power is the main reason for the high environmental impacts of the current electricity mixes. The UCTE electricity mix causes the highest amount of greenhouse gas emissions and the largest environmental impacts. The share of non renewable energy sources in the year 2050 decreases about 45 to 84 % (depending on the scenario) compared to the present Swiss production mix.

The environmental impacts with electricity trade are larger than without trade. This is especially true for the electricity mix of the scenario WWB, which has a large share of fossil fueled electricity produces without CCS-technologies. When comparing the electricity mixes of the scenarios NEP and POM (including trade) it is noticeable, that POM electricity has the lower global warming potential than NEP electricity. This results from the lower share of fossil fueled domestic electricity production and the high share of imported electricity, which includes fossil fueled electricity produced with CCS-technologies. These come with low CO_2-emissions.

Content

1 Introduction

1.1 Background

On May 25 in 2011 the Federal Council of Switzerland declared the gradual exit from nuclear power generation. In this context the Energy Strategy 2050 was elaborated. It outlines possible ways of energy supply and shows the impacts of different energy systems regarding economy, environment, society and security of energy supply.

The Energy Strategy 2050 implies three scenarios for the development of energy production and consumption. The scenarios 'business as usual' (Weiter wie bisher, WWB), 'new energy policies' (Neue Energiepolitik, NEP) and 'political measures' (Politische Massnahmen, POM) differ in socio-economic, political and technical parameters (for details about the scenarios see Prognos (2012)). Within each scenario two to three variations of the technolog mix used for electricity production are elaborated (option C, option E and option C+E).

1.2 Goal and Scope

This study aims for modeling the environmental impacts of possible future electricity mixes based on the scenarios of the Swiss Energy Strategy 2050 (Prognos 2012). The analysis is conducted for the year 2050 and for Switzerland. Three electricity mixes are analyzed: one option per each scenario. For 'business as usual' the energy production option C is analyzed, for 'new energy policies' option C+E and for 'political measures' option E are modeled. In the year 2050 nuclear power plants are replaced by renewable energies and – depending on the scenario – fossil fuels or imports.

The three electricity mixes are modeled in two ways. Firstly, they are modeled according to the information given in Prognos (2012). Secondly, it is assumed that traded electricity has the same share like today. The traded (imported) electricity is represented by future European electricity mixes.

The functional unit of this study is 1 MJ of electricity consumed in Switzerland (low voltage). A commercial LCA software (Simapro 7.3.3) is used to model the product system, to calculate the life cycle inventory and impact assessment results and to document the data (PRé Consultants 2012). Background data are represented by ecoinvent data v2.2 (ecoinvent Centre 2010) including updates regarding photovoltaics, hydroelectric power plants, and transmission and distribution.

Present technologies and their environmental impacts are used in the LCA models. Possible future technological improvements are disregarded. The life cycle inventories are established in line with the quality guidelines of ecoinvent data v2.2. Measures on the consumer side, such as storage, are not taken into account.

The study is conducted for the Office for Building Construction of the City of Zurich (Amt für Hochbauten). The results of this study are used as basic information for assessing different future energy policies regarding their environmental performance.

1.3 Impact Assessment Methods

The following set of indicators is used in this study:

1. Cumulative energy demand (CED), renewable and non renewable (MJ oil-eq)
2. Global Warming Potential 2007 (kg CO_2-eq)
3. Ecological Scarcity 2006 (UBP)

These indicators are used within the KBOB list (KBOB et al. 2012), as well as in various codes of practice of SIA (SIA 2009, 2011a, b).

For a more detailed description of the impact assessment methods see in the Appendix.

2 Life Cycle Inventories

2.1 Description of the Supply Chain

The inventory of the electricity production in each scenario includes the production itself, the infrastructure of the power plants and the distribution net as well as waste streams. Losses in electricity transformation and transmission as well as emissions are accounted for. We point out, that in this study only present technologies and their environmental impacts are analyzed. Technical improvement or new technologies are not taken into account except for carbon capture and storage in European hard coal and natural gas power plants as modelled in the NEEDS scenarios NEP and POM.

2.2 Electricity production

2.2.1 Overview

Electricity in the year 2050 has either renewable or fossil (non-renewable) origin. There are no more nuclear power stations. Renewable energy sources are of solar, wind, wood, biogas and geothermal origin as well as hydro power. Additionally, waste is burnt in incineration plants. Fossil sources of domestic production are fuel oil and natural gas. Imported power contains furthermore nuclear and hard coal energy sources. Tab. 2.1 shows the specifications of the power plants and the different origins.

Tab. 2.1 Power production technologies subdivided by its energy source

Renewables	Non-renewables
Hydropower	Nuclear power
Run-of-river power plants	Pressure water reactors (PWR)
Reservoir power plants	Boiling water reactors (BWR)
Small hydropower plants	Fossil fuels
Pumped Storage	Fuel oil
Other renewables	Natural gas
Solar	Hard Coal (for imports)
Wind	Waste
Wood	Waste
Agricultural Biogas	
Biogas	
Geothermal	

The future energy mix is modelled by using present energy production technologies. The production shares within one power plant technology given by the Energy Strategy 2050 (Prognos 2012) are further split to production plant types according to present shares. This is done for biogas and natural gas power plant technologies.

The production levels in 2050 for each scenario and each option are defined by the Energy Strategy 2050 (Prognos 2012) and amount to 82.33 TWh for WWB, 74.37 TWh for NEP resp. 79.02 TWh for the POM-scenario (net Swiss mix). These are net production volumes (own consumption of the power plants subtracted). Besides the data given, the calculations are based on the updated electricity mix in Switzerland (see Itten et al. 2012) and ecoinvent data v2.2 (ecoinvent Centre 2010).

2.2.2 Renewable energy sources

Regarding hydro power four different production plant types are differentiated: run-of-river power plant, reservoir power plants, small hydro power plants and pumped storage power. The electricity consumption of pumped storage is considerably high (efficiency 80 %), hence the pumped storage plants are modelled with the corresponding electricity mix 2050. The share of pumped storage power plants is calculated from the electricity demand of the pumps given by the Energy Strategy 2050 (Prognos 2012). The shares between the other three hydroelectric power plant types are calculated according to the present situation described in Itten et al. (2012). The following table shows the shares of hydro power per scenario.

Tab. 2.2 Shares of domestic hydro power per each scenario WWB, NEP and POM

Hydro power technology	WWB, option C	NEP, option C+E	POM, option E
Total, hydro power	50.5 %	59.4 %	55.9 %
Run-of-river power plant	14.6 %	18.2 %	17.1 %
Reservoir power plant	23.4 %	26.8 %	25.2 %
Small hydro power plant	5.2 %	6.3 %	5.9 %
Pumped storage	7.3 %	8.1 %	7.6 %

Electricity from biogas is split into biogas from industrial source and from agricultural source according to the present situation (Itten et al. 2012). The shares of electricity production from new renewable energy sources are shown in Tab. 2.3. Because of lack of data it is assumed that domestic geothermal energy production equals european wind power production and is modeled accordingly.

Tab. 2.3 Shares of the domestic new renewable power per each scenario WWB, NEP and POM

Technology	WWB, option C	NEP, option C+E	POM, option E
Total, new renewable sources (except hydro power)	10.9 %	30.4 %	28.6 %
Solar power	7.2 %	15.0 %	14.1 %
Wind power	1.7 %	5.7 %	5.4 %
Wood power	0.8 %	1.7 %	1.6 %
Biogas (agricultural source)	0.4 %	1.2 %	1.1 %
Biogas (industrial source)	0.3 %	1.0 %	0.9 %
Geothermal power	0.5 %	5.9 %	5.6 %

2.2.3 Fossil energy sources

The non-renewable energy sources are fossil fuels. There are no nuclear power plants within the scenarios in 2050 in Switzerland. The only nuclear power comes from import. Tab. 2.4 shows the shares of fossil fuels. Natural gas is modelled in combined heat and power plants and gas combined cycle plants.

Tab. 2.4 Shares of domestic non-renewable power per each scenario WWB, NEP and POM

Technology	WWB, option C	NEP, option C+E	POM, option E
Total, non-renewables	35.8%	6.3%	2.7%
Pressure water reactors (PWR)	0.0%	0.0%	0.0%
Boiling water reactors (BWR)	0.0%	0.0%	0.0%
Fuel oil	0.5%	0.4%	0.3%
Gas combined cycle plants (GCC)	31.8%	2.5%	0.0%
Combined heat and power plant	3.6%	3.4%	2.4%

2.2.4 Electricity import

In scenario POM 9.1 % of the electricity consumed is from import. The import is modelled according to the electricity trade based on the scenarios of electricity mixes in Europe based on NEEDS (New Energy Externalities Developments for Sustainability, Frischknecht et al. 2008a), see also subchapter 2.7

2.2.5 Electricity from waste

50 % of the electricity from waste incineration plants stems from renewable energy sources. The remaining 50 % are considered as fossil (from plastic wastes). According to Prognos (2012) the fossil share of electricity from waste incineration plants is included in the balance of fossil fuel based electricity. Therefore a share of 50 % of the electricity produced in waste incineration plants is subtracted from the electricity production from fossil fuels.

2.3 'Business as usual', option C

Climate and energy policies have no prioritiy in Switzerland. The established policies are continued, but there are no strict energy goals to achieve. No new policies regarding renewable energy are set up. Within this scenario all electricity is of domestic origin. A gap between power production and consumption is covered with centrally operated gas combined cycle power stations run with fossil natural gas. Tab. 2.5 shows the production amounts and the ecoinvent datasets used in the modelling.

Tab. 2.5 Production levels and modelling of scenario ‘busines as usual’, option C

Production plant	**Production mix [TWh]**	**Production mix [%]**	**ecoinvent dataset name**
Total mix consumed	82.3	100.0 %	
Domestic gross-production	82.3		
Renewables	50.5	61.4 %	
Hydropower	41.6	50.5 %	
Run-of-river power plants	12.0	14.6 %	electricity, hydropower, at run-of-river power plant
Run-of-river power plants	12.0	14.6 %	electricity, hydropower, at run-of-river power plant
Reservoir power plants	19.3	23.4 %	electricity, hydropower, net, at reservoir power plant
Small hydropower plants	4.3	5.2 %	electricity, hydropower, at small hydropower plant
Pumped Storage	6.0	7.3 %	electricity, hydropower, at pumped storage power plant
New renewables	9.0	10.9 %	
Solar	5.9	7.2 %	electricity, production mix photovoltaic, at plant
Wind	1.4	1.7 %	electricity, at wind power plant
Wood	0.7	0.8 %	electricity, at cogen 6400kWth, wood, allocation exergy
Agricultural Biogas	0.3	0.4 %	electricity, at cogen, biogas agricultural mix, allocation exergy
Biogas	0.2	0.3 %	electricity, at cogen with biogas engine, allocation exergy
Geothermal	0.4	0.5 %	electricity, at wind power plant
Non-renewables	29.5	35.8 %	
Nuclear power	0.0	0.0 %	
Pressure water reactors (PWR)	0.0	0.0 %	electricity, nuclear, at power plant pressure water reactor
Boiling water reactors (BWR)	0.0	0.0 %	electricity, nuclear, at power plant boiling water reactor
Fossil fuels	29.5	35.8 %	
Fuel oil	0.4	0.5 %	electricity, at cogen 200kWe diesel SCR, allocation exergy
Natural gas	29.1	35.4 %	
Gas combined cycle plants (GCC)	26.2	31.8 %	electricity, natural gas, at combined cycle plant NGCC_100% electricity
Combined heat and power plant	3.0	3.6 %	electricity, at cogen 500kWe lean burn, allocation exergy
Waste	2.3	2.8 %	electricity from waste, at municipal waste incineration plant
Imports	0.0	0.0 %	-
Export	0.0	0.0 %	-

2.4 'New energy policies', option C+E

In NEP renewable energy sources as well as energy efficient technologies are pushed intensely. Key technologies are advanced systematically. Energy politics have a high priority. Within the scenario NEP all electricity is of domestic origin. A gap between power production and consumption is covered with renewable energies combined with fossil fuels (gas combined cycle power stations run with natural gas, Prognos 2012). About 11 % electricity is exported. The exported electricity shows the same technology mix like domestic supply. Tab. 2.6 shows the production amounts and the ecoinvent datasets used in the modelling.

Tab. 2.6 Production levels and modelling of scenario 'new energy policies', option C+E

Production plant	**Production mix [TWh]**	**Production mix [%]**	**ecoinvent dataset name**
Total mix consumed	74.4	100.0%	
Domestic gross-production	83.6		
Renewables	66.7	89.7 %	
Hydropower	44.2	59.4 %	
Run-of-river power plants	4.7	18.2 %	electricity, hydropower, at run-of-river power plant
Reservoir power plants	13.5	26.8 %	electricity, hydropower, net, at reservoir power plant
Small hydropower plants	19.9	6.3 %	electricity, hydropower, at small hydropower plant
Pumped Storage	6.0	8.1 %	electricity, hydropower, at pumped storage power plant
New renewables	22.6	30.4 %	
Solar	11.1	15.0 %	electricity, production mix photovoltaic, at plant
Wind	4.3	5.7 %	electricity, at wind power plant
Wood	1.2	1.7 %	electricity, at cogen 6400kWth, wood, allocation exergy
Agricultural Biogas	0.9	1.2 %	electricity, at cogen, biogas agricultural mix, allocation exergy
Biogas	0.7	1.0 %	electricity, at cogen with biogas engine, allocation exergy
Geothermal	4.4	5.9 %	electricity, at wind power plant

Production plant	Production mix [TWh]	Production mix [%]	ecoinvent dataset name
Non-renewables	4.7	6.3 %	
Nuclear power	0.0	0.0 %	
Pressure water reactors (PWR)	0.0	0.0 %	electricity, nuclear, at power plant pressure water reactor
Boiling water reactors (BWR)	0.0	0.0 %	electricity, nuclear, at power plant boiling water reactor
Fossil fuels	4.7	6.3 %	
Fuel oil	0.4	0.4 %	electricity, at cogen 200kWe diesel SCR, allocation exergy
Natural gas	4.3	5.9 %	
Gas combined cycle plants (GCC)	1.6	2.5 %	electricity, natural gas, at combined cycle plant NGCC_100% electricity
Combined heat and power plant	2.5	3.4 %	electricity, at cogen 500kWe lean burn, allocation exergy
Waste	3.0	4.0 %	electricity from waste, at municipal waste incineration plant
Imports	0.0	0.0 %	-
Export	9.3	11.3 %	-

2.5 'Political measures', option E

POM pursues high ambitioned energy policies. Efficient technologies are supported and pushed. Within the scenario POM the focus of production is still on renewable energy sources. However a part of the energy consumption is covered by import (approximately 9 %, Prognos 2012). Tab. 2.7 shows the production amounts and the ecoinvent datasets used in the modelling.

Tab. 2.7 Production levels and modelling of scenario POM option E

Production plant	Production mix [TWh]	Production mix [%]	ecoinvent dataset name
Total mix consumed	79.0	100.0 %	
Domestic gross-production	77.4		
Renewables	66.7	84.5 %	
Hydropower	44.2	55.9 %	
Run-of-river power plants	13.5	17.1 %	electricity, hydropower, at run-of-river power plant
Reservoir power plants	19.9	25.2 %	electricity, hydropower, net, at reservoir power plant
Small hydropower plants	4.7	5.9 %	electricity, hydropower, at small hydropower plant
Pumped Storage	6.0	7.6 %	electricity, hydropower, at pumped storage power plant
New renewables	22.6	28.6 %	
Solar	11.1	14.1 %	electricity, production mix photovoltaic, at plant
Wind	4.3	5.4 %	electricity, at wind power plant
Wood	1.2	1.6 %	electricity, at cogen 6400kWth, wood, allocation exergy
Agricultural Biogas	0.9	1.1 %	electricity, at cogen, biogas agricultural mix, allocation exergy
Biogas	0.7	0.9 %	electricity, at cogen with biogas engine, allocation exergy
Geothermal	4.4	5.6 %	electricity, at wind power plant
Non-renewables	2.1	2.7 %	
Nuclear power	0.0	0.0 %	
Pressure water reactors (PWR)	0.0	0.0 %	electricity, nuclear, at power plant pressure water reactor
Boiling water reactors (BWR)	0.0	0.0 %	electricity, nuclear, at power plant boiling water reactor

Production plant	Production mix [TWh]	Production mix [%]	ecoinvent dataset name
Fossil fuels	2.1	2.7 %	
Fuel oil	0.2	0.3 %	electricity, at cogen 200kWe diesel SCR, allocation exergy
Natural gas	1.9	2.4 %	
Gas combined cycle plants (GCC)	0.0	0.0 %	electricity, natural gas, at combined cycle plant NGCC_100% electricity
Combined heat and power plant	1.9	2.4 %	electricity, at cogen 500kWe lean burn, allocation exergy
Waste	3.0	3.7 %	electricity from waste, at municipal waste incineration plant
Import	7.2	9.1 %	-
Export	5.5	7.0 %	-

2.6 Transmission and distribution network

2.6.1 Electricity demand and losses

The total losses are given in the Swiss electricity statistics (BFE 2010). For the year 2009 the total electricity losses were 6.99 %. It is assumed that this amount does not change significantly to the year 2050, as it did not change significantly over the last 10 years (BFE 2010). It is expected that the assignment of the electricity losses to the different voltage levels does not change largely to 2050. They are based on data according to Itten et al. (2012) and are modelled likewise.

The electricity losses during long-distance transmission are calculated according to Itten et al. (2012).

2.6.2 Material use

The facilities of the whole electricity grid come to the arial lines, cables, masts, technical equipment, as transformers, SF_6 gas insulated switchgear as well as buildings. The grid itself is diveded into three levels, namely high, medium and low voltage.

All material demands for the infrastructure, the grid, the buildings and all constructions and its impacts are calculated according to Itten et al. (2012).

2.7 Electricity trade

According to Itten et al. (2012) 64.6 % of the electricity consumed in Switzerland in 2012 originates from domestic production. Around 35.6 % of the electricity is from imports based on electricity trade. It is difficult to estimate future shares of electricity trade. The Association of Swiss Electric Power Utilities (VSE) published a report with three different scenarios (VSE 2012).

The amounts of electricity imported according to VSE varies between a maximum of 24 and 27 TWh (in 2035) and between 7 and 23 TWh (in 2050). The share of imports in the scenario POM is in accordance with the lower limit given by the VSE-scenarios. The large amounts of imported electricity are mainly due to a delayed installation and operation of additional renewable power production capacities when compared to the scenarios of the energy strategy 2050. Hence, the VSE scenarios do neither address electricity trade as occuring today.

The scenarios of VSE do not match with the ones of the Energy Strategy 2050 (economical developments, policy measures). It is thus not possible to use the import shares of the VSE scenarios. Dedicated trade scenarios compatible with those of the Energy Strategy 2050 would be needed in addition to the existing ones to get a consistent answer regarding the trade related import shares. This was out of reach within the given budget.

VSE (2012, p.80) states that „future imports and exports will be more important than today. Imports are often more cost efficient than the construction and operation of new domestic natural gas power plants."

Therefore constant relative shares of domestically produced and traded electricity from today until 2050 were assumed. Hence, electricity trade grows in parallel with growing electricity consumption. This simplifying assumption does apply on all three scenarios. It does not rely on speculations about electricity prices.

Because the quality of traded electricity is more important than its share on domestic consumption, we differentiate three different technology mixes. Electricity trade is modeled according to the scenarios of electricity mixes in Europe based on NEEDS (New Energy Externalities Developments for Sustainability, Frischknecht et al. 2008a). Within NEEDS the electricity mixes are modeled in three different ways. The LCI background data are investigated for three scenarios (pessimistic, optimistic-realistic, and very optimistic). In NEEDS for each scenario two time horizons with the reference years 2025 and 2050 are considered. In this study we use the 2050 electricity mixes.

The LCIs of the production of commodities in the future are modeled considering further development of production techniques (in terms of energy and raw material efficiency, energy carriers used and emission factors). For further data on modeling of those scenarios we refer to NEEDS (Frischknecht 2010). Each scenario implies a certain technological development: scenario 'pessimistic' assumes technologies according to business as usual. This matches with the scenario WWB in this study. Scenario 'optimistic-realistic' follows the pathway of technology development as far as possible according to predictions and goals of the industry that seem reasonable to be achieved. The '440 ppm electricity mix' scenario (440ppm) is applied on European electricity supply. This scenario refers to POM in this study. For the scenario 'very optimistic' the enhanced renewables electricity mix scenario (Renewables) is applied on European electricity supply and this matches with scenario NEP. In Scenario POM electricity trade takes place in addition to imported electricity.

Carbon capture and storage (CCS) is taken into account for hard coal and for natural gas power production in scenarios NEP and POM. These technologies are modeled based on German common hard coal and natural gas power plants. However the CO_2 emissions are reduced by 90 % and the overall efficiency is diminished by 7 %. An efficency enhancement due to future technological improvement is accounted for. No CCS-technologies for lignite were applied because of its small share in the mix.

The Swiss supply mixes (including trade) are hence modeled with 64.4 % of domestic production and 35.6 % of the European mix according to NEEDS in the year 2050. The share of domestic production and import bases on the present situation (Itten et al. 2012). Tab. 2.8 to Tab. 2.10 show the modeling data of the European electricity mixes.

Tab. 2.8 Modeling of the European trade electricity mix, scenario WWB

Technology according to NEEDS	Modelling used in this study	Country code	Unit	Amount
Hard coal power, average	electricity, hard coal, at power plant	UCTE	kWh	2.64E-1
Lignite, at power plant 950 MF	electricity, lignite, at power plant	UCTE	kWh	9.68E-2
Oil at power plant	electricity, oil, at power plant	UCTE	kWh	6.02E-3
Natural gas, at combined cycle plant 500 Mwe	electricity, natural gas, at combined cycle plant, best technology	RER	kWh	1.56E-1
Natural gas, at turbine, 50 Mwe	electricity, natural gas, at power plant	UCTE	kWh	2.98E-2
Nuclear, average	electricity, nuclear, at power plant	UCTE	kWh	2.20E-1
Biomass, average	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	3.64E-2
Hydropower, at run-of-river power plant	electricity, hydropower, at run-of-river power plant without reservoir	RER	kWh	5.59E-2
Hydropower, at reservoir power plant, alpine region	electricity, hydropower, at reservoir power plant, alpine region	RER	kWh	7.96E-2
Hydropower, at pumped storage power plant	electricity, hydropower, at pumped storage power plant	RER	kWh	6.57E-3
Wind power plant	electricity, at wind power plant	RER	kWh	3.19E-2
Offshore wind park 1440 MW	electricity, at wind power plant 2MW, offshore	OCE	kWh	1.40E-2
Photovoltaic average	electricity, production mix photovoltaic, at plant	DE	kWh	3.17E-3
Solar, thermal average	electricity, production mix photovoltaic, at plant	DE	kWh	5.69E-4

Tab. 2.9 Modeling of the European trade electricity mix, scenario NEP

Energy carrier	Data set	Country code	Unit	Amount
Hard coal, average UCTE	electricity, hard coal, at power plant	UCTE	kWh	1.63E-2
Hard coal with CCS, average UCTE	electricity, hard coal with CCS, DE	DE	kWh	8.19E-3
Hard coal, at IGCC power plant 450MW RER	electricity, hard coal, at power plant	UCTE	kWh	8.33E-4
Hard coal IGCC with CCS, aver-age UCTE	electricity, hard coal with CCS, DE	DE	kWh	4.13E-3
Lignite, at power plant 950 MW RER	electricity, lignite, at power plant	UCTE	kWh	2.42E-10
Oil, at power plant UCTE	electricity, oil, at power plant	UCTE	kWh	1.56E-9
Natural gas, at combined cycle plant, 500MWe RER	electricity, natural gas, at combined cycle plant, best technology	RER	kWh	1.17E-1
Natural gas, at turbine, 50MWe RER	electricity, natural gas, at power plant	UCTE	kWh	4.77E-2
Natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield RER	electricity, natural gas with CCS, at power plant, DE	DE	kWh	2.76E-3
Biomass, average UCTE	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	1.58E-1
Hydropower, at run-of-river power plant RER	electricity, hydropower, at run-of-river power plant without reservoir	RER	kWh	7.21E-02
Hydropower, at reservoir power plant, alpine region RER	electricity, hydropower, at reservoir power plant, alpine region	RER	kWh	1.61E-01
Hydropower, at pumped storage power plant UCTE	electricity, energy strategy 2050, NEP, hydropower, at pumped storage plant	CH	kWh	9.10E-03
Wind power plant RER	electricity, at wind power plant	RER	kWh	2.60E-01
Offshore wind park 2496MW DK	electricity, at wind power plant 2MW, offshore	OCE	kWh	6.30E-2
Photovoltaic, average UCTE	electricity, production mix photovoltaic, at plant	DE	kWh	6.53E-02
Solar thermal, average UCTE	electricity, production mix photovoltaic, at plant	DE	kWh	1.43E-02

Tab. 2.10 Modeling of the European trade electricity mix, scenario POM

Energy carrier	Data set	Country code	Unit	Amount
Hard coal with CCS, average UCTE	electricity, hard coal with CCS, DE	DE	kWh	3.37E-5
Hard coal IGCC with CCS, average UCTE	electricity, hard coal with CCS, DE	DE	kWh	5.83E-2
Oil, at power plant UCTE	electricity, oil, at power plant	UCTE	kWh	1.82E-3
Natural gas, at combined cycle plant, 500MWe RER	electricity, natural gas, at combined cycle plant, best technology	RER	kWh	3.13E-2
Natural gas, CC plant, 500MWe post CCS, 400km&2500m deplet gasfield RER	electricity, natural gas with CSS, at power plant, DE	DE	kWh	3.83E-1
Natural gas, at cogeneration 200kWe lean burn, allocation exergy RER	electricity, natural gas, at power plant	UCTE	kWh	6.33E-4
Fuel cell, natural gas, average UCTE	electricity, biogas, allocation exergy, at SOFC fuel cell 125kWe, future	CH	kWh	1.34E-3
Nuclear, average UCTE	electricity, nuclear, at power plant	UCTE	kWh	2.44E-1
Biomass, average UCTE	electricity, at cogen 6400kWth, wood, allocation exergy	CH	kWh	3.29E-2
Hydropower, at run-of-river power plant RER	electricity, hydropower, at run-of-river power plant without reservoir	RER	kWh	4.42E-2
Hydropower, at reservoir power plant, alpine region RER	electricity, hydropower, at reservoir power plant, alpine region	RER	kWh	1.02E-1
Hydropower, at pumped storage power plant UCTE	electricity, energy strategy 2050, POM, hydropower, at pumped storage plant	CH	kWh	4.91E-3
Wind power plant RER	electricity, at wind power plant	RER	kWh	3.43E-2
Offshore wind park 1944MW DK	electricity, at wind power plant 2MW, offshore	OCE	kWh	3.57E-02
Photovoltaic, average UCTE	electricity, production mix photovoltaic, at plant	DE	kWh	3.36E-03
Solar thermal, average UCTE	electricity, production mix photovoltaic, at plant	DE	kWh	4.55E-04
Wave energy, 7MW RER	electricity, hydropower, at run-of-river power plant without reservoir	RER	kWh	2.15E-02

2.8 Data quality

The total production data are given by the authors of the Energy Strategy 2050 (Prognos 2012) and are considered as reliable. The data about losses, transformation, emissions, distribution and material use base on actual Swiss and european data (Itten et al. 2012) and are likewise considered having a small uncertainty.

However the temporal correlation is weak, as there is an extrapolation from present data to a future situation (> 35 years). While this does hardly matter with regard to hydroelectric or gas combined cycle power plants, it is of importance with regard to photovoltaics, where substantial efficiency gains are to be expected and with regard to imports, where a change in the european electricity mix towards renewables is likely to happen. These latter changes are modeled based on the scenarios in the NEEDS-study (Frischknecht et al. 2008a), see also subchapter 2.7.

3 Cumulative Results and Interpretation

3.1 Overview

This chapter contains a description of selected cumulative results and their main drivers. All results are shown in Tab. 3.9. The graphs and tables use the following grouping of technologies: 'Hydro power' aggregates run-of-river power plants, small hydro power plants and reservoir power plants. 'Hydro power, pumped storage' includes the electricity produced with water pumped up once. 'Photovoltaic power' represents electricity produced with domestic photovoltaic power plants. 'Renewables and waste' contains electricity produced with wind, wood, biogas, geothermal energy and waste. 'Fossil power' combines natural gas, coal and fuel oil power plants. And 'Imports' represents the electricity imported or traded from the European grid according to the trade mix.

The environmental impacts related to transmission and distribution (due to electricity losses and the construction of the power lines and switching stations) are attributed to the technologies in proportion to their shares in the electricity mix.

3.2 Swiss production mixes 2050

Subchaper 3.2 contains a description of the results fo the Swiss production mixes 2050 and subchapter 3.3 contains a description of the results of the Swiss supply mixes in 2050 , including electricity trade. Subchapter 3.4 summarizes the results and includes a comparison with the current electricity mixes.

3.2.1 Global Warming Potential (GWP)

The Global Warming Potential of electricity consumed in Switzerland varies per scenario. It is calculated in g carbon dioxide (CO_2 eq) per 1 MJ.

In scenario WWB the GWP amounts to 59.1 g CO_2 eq/MJ, in NEP to 21.2 g CO_2 eq/MJ and in scenario POM to 16.9 g CO_2 eq/MJ. Tab. 3.2 and Fig. 3.1 show the greenhouse gas emissions per scenario and per technology. POM has the smallest GWP of the scenarios analyzed.

In scenario 'Business as usual' about 36 % of the electricity is produced by fossil fuels (fuel oil and natural gas). Hence the GWP of this scenario is higher than in the other two scenarios. Abour 87 % of the GWP in 'Business as usual' results from burning natural gas. In scenario 'New Energy Policies' this amounts to 46 % of the GWP. In scenario

POM 27 % of the GWP result of burning of natural gas. Tab. 3.1 shows the total amount of CO_2 emitted in each scenario in mega tons.

Tab. 3.1 Total amount of greenhouse gases emitted per year per scenario WWB, NEP and POM in [Mt CO_2 eq/a]

	WWB [Mt CO_2 eq/a]	**NEP [Mt CO_2 eq/a]**	**POM [Mt CO_2 eq/a]**
CO_2-eq emitted (total)	17.5	5.7	4.8

The consumption of fossil fuels is the main source of greenhouse gas emissions. Further emissions are caused in the supply chain (construction of power plants or parts (example photovoltaic panels)) and by the infrastructure and transmission.

The contribution to the greenhouse gas emissions differ per technology used for the electricity production. Fig. 3.1 illustrates the shares to the global warming potential.

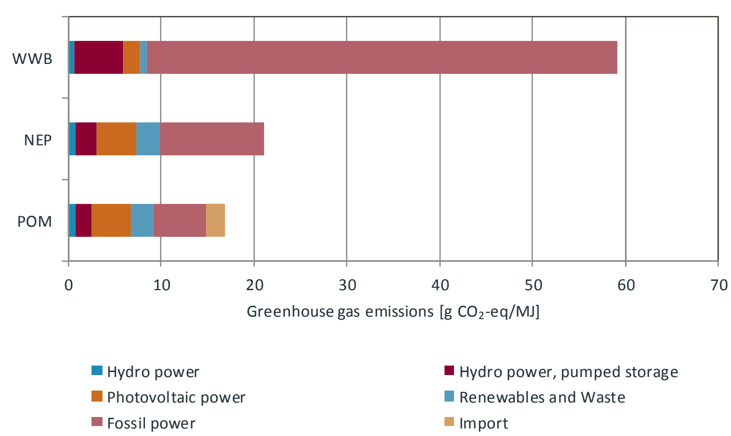

Fig. 3.1 Global warming potential of the electricity mix per scenario in [g CO_2-eq/MJ]

Within scenario POM the consumption of fossil fuels causes the largest share of greenhouse gas emissions. The import does not contribute a lot, as the imported electricity from fossil fuels is produced with CCS technologies. The shares to the global warming potential per technology are shown in Tab. 3.2. It is assumed, that there are no CCS technologies applied in Switzerland.

Tab. 3.2 Greenhouse gas emissions for WWB, NEP and POM in [g CO_2-eq/MJ]

Technology / Scenario		Total	Hydro power	Hydro power, pumped storage	Photovoltaics	Renewables and Waste	Fossil power	Import
WWB	g CO_2 eq/MJ	**59.15**	0.67	5.28	1.85	0.68	50.67	0.00
NEP	g CO_2 eq/MJ	**21.18**	0.87	2.23	4.23	2.53	11.32	0.00
POM	g CO_2 eq/MJ	**16.88**	0.86	1.74	4.17	2.49	5.64	1.98

3.2.2 Ecological Scarcity 2006

The production of one MJ of electricity results in 39.5, 26.6 and 26.8 eco-points/MJ depending on the scenario. Scenario NEP causes the lowest environmental impacts. The environmental impacts of the electricity mixes are shown in Tab. 3.3. Fig. 3.2 illustrates the impacts per aggregated technology category. The categories are merged as described in Section 3.2.

Tab. 3.3 Environmental impacts quantified with the ecological scarcity method 2006 for WWB, NEP and POM [eco-points/MJ]

Technology / Scenario		Total	Hydro power	Hydro power, pumped storage	Photovoltaics	Renewables and Waste	Fossil power	Import
WWB	Eco-points/MJ	**39.50**	1.74	3.65	3.48	1.66	28.97	0.00
NEP	Eco-points/MJ	**26.64**	2.42	2.84	8.52	5.62	7.24	0.00
POM	Eco-points/MJ	**26.78**	2.29	2.72	8.09	5.32	3.57	4.78

In scenario WWB the electricity from fossil fuels causes the largest share of environmental impacts, followed by pumped storage power production. In scenarios NEP and POM photovoltaic power and fossil fuels cause the largest share of environmental impacts.

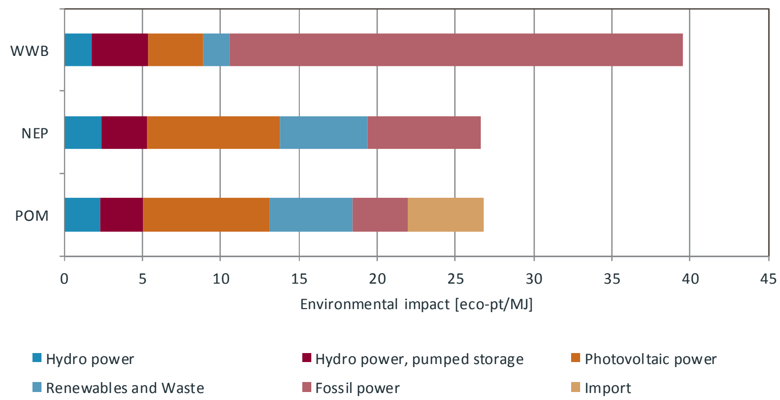

Fig. 3.2 Environmental impacts of the electricity mix per scenario in [eco-points/MJ]

3.2.3 Cumulative Energy Demand

The total cumulative energy demand (CED) for the production of one MJ electricity in 2050 is similar for all three scenarios, namely 1.7 MJ oil-eq/MJ (WWB) and 1.4 MJ oil-eq/MJ for NEP and POM. The energy mix in scenario NEP causes the lowest cumulative energy demand.

Fig. 3.3 shows the composition of energy resource input per MJ electricity produced. It illustrates that the mixes with a higher the share of renewable sources (NEP and POM) show a lower cumulative energy demand.

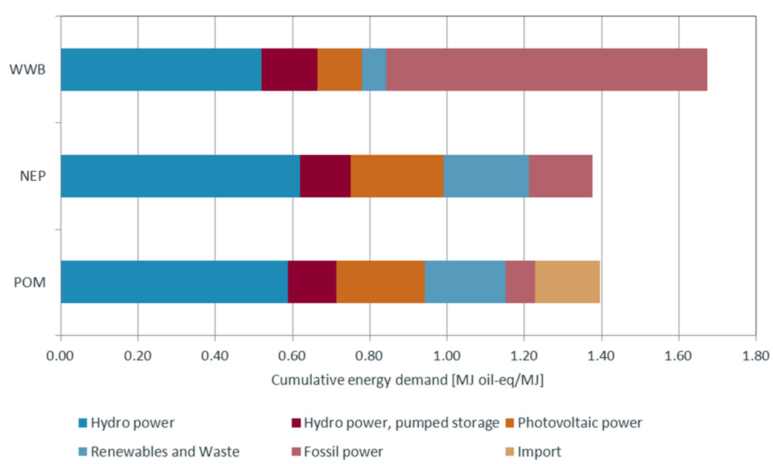

Fig. 3.3 Cumulative energy demand of the electricity mix per scenario in [MJ oil-eq/MJ]

Within the scenario WWB the consumption of non-renewable, fossil energy sources (49.8 %), as well as hydro power (31.0 %) have the largest share in the CED. The fossil energy source is mainly natural gas. Hydro power contributes almost one-third (and up to 45 % in NEP) to the total cumulative energy demand in all scenarios. In scenarios

NEP and POM wind/solar/geothermal (16.0 %, and 15.0 %) are further important primary energy sources. Tab. 3.4 summarizes the cumulative energy demand per aggregated technology.

Tab. 3.4 Cumulative energy demand of the electricity mixes per scenario in [MJ oil-eq/MJ]

Technology / Scenario		Total	Hydro power	Hydro power, pumped storage	Photovoltaics	Renewables and Waste	Fossil power	Import
WWB	MJ oil-eq/MJ	**1.67**	0.52	0.15	0.11	0.06	0.83	0.00
NEP	MJ oil-eq/MJ	**1.38**	0.62	0.13	0.24	0.22	0.16	0.00
POM	MJ oil-eq/MJ	**1.40**	0.59	0.13	0.23	0.21	0.08	0.17

3.3 Swiss supply mixes 2050, including electricity trade

3.3.1 Global warming potential

The Global Warming Potential of electricity consumed in Switzerland including electricity trade varies per scenario. In scenario WWB the GWP amounts to 93.7 g CO_2 eq/MJ, in NEP to 27.5 g CO_2 eq/MJ and in scenario POM to 21.8 g CO_2 eq/MJ. In Tab. 3.5 and in Fig. 3.4 the greenhouse gas emissions per scenario and per technology are illustrated. The scenario POM has the smallest GWP of the scenarios analyzed, scenario WWB the largest.

As Fig. 3.4 shows the largest share within all three scenarios, but especially within scenario WWB comes from fossil fuels. In WWB 57.9 % of the emitted CO_2 equivalents result form the traded and hence imported electricity. In scenarios NEP and POM the CO_2-emission-equivalents from domestic production and from traded electricity are about equal. Tab. 3.5 shows the total amount of CO_2 emitted in each scenario in mega tons.

Tab. 3.5 Total amount of greenhouse gases emitted per year per scenario WWB, NEP and POM in [Mt CO_2 eq/a]

	WWB [Mt CO_2 eq/a]	**NEP [Mt CO_2 eq/a]**	**POM [Mt CO_2 eq/a]**
CO_2-eq emitted (total)	27.8	7.4	6.2

The consumption of fossil fuels is the main source of greenhouse gas emissions. The contribution to the greenhouse gas emissions differ per technology used for the electricity production. Fig. 3.4 illustrates the shares to the global warming potential per technology including domestic production and trade. Tab. 3.6 shows the greenhouse gas emissions disclosing the trade separately.

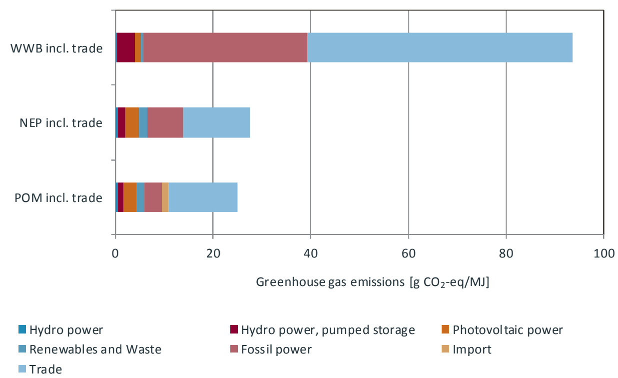

Fig. 3.4 Global warming potential of the electricity mix including traded electricty per scenario in [g CO_2-eq/MJ]

Within scenario POM the import causes the largest share of greenhouse gas emissions due to coal based electricity.The shares to the global warming potential per technology are shown in Tab. 3.6. The trade is accounted for as separate category.

Tab. 3.6 Greenhouse gas emissions of the electricity mix including electricity trade per scenario in [g CO_2-eq/MJ]

Technology / Scenario		**Total**	**Hydro power**	**Hydro power, pumped storage**	**Photovoltaics**	**Fossil power**	**Import**	**Renewables and Waste**	**Trade**
WWB incl. trade	g CO_2 eq/MJ	**93.71**	0.45	3.52	1.23	33.79	0.00	0.45	54.27
NEP incl. trade	g CO_2 eq/MJ	**25.07**	0.57	1.47	2.78	7.43	0.00	1.66	13.59
POM incl. trade	g CO_2 eq/MJ	**16.88**	0.55	1.12	2.69	1.61	3.64	1.28	14.19

3.3.2 Ecological Scarcity 2006

The production of one MJ of electricity including trade results in 76.9, 32.7 and 45.1 eco-points/MJ for WWB, NEP and POM. Scenario NEP causes the lowest environmental impacts. The environmental impacts of the electricity mixes including electricity trade are shown in Tab. 3.7. The production technologies are merged as described in Section 3.2.

Tab. 3.7 Environmental impacts quantified with the ecological scarcity method 2006 of the electricity mix including electricity trade per scenario in [eco-points/MJ]

Technology / Scenario		Total	Hydro power	Hydro power, pumped storage	Photovoltaics	Fossil power	Import	Renewables and Waste	Trade
WWB incl. trade	Eco-points/MJ	**76.89**	1.03	2.18	0.99	2.08	17.27	0.00	53.34
NEP incl. trade	Eco-points/MJ	**32.69**	1.49	1.76	3.47	5.26	4.47	0.00	16.24
POM incl. trade	Eco-points/MJ	**45.10**	1.28	1.52	4.53	2.00	2.68	2.98	30.10

In scenario WWB the largest share of environmental impacts is caused by the imported electricity and hence electricity from coal, natural gas and nuclear power, followed by the domestic electricity production from fossil fuels. In scenarios NEP and POM photovoltaic power and fossil fuels cause the largest share of environmental impacts besides the traded and imported electricity. Fig. 3.5 illustrates the impacts per aggregated technology category.

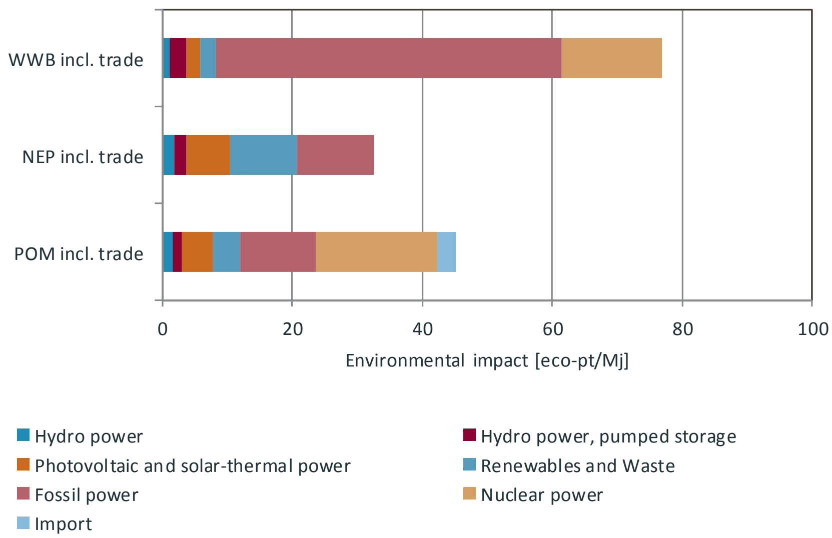

Fig. 3.5 Environmental impacts of the electricity mix including electricity trade per scenario in [eco-points/MJ]

3.3.3 Cumulative Energy Demand

The total cumulative energy demand (CED) for the production of one MJ electricity including electricity trade in 2050 is 2.2 MJ oil-eq/MJ (WWB), 1.6 MJ oil-eq/MJ (NEP) and 1.9 MJ oil-eq/MJ (POM). The energy mix including electricity trade in scenario NEP has the lowest cumulative energy demand. Fig. 3.6 shows the composition of resource input for all three scenarios, including trade in the different technology categories.

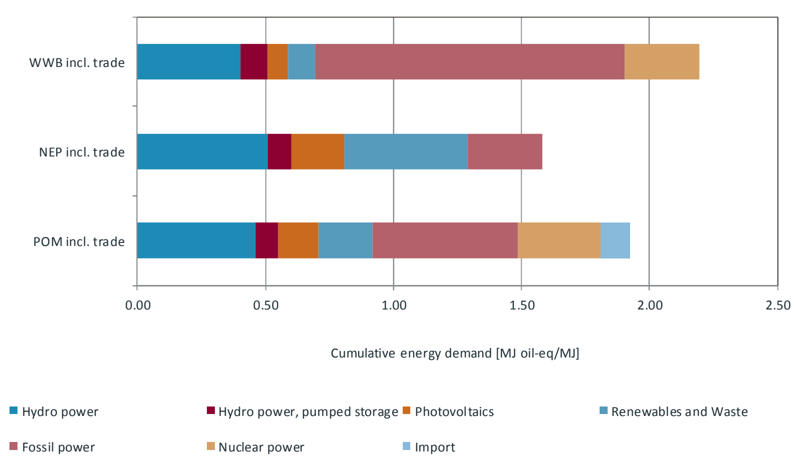

Fig. 3.6 Cumulative energy demand of the electricity mix including electricity trade per scenario in [MJ oil-eq/MJ]

The higher the share of renewable resources is (in NEP), the lower ist the cumulative energy demand.

The consumption of non-renewable, fossil energy sources as well as hydro power have the largest share in the CED in the scenarios WWB and POM. Tab. 3.4 summarizes the cumulative energy demand per aggregated technology.

Tab. 3.8 Cumulative energy demand of the electricity mixes including electricity trade per scenario in [MJ oil-eq/MJ]

Technology / Scenario		**Total**	**Hydro power**	**Hydro power, pumped storage**	**Photovoltaics**	**Renewables and Waste**	**Fossil power**	**Import**	**Trade**
WWB incl. trade	MJ oil-eq/MJ	**2.20**	0.35	0.10	0.04	0.08	0.56	0.00	1.07
NEP incl. trade	MJ oil-eq/MJ	**1.58**	0.42	0.09	0.15	0.16	0.11	0.00	0.66
POM incl. trade	MJ oil-eq/MJ	**1.92**	0.39	0.08	0.15	0.05	0.14	0.11	0.99

3.4 Summary of the Results

Tab. 3.9 gives an overview (low voltage level) on all results for all scenarios. Regarding the indicators global warming potential, cumulative energy demand (total) and ecological scarcity, the electricity mix in scenario 'new energy policies, NEP' has the smallest impact of the three scenarios analyzed. Leaving trade aside, about 90 % of the energy is of renewable origin and no electricity is imported.

Tab. 3.9 Summary of the cumulative results of electricity mixes, with and without trade, according to the scenarios in the Energy Strategy 2050, as well as the present electricity mixes in Switzerland and Europe

Electricity mix	Primary energy total MJ oil-eq/MJ	Primary energy non-renewable (fossil and nuclear) MJ oil-eq/MJ	Primary energy non-renewable - fossil MJ oil-eq/MJ	Primary energy non-renewable - nuclear MJ oil-eq/MJ	Primary energy renewable MJ oil-eq/MJ	Primary energy waste/ wasteheat MJ oil-eq/MJ	Carbon dioxide fossil g CO_2-eq/MJ	Global warming potential g CO_2-eq/MJ	Ecological scarcity eco-pt/ MJ
WWB, option C	1.67	0.96	0.94	0.02	0.72	0.00	54.2	59.2	39.5
NEP, option C+E	1.38	0.28	0.26	0.02	1.09	0.00	17.0	21.2	26.6
POM, option E	1.40	0.29	0.23	0.06	1.11	0.00	12.8	16.9	26.8
WWB incl. trade, option C	2.20	1.61	1.28	0.32	0.59	0.00	86.9	93.7	76.9
NEP incl. trade, option C+E	1.58	0.41	0.39	0.02	1.18	0.00	23.4	27.5	32.7
POM, incl. trade, option E	1.92	1.06	0.69	0.38	0.86	0.00	16.8	21.8	45.1
CH-Production mix[1]	2.41	1.76	0.10 [2]	1.65 [2]	0.65 [2]	-	0.007 [2]	8.3	75.7
CH-Supply mix[1]	3.05	2.63	0.51 [2]	2.13 [2]	0.42 [2]	0.02 [2]	0.038 [2]	41.3	125
UCTE-Mix[1]	3.54	3.32	2.01 [2]	1.32 [2]	0.22 [2]	-	0.156 [2]	165.0	177

1 data from the KBOB recommendation, July 2012 (KBOB et al. 2012)

2 data from Frischknecht & Itten (2011)

The infrastructure has a significant share in the final result of the ecological scarcity and a smaller one in the two other impact categories. The transmission does not contribute significantly to any of the three indicators under study.The use of fossil fuels has a large impact on the indicators GWP and CED. Hence the scneario WWB has a higher impact than NEP or POM.

It becomes evident, that a smaller share of electricity produced with fossil fuels and nuclear power results in lower environmental impacts quantified with the ecological scarcity method, with CED (total, and non renewable) and with GWP.

The cumulative energy demand of the electricity mixes in the year 2050 are clearly lower than the primary energy demand in Switzerland in 2012 (production mix as well as supply mix). The share of non renewable energy sources in the year 2050 decreases about 45 to 84 % (depending on the scenario) compared to the present Swiss production mix. However the todays production mix causes smaller CO_2-emissions than all three future scenarios. This is mainly because of the electricity production from nucear power, which has a small global warming potential compared to other technologies. At the same time, nuclear power is the main reason for the high values today in the environmental scarcity method. The UCTE electricity mix causes the highest amount of greenhouse gas emissions and the largest environmental impacts.

The environmental impacts with electricity trade are larger than without trade. This is especially true for the scenario WWB, which has a large share of fossil fuel for the power production and no CCS technologies. Furthermore it includes a relatively high share of nuclear power. The higher the share of renewable energy sources becomes within a scenario, the smaller are the gaps between the scenarios with and without trade. Hence the environmental impacts of the scenario NEP are nearest to these without trade, namely 15 – 30 % higher than without trade. For scenario WWB the environmental impacts are 31 – 95 % higher when including trade. When comparing the scenarios NEP and POM (with trade) it is noticeable, that POM has the lower global warming potential. This results from the high share of imported electricity, which includes electricity from fossil fuel power plants equiped with CCS-technologies. These come with low CO_2-emissions.

References

BFE 2010	BFE (2010) Schweizerische Elektrizitätsstatistik 2009. Bundesamt für Energie, Bern, CH, retrieved from: http://www.bfe.admin.ch/themen/00526/00541/00542/00630/index.html?lang=de&dossier_id=04840.
Boustead & Hancock 1979	Boustead I. and Hancock G. F. (1979) Handbook of Industrial Energy Analysis. Ellis Horwood Ltd., Chichester, England.
Büsser et al. 2012	Büsser S., Frischknecht R., Kiyotada H. and Kono J. (2012) Ecological Scarcity Japan. ESU-services Ltd., Uster.
ecoinvent Centre 2010	ecoinvent Centre (2010) ecoinvent data v2.2, ecoinvent reports No. 1-25. Swiss Centre for Life Cycle Inventories, Duebendorf, Switzerland, retrieved from: www.ecoinvent.org.
Frischknecht et al. 2007	Frischknecht R., Jungbluth N., Althaus H.-J., Bauer C., Doka G., Dones R., Hellweg S., Hischier R., Humbert S., Margni M. and Nemecek T. (2007) Implementation of Life Cycle Impact Assessment Methods. ecoinvent report No. 3, v2.0. Swiss Centre for Life Cycle Inventories, Dübendorf, CH, retrieved from: www.ecoinvent.org.
Frischknecht et al. 2008a	Frischknecht R., Faist Emmenegger M., Steiner R., Tuchschmid M. and Gärtner S. (2008a) LCA of Background processes. In: NEEDS Project, Deliverable 15.1. ESU-services and ifeu, Uster and Heidelberg, retrieved from: www.needs-project.org/RS1a/RS1a%20D15.1%20LCA%20of%20background%20processes.pdf.
Frischknecht et al. 2008b	Frischknecht R., Steiner R. and Jungbluth N. (2008b) Methode der ökologischen Knappheit - Ökofaktoren 2006. Umwelt-Wissen Nr. 0906. Bundesamt für Umwelt (BAFU), Bern, retrieved from: www.bafu.admin.ch/publikationen/publikation/01031/index.html?lang=de.
Frischknecht 2010	Frischknecht R. (2010) NEEDS: Effective assessment of long-term sustainable energy policies in Europe by integrating LCA, external costs and energy planning models. In proceedings from: Der Systemblick auf Innovation – Technikfolgenabschätzung in der Technikgestaltung, NTA4 – Vierte Konferenz des Netzwerkes TA, 24.-26. November 2010, Berlin, retrieved from: http://www.itas.fzk.de/v/nta4/.
Frischknecht & Itten 2011	Frischknecht R. and Itten R. (2011) Primärenergiefaktoren von Energiesystemen, Version 2.2. im Auftrag des Bundesamtes für Energie BfE, ESU-services Ltd., Uster, CH, retrieved from: http://www.esu-services.ch/publications/energy/.
Itten et al. 2012	Itten R., Frischknecht R. and Stucki M. (2012) Life Cycle Inventories of Electricity Mixes and Grid. ESU-services Ltd., Uster, Switzerland, retrieved from: http://www.esu-services.ch/data/public-lci-reports/.

KBOB et al. 2012 — KBOB, eco-bau and IPB (2012) Ökobilanzdaten im Baubereich, Stand Juli 2012. Koordinationskonferenz der Bau- und Liegenschaftsorgane der öffentlichen Bauherren c/o BBL Bundesamt für Bauten und Logistik, retrieved from: http://www.bbl.admin.ch/kbob/00493/00495/index.html?lang=de.

Miyazaki et al. 2004 — Miyazaki N., Siegenthaler C., Schoenbaum T. and Azuma K. (2004) Japan Environmental Policy Priorities Index (JEPIX) - Calculation of Ecofactors for Japan: Method for Environmental Accounting based on the EcoScarcity Principle. 7. International Christian University Social Science Research Institute, Tokyo.

Nordic Council of Ministers 1995 — Nordic Council of Ministers (1995) LCA-NORDIC technical report no. 10 and special reports no. 1-2., Kopenhagen.

Pimentel 1973 — Pimentel D. (1973) Food Production and the Energy Crisis. In: Science, 182(4111), pp. 443-449.

PRé Consultants 2012 — PRé Consultants (2012) SimaPro 7.3.3, Amersfoort, NL, retrieved from: www.esu-services.ch/simapro/.

Prognos 2012 — Prognos (2012) Die Energieperspektiven für die Schweiz bis 2050; Energienachfrage und Elektrizitätsangebot in der Schweiz 2000 - 2050. Bundesamt für Energie, BFE, Bern.

SGP 1994 — SGP (1994) Etude relative à la normalisation écologique des emballages en Belgique, raport final au ministre belge de la santé publique, de l'intégration sociale et de l'environnement, Liège.

SIA 2009 — SIA (2009) Graue Energie von Gebäuden, Merkblatt 2032. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich.

SIA 2011a — SIA (2011a) SIA-Effizienzpfad Energie, Merkblatt 2040. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich.

SIA 2011b — SIA (2011b) Mobilität – Energiebedarf in Abhängigkeit vom Gebäudestandort, Merkblatt 2039. Schweizerischer Ingenieur- und Architektenverein (SIA), Zürich, Schweiz.

Solomon et al. 2007 — Solomon S., Qin D., Manning M., Alley R. B., Berntsen T., Bindoff N. L., Chen Z., Chidthaisong A., Gregory J. M., Hegerl G. C., Heimann M., Hewitson B., Hoskins B. J., Joos F., Jouzel J., Kattsov V., Lohmann U., Matsuno T., Molina M., Nicholls N., Overpeck J., Raga G., Ramaswamy V., Ren J., Rusticucci M., Somerville R., Stocker T. F., Whetton P., Wood R. A. and Wratt D. (2007) Technical Summary. In: Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.

VSE 2012 — VSE (2012) Wege in die neue Stromzukunft; Gesamtbericht. Verband Schweizerischer Stromunternehmen (VSE), Aarau.

Appendix

Cumulative Energy Demand (CED)

The CED (implementation according to Frischknecht et al. 2007) describes the consumption of fossil, nuclear and renewable energy sources throughout the life cycle of a good or a service. This includes the direct uses as well as the indirect or grey consumption of energy due to the use of, e.g. plastics as construction or raw materials. This method has been developed in the early seventies after the first oil price crisis and has a long tradition (Boustead & Hancock 1979; Pimentel 1973). A CED assessment can be a good starting point in an environmental assessment due to its simplicity in concept and its easy comparability with CED results in other studies. However, it does not assess environmental impacts and, as a consequence, cannot replace an assessment with the help of a comprehensive impact assessment method such as Ecological Scarcity 2006.

The following two CED indicators are calculated:

- CED, non-renewable (MJ oil-eq.) – fossil and nuclear
- CED, renewable (MJ oil-eq.) – hydro, solar, wind, geothermal, biomass

Global Warming Potential 2007 (GWP)

All substances that contribute to climate change are included in the global warming potential (GWP) indicator according to IPCC (Solomon et al. 2007). The residence time of the substances in the atmosphere and the expected immission design are considered to determine the global warming potentials. The potential impact of the emission of one kilogramme of a greenhouse gas is compared to the emission of one kilogramme CO_2 resulting in kg CO_2-equivalents. These so called global warming potentials are determined applying different time horizons (20, 100 and 500 years). The short integration period of 20 years is relevant because a limitation of the gradient of change in temperature is required to secure the adaptation ability of terrestrial ecosystems. The long integration time of 500 years is about equivalent with the integration until infinity. This allows monitoring the overall change in temperature and thus the overall sea level rise, etc. In this study a time horizon of 100 years is chosen.

Ecological Scarcity 2006

The ecological scarcity method (Frischknecht et al. 2008b) evaluates the inventory results on a distance to target principle. The calculation of the eco-factors is based on one hand on the actual emissions (actual flow) and on the other hand on Swiss environmental policy and legislation (critical flow). These goals are:

- Ideally mandatory or at least defined as goals by the competent authorities,

- formulated by a democratic or legitimised authority, and
- preferably aligned with sustainability.

The weighting is based on the goals of the Swiss environmental policy; global and local impact categories are translated to Swiss conditions, i.e. normalised. The method is applicable to other regions as well. Eco-factors were also developed for the Netherlands, Norway, Sweden (Nordic Council of Ministers 1995, Tab. A22 / A23), Belgium (SGP 1994) and Japan (Büsser et al. 2012; Miyazaki et al. 2004).

The ecological scarcity method allows for an optimisation within the framework of a country's environmental goals.

The environmental and political relevance is essential for the choice of substances. The environmental policy does not define goals for all potential pollutants and resources. Thus the list of eco-factors is limited. This particularly applies to substances with low or unknown environmental relevance in Switzerland and Europe (e.g. sulphate emissions in water bodies).

It has to be noted, that not all potential impact on the environment or health can be accounted for. However the choice of these three impact assessment methods provides a broad picture of the impacts.