Update and extension of the inventory data for energy gases

Final Report

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Zusammenfassung

Einleitung

Ziel des Projekts

Erdgas spielt heute als Energieträger eine wichtige Rolle, welche in Zukunft wohl bedeutender werden wird, wie die nachfolgende Prognose von BP (Abbildung links) zeigt. Gleichzeitig befinden wir uns in einem raschen Umbruch der Fördertechnologien (hin zu mehr shale gas), der Verteiltechnologie (von Pipelines zu Flüssigtransport als LNG – siehe Abbildung rechts) und dem Trend hin zu erneuerbaren Energiegasen.

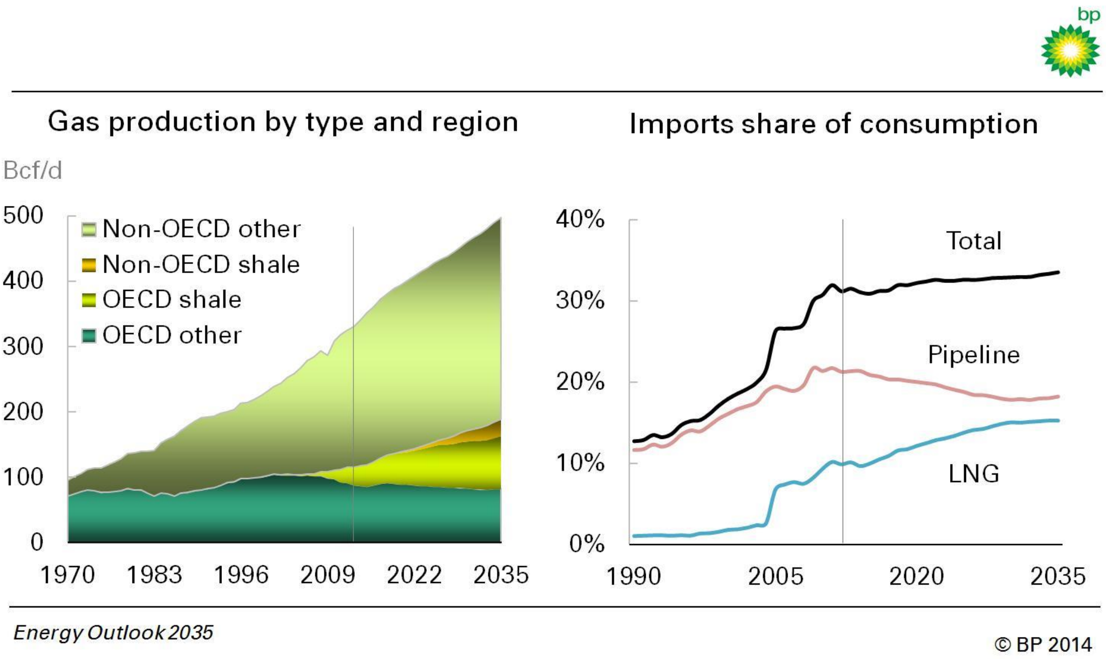

Figure 1: Trends im Gassektor (BP Amoco 2014): (links) Gasproduktion bei Typ und Region und (rechts) globale Importanteile.

Ziel dieses Projekts ist es daher, einerseits die für Ecoinvent verfügbare Datenbasis zu Energiegasen[1] zu aktualisieren und gegebenenfalls zu harmonisieren. Andererseits sollen die in verschiedenen Studien bereits bilanzierten neuen Energiegase un djene, von denen gegenwärtig eine Bilanz erstellt wird, für die Aufnahme in die Ecoinvent-Datenbank aufbereitet werden.

Vorgehen

Für die Erdgas-Produktionskette wurden die Datensätze von ecoinvent v2.2 als Basis für die aktualisierten Datensätze eingesetzt und folgende Daten integriert:

[1] Gasförmige Energieträger aus fossilen oder erneuerbaren Quellen

- Die erarbeiteten Daten der Studie „**Methanemissionen des Erdgas-Netzes**“, welche durch den Schweizerischen Verein des Gas- und Wasserfaches (SVGW) und das Bundesamt für Umwelt (BAFU) finanziert worden ist (Del Duce & Faist, 2014)
- Die aktuellen Daten zur Erdgasproduktion in Russland, Nigeria und dem Mittleren Osten sowie Korrekturen aus www.lc-inventories.ch (Natural gas supply (Schori and Frischknecht 2012))
- Die aktualisierten Datensätze zur konventionellen Erdgasförderung, insbesondere der Produktion und des Transports von LNG, wo eine neue Datengrundlage verfügbar ist (Heede 2006; Norwegian Oil and Gas Association 2014; UNFCCC 2014a; UNFCCC 2014b).

Für die Energiegase aus biogenen Quellen wurden folgende Vorgehensweisen gewählt:

- **Biogas**: ecoinvent beinhaltet verschiedene Biogas-Datensätze, die nicht ganz konsistent modelliert worden sind und nicht dem neusten Technologiestand entsprechen. Die verfügbaren Datensätze wurden aufdatiert und harmonisiert. Als Grundlage wurden die neusten Inventarstudien zu Biogas aus Bioabfall, aus Energiepflanzen und anderen Substraten (Dinkel et al. 2012; Stucki et al. 2012), die auf www.lc-inventories.ch veröffentlicht worden sind, sowie Studien von Quantis für Energie 360° (Biogasproduktion vom Bioabfall, Aufbereitung von Biogas aus Klärschlamm und Bioabfall (Del Duce and Zah 2015a) verwendet .
- **Holzmethan**: die Inventare für die Holzvergasung mit den Festbett- und Wirbelschichttechnologie wurden aktualisiert resp. erneuert, um den Technologiemix in der Schweiz besser abbilden zu können.
- **PtG (Power-to-Gas)**: In einer weiteren Studie von Quantis im Auftrag des BAFU wurden die Umweltauswirkungen verschiedener Power-to-Gas Produktionsketten untersucht. Aus dieser Arbeit wurden typische Inventare für diese Technologie entwickelt.

Erdgas

Übersicht der Struktur der Erdgasproduktionskette

Das folgende Bild stellt vereinfacht die Modellierung der Erdgasproduktionskette in der ecoinvent v3 Datenbank dar. Die Exploration, Förderung und Aufbereitung werden in den Datensätzen “natural gas production” beschrieben. Der Ferntransport in Pipelines wird durch die Datensätze “transport, pipeline, long-distance, NG (natural gas)” dargestellt. Diese Datensätze beinhalten die Verluste während dem Transport sowie den Energiebedarf für die Rekompression und die Infrastruktur für die Pipelines. Die importierenden Länder beziehen Erdgas aus verschiedenen produzierenden

Ländern, teilweise über Transitländer. Hier wird wie in den früheren Versionen von ecoinvent nur die schlussendliche Herkunft des Erdgases dargestellt. Der Herkunftmix wird in den Datensätzen "market for NG, high pressure" zusammengestellt. Der Markt-Datensatz beinhaltet die Emissionen für die Verteilung im Netz. Der Datensatz "natural gas reduction from high to low pressure" stellt die Verbindung zwischen den Märkten für Hochdruck- resp. Niederdruckerdgas dar.

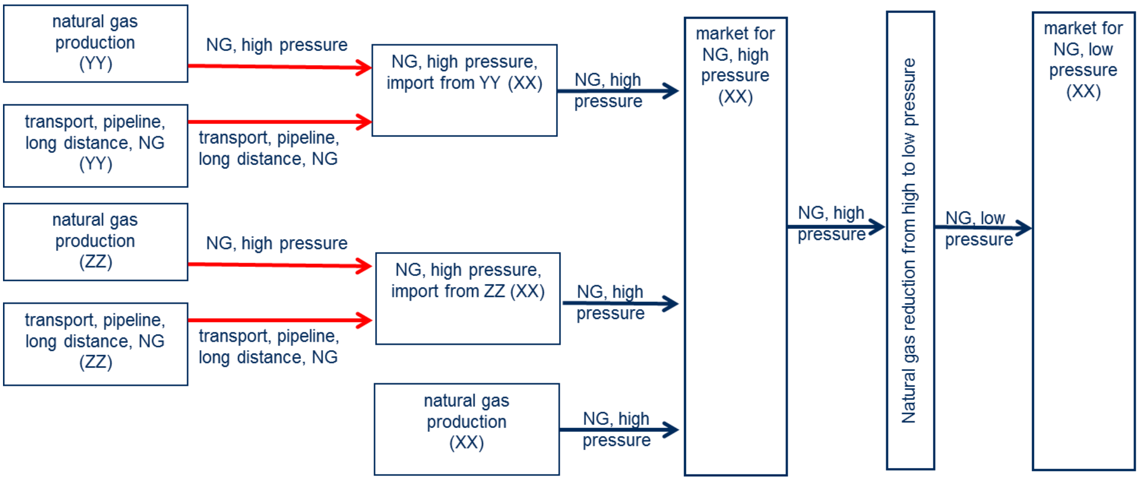

Figure 2: *Übersicht der Modellierung von der Erdgasproduktions- und Verteilungskette in der ecoinvent v3 Datenbank.*

Die LNG (Liquid Natural Gas)-Transportkette beinhaltet zusätzlich die Datensätze für die Verflüssigung, den Schiffstransport und die Verdampfung vom Erdgas.

Aktualisierungen

Die aktualisierten Datensätze werden im Detail in den Kapiteln 3.2, 3.3, 3.4, 3.5 und 3.6 beschrieben. Die Produktion von Erdgas und Erdöl in Norwegen konnte basierend auf dem neusten Bericht der Norwegian Oil and Gas Association (Norwegian Oil and Gas Association 2014) auf den aktuellsten Stand gebracht werden. Dies ist wichtig, da aus diesem Land ein grosser Teil der Erdgasproduktion für Europa stammt (s. Kap. 3.5). Die Produktionsdaten anderer Förderländer (Niederlanden, Russland) wurden punktuell verbessert, u.a. basierend auf dem Bericht von (Schori and Frischknecht 2012) zur Produktion in der Russischen Föderation. Die aktualisierten Datensätze werden im Detail im Kapitel 3.2 und 3.3 beschrieben.

Der ***Ferntransport*** von Erdgas in Pipelines und als LNG wurde bzgl. der Verluste und dem Energieverbrauch beim Schiffstransport aktualisiert. Dafür konnten neuere Quellen (Wuppertal Institute 2005; Sevenster and Croezen 2006; UNFCCC 2014a) genutzt werden. Die Angaben zu den neuen Inventarflüssen werden im Kapitel 3.4 präsentiert.

Die ***Zusammensetzung der Herkunftsländer*** im Konsummix von achtzehn europäischen Ländern wurde anhand der neusten BP-Statistik (BP Amoco 2014) aufdatiert. Die Herkunftsmixe werden im Detail im Kapitel 3.5 beschrieben.

Die Verluste sowie die Materialzusammensetzung der Erdgaspipelines im ***Schweizer Erdgasnetz*** wurden anhand der kürzlich erarbeiteten Studie (Del Duce and Faist Emmenegger 2014) in aktualisierten Datensätzen zusammengefasst. Diese werden im Kapitel 3.6 ausführlich beschrieben.

Biogas, Holz-SNG und strombasierte Treibstoffe

Übersicht

Das Ziel in diesem Projekt bezüglich der Energieträger Biogas, synthetisches Gas aus Holz (Holz-SNG) und strombasierte Treibstoffe („Power-to-Gas") ist es, die verfügbare Datensätze (hauptsächlich aus ecoinvent v2.2 und aus jüngsten Inventarprojekten) zu sammeln und zu harmonisieren.

Aktualisierungen

Die Harmonisierung der aktuell verfügbaren Inventare erfolgte, indem neue Datensätze für die ***Biogasproduktion und Bioabfallentsorgung*** erstellt wurden, welche die ecoinvent-Datensätze als Grundlage nehmen und spezifische Werte aus den Datensätzen von (Dinkel et al. 2012) integrieren. Die Ecoinvent-Inventare wurden gewählt, da sie die detaillierteste Dokumentation aufweisen. Die Werte von Dinkel et al. (2012) wurden dann genutzt, um die ecoinvent-Inventare zu vervollständigen oder wenn der Vergleich mit der Studie von Del Duce and Zah (2015a) darauf hinwies, dass diese Werte geeigneter sind. Die Datensätze werden in Detail im Kapitel 4.1 beschrieben.

Synthetisches Erdgas (SNG) aus Holz ensteht durch Holzvergasung mit anschliessendem Methanisierungsschritt (Jungbluth et al. 2007). Ecoinvent v2.2 berücksichtigt zwei mögliche Vergasungsprozesse: Festbett- und Wirbelschichtvergasung. Die Daten, die in der Hotspot-Analyse von Del Duce and Zah (2015b) gesammelt wurden, erlaubten eine Aktualisiserung der Datensätze für die Holzvergasung. Diese Datensätze beinhalten die nötige Infrastruktur und notwendigen Ressourcen für die Vorbereitung des Holzes, die Vergasung, die Reinigung des Synthesegases und die Aufbereitung des SNG zu Erdgasqualität. Die Datensätze werden ausführlich im Kapitel 4.2 beschrieben.

Für strombasierte Energieträger (Power-to-Gas) existieren noch keine Inventare in der ecoinvent Datenbank. Die kürzlich erarbeitete Studie von Quantis über diese Technologie erlaubt es, typische Prozesse für die Herstellung von Methan oder Wasserstoff aus Strom zu bilden. Die in dieser Kette beschriebenen Schritte sind die Elektrolyse, die CO_2-Abscheidung aus Abgasen und aus der Atmosphäre sowie die Methanproduktion.

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Abbreviations and acronyms

CO_2	Carbon Dioxide
DZ	Algeria
GHG	Greenhouse gas
GLO	Global / world average
HDPE	High density polyethylene
IPCC	Intergovernmental Panel on Climate Change
ISO	International Organization for Standardization
kWh	Kilowatt-hour = 3,600,000 joules (j)
LCA	Life Cycle Assessment
LCI	Life Cycle Inventory
LCIA	Life Cycle Impact Assessment
LNG	Liquefied natural gas
MJ	Megajoule = 1,000,000 joules, (948 Btu)
NG	Natural gas
NGL	Natural Gas Liquids
Nm^3	Norm cubic meter
OCE	Ocean
PEM	Polymer electrolyte membrane
RME	Middle East Region
Sm^3	Standard cubic meter; 1 Sm^3 equals approximately 1 Nm^3
SNG	Synthetic natural gas
SOEL	High temperature electrolysis

1 Introduction

1.1 Energy gases

The available life cycle inventory data for energy gases (gaseous energy sources from fossil or biogenic origin) in the ecoinvent database is partly outdated with regard to natural gas and, with regard to biogenic sourced gas, incomplete and partly not consistent. Natural gas and gas from biogenic sources, however, play today an important role as fuel sources and will be even more in the future, as the projected future consumption from BP shows in Figure 3 (left). Simultaneously, the technologies for transport of natural gas change rapidly, as Figure 3 on the right shows, with a trend to more LNG distribution.

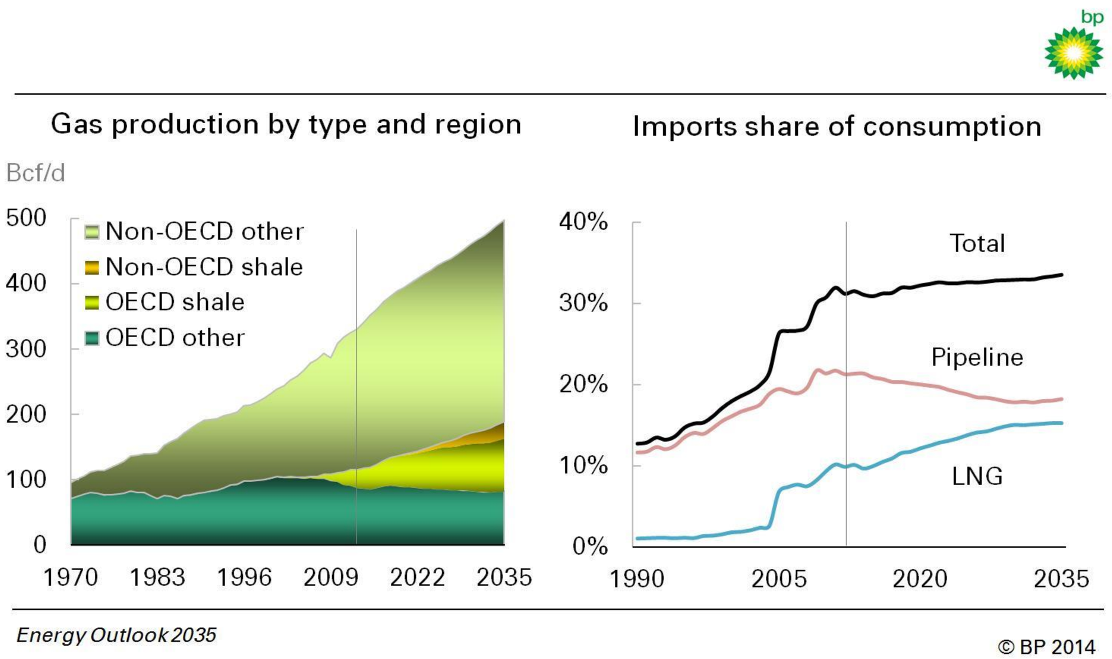

Figure 3: Trends in the gas sector (BP Amoco 2014): (left) gas production by type and region and (right) global import shares.

1.2 Aim of the project and used approach

Aim of this project was therefore to update the data basis for energy gases. Moreover, the data and inventories gathered in various completed or current studies should be made available for the ecoinvent version 3 database.

1.2.1 Natural gas

In this part of the project, starting from ecoinvent v2.2 original natural gas datasets, new inventories were developed by:

- Integrating the data from the study „Methanemissionen des Erdgas-Netzes“ (methane emissions of the natural gas network in Switzerland and the upstream processes) from the study mandated by the Swiss natural gas association (SVGW) and the Swiss Federal Office for the Environment (FOEN/BAFU) (Del Duce & Faist, 2014)
- Taking into account recent data for natural gas production in the Russian Federation, North African Countries and the Middle East from www.lc-inventories.ch (Natural gas supply (Schori and Frischknecht 2012))
- Updating the upstream supply chain (production, processing and transport of natural gas) where new data were available.

1.2.2 Gas from alternative sources

- **Biogas**: ecoinvent contains various biogas datasets, which are however not modelled consistently and do not represent the latest state of the technology. The available datasets were updated and harmonised in this project based on recent studies published on www.lc-inventories.ch (biogas from biowaste, from energy crops and from other substrates) and the studies made for Energie 360° by Quantis (biogas production from biowaste, processing (upgrading) of biogas from sewage sludge and biowaste to biomethane quality). The specific references and data sources are detailed in Chapter 3.6.
- **PtG (Power-to-Gas)**: Quantis conducted a study on the environmental impacts of several power-to-gas pathways mandated by the the Swiss Federal Office for the Environment (FOEN/BAFU). Typical inventories for this technology were developed in this project.
- **Methane from wood**: An inventory for synthetic natural gas production already exists in ecoinvent v2.2. It is based on the process developed in Güssing, Austria (fluidized bed reactor). Since it is expected that fixed bed gasification will also become a relevant option in Switzerland, an inventory for this technology was developed.

2 Methodology

2.1 Data sources

2.1.1 Natural gas

In this study we updated the ecoinvent v2.2 datasets on natural gas and energy gases based on the original v2.2 datasets and new and more recent sources. The new datasets and the datasets they replace are described in the following chapters. The original datasets were published in the natural gas ecoinvent report (Faist Emmenegger et al. 2007) and had been partly updated in Schori and Frischknecht (2012). We based our update on these datasets, together with the newest publication like the one on methane emissions (Del Duce and Faist Emmenegger 2014) as well as further literature such as the latest environmental report for the Norwegian gas production (Norwegian Oil and Gas Association 2014), the study of the Wuppertal institute on methane emissions from the pipeline transport from the Russian Federation (Wuppertal Institute 2005) or national reporting to UNFCCC from producing countries (MATET 2010; UNFCCC 2014a; UNFCCC 2014b). The literature used in this project is described in the single chapters and listed in the reference list at the end of this document.

Moreover, (Exergia - E3M Lab -COWI 2014) presents a review of available recent data and description of planned data collection from industry. As the publication is only an interim report, the data provided is still scarce. However, this publication is very promising in terms of update of the natural gas supply chain. We used this study to derive and update the transport distances from the natural gas production fields to the importing country, as the modelling of the supply chain in version 3 of the ecoinvent database allows differentiating the import distance for each country. This is particularly relevant in the case of import from Russia, where the leakages from gas transport via pipeline are significant for the overall results of the supply chain and where the distance can vary between 3’000km (distance from Urengoy field to Finland) and 6’000km (to the Netherlands).

While it was possible for the first versions of the ecoinvent database (1.0 to 2.2) to rely on environmental reports in the data collection for natural gas production, this source of data almost disappeared, as the EHS or sustainability reports nowadays contain only little specific data. Further, as many natural gas companies have been integrated in bigger holdings (e.g. NAM was integrated into Shell), the sustainability reports focus on the data of the entire holding without addressing the details of local infrastructure. It is therefore to hope that the study on actual data for diesel, petrol, kerosene and natural gas (Exergia - E3M Lab -COWI 2014) will be able to provide actual and accurate industry data in the next years.

2.1.2 Methane and fuels from renewable pathways: biogas from biowaste, synthetic natural gas from wood and electricity based fuels.

Next to fossil natural gas, available datasets addressing biogas from biowaste, synthetic natural gas from wood and fuels from renewable electricity have also been harmonised and made public within this project.

Data concerning biogas form biowaste and the disposal of biowaste has been published in the original ecoinvent v2.2 report nr. 17 “Life Cycle Inventories of Bioenergy” (Jungbluth et al. 2007), as well as in two more recent reports (Stucki et al. 2011; Dinkel et al. 2012). Further, data on a current-technology biowaste disposal and biogas production plant in Switzerland is available from(Del Duce and Zah 2015a).

With respect to synthetic natural gas (SNG) from wood, the main source of data is the ecoinvent report on Bioenergy (Jungbluth et al. 2007) with an update of some aspects presented in Del Duce and Zah (2015b).

Finally, data addressing the production of fuels from renewable electricity has been published in Spielmann et al. (2015).

2.2 Characteristics of the gases

2.2.1 Composition of the Swiss natural gas

For the methane content of Swiss natural gas, we use actual industry data as shown in Table 1.

	Natural gas, CH
	kg / Nm^3
Methane	0.652
Ethane	0.033
Propane	0.014
Butane	0.007
Other HC	0.003
CO_2	0.012
N_2	0.066

Table 1: Composition of the natural gas distributed in Switzerland. The concentrations were where necessary scaled to Nm^3. Sources: (Del Duce and Faist Emmenegger 2014 (methane); Faist Emmenegger et al. 2007 (other substances)).

The lower heating value is 36.4 MJ/Nm^3 and the higher heating value 40.5 MJ/Nm^3 (Del Duce and Faist Emmenegger 2014).

For raw natural gas and natural gas from other origins, we use the data as provided in Faist Emmenegger et al. (2007), which was also taken over in Schori and Frischknecht (2012).

2.2.2 Standardized calorific value for natural gas in ecoinvent v3

The ecoinvent version 3 database uses a standardized calorific value for natural gas (39 MJ/m^3), while the energy content as well as the composition of natural gas can vary depending on the origin. For the calculations of the dataset exchanges, we use the specific natural gas composition as described in in (Faist Emmenegger et al. 2007) / (Schori and Frischknecht 2012). We adapt the datasets to the standard calorific value of the version 3 by scaling the reference flow and the production volumes according to the energy content of the gas as described in Faist Emmenegger et al. (2007) and Schori and Frischknecht (2012).

BP (BP Amoco 2014) gives in its statistics a conversion value of 37.8 MJ/m^3 for natural gas[2]. We use this value here to scale production and trade data from this statistic to cubic meters in ecoinvent v3. For the statistics of the Norwegian Oil and Gas Association, the LHV value is 36.04 MJ/Sm^3 [3]. This value is applied in the Norwegian gas production.

2.2.3 Properties of biogas and SNG

The new biogas datasets have been modelled starting from the original ecoinvent v2.2 inventories and are based on the same biogas properties. As such, with respect to the gas composition, 67 % methane and 32 % carbon dioxide were assumed for the two major contributions in biogas from biowaste (Jungbluth et al. 2007). After upgrading, these two components reach ≥ 96 % for methane and ≤ 2 % in the case of carbon dioxide. For SNG, the same composition as upgraded biogas has been assumed.

2.3 Inventories and documentation

The present report describes the methodological choices as well as the data used to produce the inventories. Where necessary it refers to previous studies without repeating their content.

The inventories are available in the ecospold 2 format for the natural gas supply chain to comply with the ecoinvent version 3 structure of the chain and so to allow a swifter integration in the version 3.3 of the ecoinvent database. For the biogas chain, the inventories are available in the Simapro 8 format csv.

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[2] 1 cubic meter natural gas in (BP Amoco 2014) corresponds to 0.9 kg oil equivalent. 1 kg oil equivalent corresponds to 42 MJ. The source does not precise if the cubic meters are standard or norm cubic meters.

[3] Using following conversion factors: 7.33 barrels/tonne (BP Amoco 2014); 0.159 Sm^3 (standard cubic meter) per barrel; 1'000 Sm^3per Sm^3oil equivalent (oe) (Norwegian Oil and Gas Association 2014); 42 MJ/kg oe (BP Amoco 2014).

3 Natural gas, updated datasets

3.1 Overview

The following picture describes the modelling of the natural gas supply chain in the ecoinvent v3 database. The exploration and production of natural gas is described in the datasets “natural gas production (YY)[4]”. The transport in long-distance pipelines is described in the datasets “transport, pipeline, long-distance, NG (natural gas), (YY)”. These datasets contain the leakage of natural gas during transport as well as the energy consumption for re-compression and the infrastructure needed for the pipeline. The natural gas is then mixed in the markets of the various countries, on the level high pressure, representing the consumption mix. The market contains the emissions due to distribution in the network. The dataset “natural gas reduction from high to low pressure” makes the link to the market for low pressure natural gas.

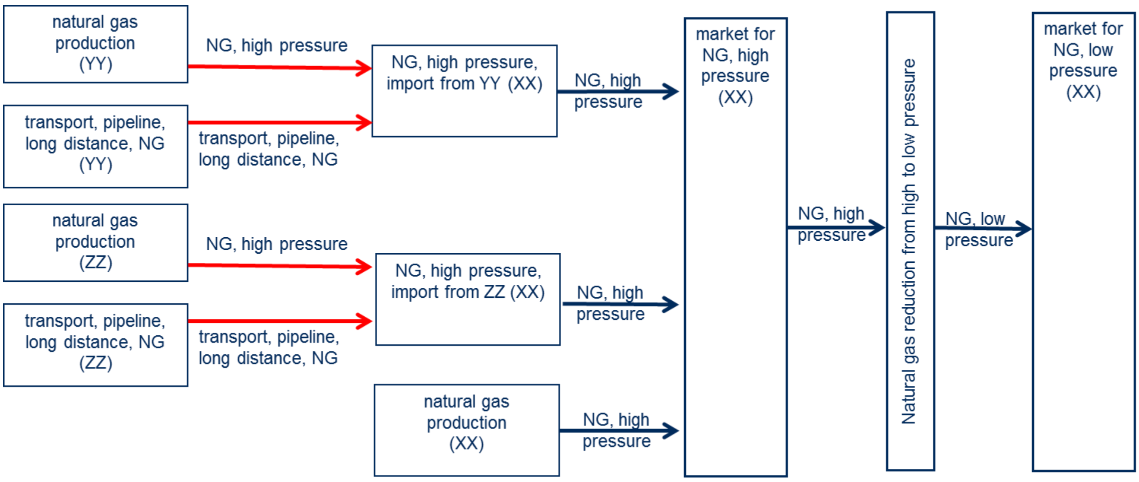

Figure 4: Overview of the modelling of the natural gas supply chain in the ecoinvent v3 database. XX, YY, ZZ stand for a specific country or region.

For the LNG supply chain, the model contains more datasets to describe the liquefaction, transport as LNG and evaporation of the natural gas.

3.2 Natural gas production

3.2.1 Petroleum and gas production in Norway

Norway is the major natural gas producer in Europe. The natural gas production on the Norwegian continental shelf has been continuously growing since 2000, while the oil production has been decreasing in the same time.

[4] YY stands for a specific country or region.

Reporting year	Net oil	Gross oil	Net gas	Gross gas	Net condensate	Gross condensate	Net NGL
2000	181 181	182 126	49 748	90 385	6 277	8 847	7 225
2001	180 884	182 071	53 895	95 041	6 561	9 310	10 924
2002	173 649	173 391	65 501	107 521	8 020	11 895	11 798
2003	165 475	164 295	73 124	118 265	11 060	15 585	12 878
2004	162 777	161 064	78 465	127 753	9 142	15 130	13 621
2005	148 137	144 776	84 963	130 807	8 422	16 395	15 735
2006	136 577	131 396	87 613	129 533	7 989	17 614	16 672
2007	128 277	119 538	89 662	136 697	3 474	16 544	16 577
2008	122 668	113 335	99 231	141 269	4 180	17 276	16 022
2009	115 443	106 116	103 464	144 526	4 421	17 364	16 048
2010	104 333	96 293	106 421	145 017	4 121	15 305	15 457
2011	97 480	89 683	103 353	141 538	4 551	15 152	16 294
2012	89 188	81 916	114 574	152 661	4 548	15 022	17 707
2013	84 945	79 669	108 746	149 070	3 974	12 355	17 685

Table 2: Oil and gas production on the Norwegian continental shelf (NCS) since 2000, for oil in million Sm^3, for gas in billion Sm^3 (Norwegian Oil and Gas Association 2014). NGL: Natural Gas Liquids.

The Norwegian Oil and Gas Association publishes a very detailed environmental report every year. We used the latest at the moment of the project (Norwegian Oil and Gas Association 2014) to update the data for oil and gas production for 2013. We use the same structure and assumptions as in Schori and Frischknecht (2012), which describes the situation for the year 2010.

This source reports an overall quantity of 4.32 E+08 Nm^3 flared gas and 2.01 E+07 kg of methane, which corresponds to 6.01 E-05 m^3 flared gas /MJ produced and 2.58 E-06 kg methane emissions /MJ.

Production Norway		OLF 2011; (Schori and Frischknecht 2012)	(Norwegian Oil and Gas Association 2014)	Comment / Table number from (Norwegian Oil and Gas Association 2014)
Reference products				
Crude oil production	kg	1.07E+11	8.25E+10	Incl. condensates
Natural gas production	Nm3	1.12E+11	1.04E+11	without injected gas; converted from Sm^3 [5]
Intermediate exchanges				
Oil crude in ground	kg	1.07E+11	8.25E+10	based on oil production
Natural gas in ground	Nm3	1.12E+11	1.04E+11	based on natural gas production
water salt ocean	m3	1.67E+08	1.30E+08	Table 2: injected sea water
water salt sole	m3	1.73E+08	1.61E+08	Table 17, produced water
chemicals organic	kg	7.24E+07	6.25E+08	Table 18
Sweet gas, burned in gas turbine, production	Nm3	3.78E+09	4.24E+09	Table 2
Natural gas burned in production flare	Nm3	3.72E+08	4.32E+08	Table 2
Diesel burned in electric generator	MJ	1.17E+10	1.082E+10	scaled from 2010 data with oil& gas production
Transport lorry	tkm	1.66E+06		transport is automatically included in the market activities
Well for exploration	m	5.86E+05	5.97E+05	scaled from 2010 data with natural gas production
drying natural gas	Nm3	6.74E+10	6.87E+10	same proportion as 2010
platform crude oil / offshore platform, petroleum	unit	5.44E+00	4.214E+00	standard data, based on production volume
plant offshore gas / offshore platform, natural gas	unit	4.09E+00	3.740E+00	standard data, based on production volume
waste, non-hazardous	kg	1.48E+07	2.90E+07	Table 28
hazardous waste	kg	1.81E+06	7.93E+06	Table 29, without drilling waste
Emissions in air				
methane fossil	kg	1.97E+07	2.01E+07	Table 24,25,27

[5] Unfortunately neither Nm3 (normal cubic meter) or Sm3 (standard cubic meter) are complete definitions in themselves. It is essential to know the standard reference conditions of temperature and pressure to define the gas volume since there are various debates about what normal and standard should be.

Most commonly used reference conditions are: Normal cubic meter (Nm3) - Temperature: 0 °C, Pressure: 1.01325 barA; Standard cubic meter (Sm3) - Temperature: 15 °C, Pressure: 1.01325 barA. (http://www.oxywise.com/en/content/news/what-is-the-difference-between-nm3-and-sm3) The 5% correspond also to the conversion value given in (Norwegian Oil and Gas Association 2014).

Production Norway		OLF 2011; (Schori and Frischknecht 2012)	(Norwegian Oil and Gas Association 2014)	Comment / Table number from (Norwegian Oil and Gas Association 2014)
ethane	kg	2.03E+06	2.07E+06	based on composition of natural gas
propane	kg	5.22E+05	5.33E+05	based on composition of natural gas
butane	kg	1.65E+05	1.68E+05	based on composition of natural gas
carbon dioxide	kg	1.13E+09	3.55E+07	Table 24, other sources (without well testing, flaring, combustion)
nmVOC	kg	2.67E+06	2.73E+07	Table 25,27
Nitrogen oxides	kg	1.70E+04	2.00E+03	Table 24, other sources (without well testing, flaring, combustion)
Sulfur dioxide	kg	3.99E+05	0.00E+00	Table 24, other sources (without well testing, flaring, combustion)
PAH	kg	9.00E+01	5.00E+01	Table 23
polychlorinated biphenyls	kg	1.70E+00	0.87	Table 23
dioxin	kg	8.00E-05	3.96E-05	Table 23
mercury	kg	2.75E-01	2.80E-01	scaled from 2010 data with natural gas production
radon	kBq	1.10E+07	1.12E+07	scaled from 2010 data with natural gas production
Emissions in water (ocean)				
Oils	kg	9.55E+04	1.69E+06	Table 9
PAH	kg		1.57E+05	Table 9
phenols	kg		5.03E+05	Table 12
arsenic	kg	8.95E+02	6.22E+02	Table 11
barite	kg	7.07E+06	7.32E+06	Table 11
cadmium	kg	2.20E+01	6.00E+00	Table 11
chromium	kg	2.25E+02	1.07E+02	Table 11
copper	kg	8.90E+01	1.09E+02	Table 11
lead	kg	2.39E+02	6.40E+01	Table 11
mercury	kg	9.00E+00	8.00E+00	Table 11
nickel	kg	2.00E+02	1.18E+02	Table 11
zinc	kg	6.95E+03	3.64E+03	Table 11
iron	kg	8.26E+05	6.45E+05	Table 11
Benzene	kg		8.92E+05	Table 10: ethylbenzene approximated with benzene
Toluene	kg		7.11E+05	Table 10
Xylene	kg		2.52E+05	Table 10

Production Norway		OLF 2011; (Schori and Frischknecht 2012)	(Norwegian Oil and Gas Association 2014)	Comment / Table number from (Norwegian Oil and Gas Association 2014)
Acetic acid	kg		4.85E+07	Table 13
Formic acid	kg		1.29E+06	Table 13
Propionic acid	kg		3.09E+06	Table 13
Carboxylic acid, unspecified	kg		8.61E+05	Table 13
Water	kg		1.61E+08	Table 17, produced water

Table 3: Inventory of the oil and gas production on the Norwegian continental shelf 2010 and 2013. Sources: (Schori and Frischknecht 2012; Norwegian Oil and Gas Association 2014).

3.2.2 Natural gas production in Russia

The dataset on natural gas production of ecoinvent v2.2 was updated in Schori and Frischknecht (2012). We compared the key figures used in the recent report with those indicated in the Wuppertal Institute study (Wuppertal Institute 2005), in ecoinvent v2.2 and in the UNFCCC report 2014 with reference year 2012 (UNFCCC 2014a).

	Ecoinvent v2.2	(Wuppertal Institute 2005)	(Schori and Frischknecht 2012)	UNFCCC 2014 (reference year 2012)
Fugitive emission rates	0.375 %	0.11 %	0.5 %	N/A
Flaring rate	0.250 %	N/A	0.206 %	0.33 %
Combustion	0.989 %	N/A	0.536 %	N/A

Table 4: Comparison of key figures of the natural gas production in the Russian Federation.

The Ecoinvent v2.2 and Schori 2012 data for fugitive emission rates are global data for the Russian production, whereas the Wuppertal figure is based on measurement in a single gas production field. There is no value for the venting in the UNFCCC report. We therefore do not change the data from the study of Schori and Frischknecht (2012), which also have more recent data for combustion. For flaring, we use information from the UNFCCC report 2014, which reports and overall burning of associated petroleum gas of 17.08 billion m^3 with a recovery rate of 76 %. We allocate the flared gas to both petroleum and gas production based on their calorific value.

Name	Value	Unit	Comment
Flared quantity	17.08	billion m^3	Overall associated petroleum gas flared
	4.099	billion m^3	Calculated with 76 % recovery rate
Gas production	2.38E+13	MJ	Original value: 654'650*10E+6 m^3
Oil produced	2.09E+13	MJ	Original value: 497'425 kt
Specific flared quantity	9.17E-05	m3/MJ	
Flaring rate	0.33 %	m3/m3	

Table 5: Calculation of the flaring rate (UNFCCC 2014, Table 3.39).

For the rest of the inventory flows, we use the data from Schori and Frischknecht (2012).

3.2.3 Petroleum and gas production in the Netherlands

NAM (Nederlandse Aardolie Maatschappij BV – NAM), the main producer of gas in the Netherlands, does not publish an environmental report containing technical data anymore. We therefore update the flaring and venting of the natural gas production based on the Dutch national inventory report (UNFCCC 2014b). The Dutch national inventory reports 318 ton of methane emission from flaring and 14'540 ton of methane emissions from venting. The overall production of oil and gas is 44 TJ oil and 2419 PJ gas.

	Methane emission (total)	Unit	Emission factor	Unit
Flaring	318.04	ton	1.31E-07	kg CH_4 /MJ
Venting	14540	ton	6.01E-06	kg CH_4 /MJ

Table 6: Total methane emissions of the oil and gas producing sector and derived emission factors (UNFCCC 2014b).

The emission factor for venting corresponds to a share of 0.0322 % natural gas vented, which is similar to the value in ecoinvent v.2.2 (0.026 %) or of a previous report from NAM in 2004 (0.02 %). The flaring factor (0.0007 %) derived from the UNFCCC figures is however much lower as previously (v2.2:0.09 %; NAM 2004: 0.058 %).

3.2.4 Natural gas production in Algeria, Middle East, Germany, Petroleum and gas production in the United Kingdom

The datasets on natural gas production in the North African Countries (Algeria, Lybia, Egypt) and in the Middle East were updated in (Schori and Frischknecht 2012). The dataset for North African Countries is based on the Algeria data, where most of the flows are approximations from the Russian dataset. The Middle East dataset is the copy of the Algerian dataset. We use this data as they base on 2010 data and no more recent or more accurate data was readily available.

The datasets for the production in Germany and in the United Kingdom (combined oil and gas production) were not updated in (Schori and Frischknecht 2012). It was not possible in this project budget to update this data, as no data was easily available for these countries..

3.2.5 Updated datasets

Dataset v2.2	Location	Activity name (new)	Reference products	Unit
combined offshore gas and oil production	NO	petroleum and gas production, off-shore, NO, 2013-2013	natural gas, high pressure petroleum	m^3
natural gas, at production onshore	RU	natural gas, at production onshore, RU, 2000 - 2012	natural gas, high pressure	m^3
combined offshore gas and oil production	NL	petroleum and gas production, off-shore, NL, 2000 - 2012	natural gas, high pressure	m^3
combined offshore gas and oil production	NL	petroleum and gas production, on-shore, NL, 2000 - 2012	natural gas, high pressure	m^3

Table 7: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3.

3.3 Processing

3.3.1 Natural gas sweetening

No new information is readily available for gas sweetening. Schori and Frischknecht (2012) reports a natural gas consumption of 0.0325 Nm^3 per Nm^3 sweetened, which should correspond to the quantity vented. This is however not consistent with the reported methane emissions (2.0 E-05 kg/Nm^3) and the methane content of German natural gas (0.69 kg/Nm^3). We therefore correct this value to 2.9 E-05 Nm^3 per Nm^3, which corresponds to a venting rate of 0.003 %.

3.3.1.1 Updated datasets

Dataset v2.2	Location	Activity name (new)	Reference flow	Unit
		Sweetening, natural gas, GLO, 2012 - 2012	Sweetening, natural gas	m^3
Sweetening, natural gas	DE	Sweetening, natural gas, DE, 2012 - 2012	Sweetening, natural gas	m^3

Table 8: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3.

3.4 Transport of natural gas for import

3.4.1 Transport per pipeline

3.4.1.1 Transmission from Russia

The transport from natural gas from the Russian Federation to Europe occurs on a long distance (over 4’000 km) with a high emission factor in comparison to transmission in Europe. It is therefore important that this emission factor is well up to date.

The best documented and most detailed study on this subject is the study from the Wuppertal institute (Wuppertal Institute 2005), which conducted a measurement campaign on the export pipeline system from Siberia to West Germany through the Northern and Central Corridor. The authors report an overall average leakage of 1 % (0.6 %-2.4 %) for the transport from Siberia to the West German border. Related to an average distance of 4’900 km (the Northern Corridor has a length of 4’300 km, the Central Corridor 5’500 km), this gives a value of 0.2 % per 1’000 km, which is the value we use here.

As a comparison, the national inventory of the Russian Federation reports in (UNFCCC 2014a) a methane leakage rate of 0.89 kg methane/kg natural gas or 0.91 % on a volume basis (m^3 gas / m^3 gas)[6]. This rate applies to the total amount transmitted in the Russian Federation (541’000 million m^3); it therefore also contains the amount consumed in the Russian Federation (exports amounted to about 200’000 million m^3 in 2013). Gazprom reports an average transmission distance of 3’300 km[7]. With these figures, we obtain a leakage rate of 0.28 %, which is about 30 % higher than the rate calculated with the values in (Wuppertal Institute 2005) or in (Schori and Frischknecht 2012), who uses for a similar figure in the UNFCCC inventory from 2011 a distance of 4'200 km (distance from Siberia to the Russian border), with a result of 0.218 % per 1’000km. Because the UNFCCC value is a very global one, the distance this value should be related to has high uncertainties and as the UNFCCC value also contains transmission in the land itself, we prefer to use the value from (Wuppertal Institute 2005).

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[6] Assuming the natural gas composition of the Russian Federation as described in (Faist Emmenegger et al. 2007; Schori and Frischknecht 2012) with 0.716 kg methane / Nm^3 and 0.73 kg natural gas / Nm^3.

[7] “In 2010, average distance of gas transmission was over 2’500 kilometers for domestic supplies and almost 3’300 kilometers for export supplies”.http://www.gazprominfo.com/articles/natural-gas-transportation/, retrieved on the June 18, 2015.

Source	Total	Emission factor per 1'000 km	Comment
Ecoinvent 2.2	1.4 %	0.23 %	Value Zittel 1998
Schori 2012	1.31 %	0.218 %	UNFCCC 2011 (0.9 % total), 4'200 km, scaled to 6'000 km
Eigene Berechnungen, UNFCCC 2014		0.28 %	UNFCCC 2014 (0.9 % total), average distance of 3'300 km (according to Gazprom).
Wuppertal institute 2005	1 % (0.6-2.4 %)	0.18 % (Marcogaz, 5'500 km) 0.204 % (4'900 km) 0.233 % (4'300 km)	Measurement campaign of Wuppertal Institute and the Max Planck Institute, corridors to Europe, 4'300 / 5'500 km long (average = 4'900km)

Table 9:Emission factors of the pipeline transport from the Russian Federation in various sources.For the rest of the data, we use the updated data as in Schori and Frischknecht (2012).

3.4.1.2 Transmission in Europe

The leakage rate (0.026 %) used in existing datasets (Faist Emmenegger et al. 2007; Schori and Frischknecht 2012) for transmission in Europe stem from literature from 1994/2000 (Battelle 1994; Reichert and Schön 2000). We use here a more recent source (Sevenster and Croezen 2006), which is based on data collected by Marcogaz from several natural gas companies. The new leakage rate is 0.019 %. It is applied to all Western European countries[8] .

3.4.1.3 Transmission in North African Countries and Middle East

The report on greenhouse gas emissions for Algeria (MATET 2010) does not give any specific figures for natural gas transmission in this country.

Similarly to (Marcogaz 2010), we use the same leakage rate for these countries as for the Russian Federation as a conservative assumption.

[8] Portugal, Spain, France, Italy, Greece, Austria, Germany, Luxemburg, Belgium, The Netherlands, United Kingdom, Denmar, Norway, Sweden, Finland.

3.4.1.4 Updated datasets

Dataset v2.2	Location	Activity name (new)	Reference flow	Unit
transport, natural gas, pipeline, long distance	DE	transport, pipeline, long distance, natural gas, DE 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, pipeline, long distance	NL	transport, pipeline, long distance, natural gas, NL 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, pipeline, long distance	RU	transport, pipeline, long distance, natural gas, RU 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, pipeline, long distance	RER	transport, pipeline, long distance, natural gas, RER without DE+NL+NO, 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, offshore pipeline, long distance	DZ	transport, pipeline, offshore, long distance, natural gas, DZ, 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, offshore pipeline, long distance	NO	transport, pipeline, offshore, long distance, natural gas, NO, 2000-2012	natural gas, high pressure	metric ton * km
-	-	transport, pipeline, offshore, long distance, natural gas, GLO, 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, onshore pipeline, long distance	DZ	transport, pipeline, onshore, long distance, natural gas, DZ, 2000-2012	natural gas, high pressure	metric ton * km
transport, natural gas, onshore pipeline, long distance	NO	transport, pipeline, onshore, long distance, natural gas, NO, 2000-2012	natural gas, high pressure	metric ton * km
-	-	transport, pipeline, onshore, long distance, natural gas, GLO, 2000-2012	natural gas, high pressure	metric ton * km

Table 10: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3.

3.4.2 LNG transport

3.4.2.1 Liquefaction plant

Data for the liquefaction plant in existing datasets (Faist Emmenegger et al. 2007; Schori and Frischknecht 2012) is based relatively old data, partly stemming from a reference book on natural gas of 1999. We use here the global average data for the existing capacity at that time as shown in a more recent study (Sevenster and Croezen 2006). This is a conservative assumption as the values reported in that publication for capacity under construction show lower gas consumption in this process (7.9-8.7 % compared to 9.9-12.9 % for 2006 existing capacity).

	Ecoinvent v2.2	Sevenster and Croezen 2006
Fugitive rate	0.05 %	0 %
Flaring rate	N/A	0.3 %
Gas consumption (total)	15 %	10.3 %

Table 11: Gas consumption, flaring and fugitive rates for the liquefaction plant. This includes the refrigeration system, auxiliary electricity and hot oil system.

3.4.2.2 LNG carriers

The dataset "transport, liquefied natural gas, freight ship" of ecoinvent version 2.2 was based on Italian data from 1999 and included only LNG as a fuel for the ship. The dataset was updated to reflect the fact that LNG carriers are operating globally and that they are mostly using both natural gas and heavy fuel oil as fuels (Heede 2006). We use here the scenario "middle use of energy" as described in Heede (2006).

	LNG	Unit	Heavy fuel oil	Unit
ecoinvent (SNAM 1999/2000)	0.73 %	%/1'000km		
Sagisaka & Inaba (1999)	0.51 %	%/1'000km		
MAN B&W	0.10 %	%/1'000 km	0.20 %	%/1'000 km
Heede 2006	0.17 %	%/1'000 km	0.034	MJ/tkm
This study (incl. return trip, empty); Based on Heede 2006	**0.34 %**	%/1'000 km		
	0.00429	**Nm^3/tkm**	**0.06789**	**MJ/tkm**

Table 12: Review of the energy consumption of LNG carriers, literature

The emissions of the energy consumption are modelled for natural gas resp. LNG with standard emissions factor of a turbine in ecoinvent for the LNG consumption and for heavy fuel oil with the dataset "heavy fuel oil, burned in refinery furnace".

	Emission factor turbine	Emissions from turbine
	kg/Nm^3	kg/tkm
Methane, fossil	2.27E-04	9.72E-07
Carbon dioxide, fossil	2.27E+00	9.72E-03
Carbon monoxide, fossil	1.59E-03	6.83E-06
NMVOC, non-methane volatile organic compounds, unspecified origin	3.98E-05	1.71E-07
Nitrogen oxides	7.72E-03	3.31E-05
Dinitrogen monoxide	3.98E-05	1.71E-07

Table 13: Emission factors used for the calculation of the LNG consumption and total emission values per tkm. The factors are the same as the one used in the ecoinvent v 2.2.

Exchange				transport, freight, sea, liquefied natural gas, GLO 2006	
Type	Name	Unit	Link	Amount	Comment
0 - ReferenceProduct	transport, freight, sea, liquefied natural gas	metric ton*km		1	
2 - ByProduct/Waste	bilge oil	kg		0.000218	
4 - ToEnvironment	NMVOC, non-methane volatile organic compou...	kg		3.72E-07	
4 - ToEnvironment	Water	m3		0.00168	Calculated value based on literature values and
4 - ToEnvironment	Water	m3		0.00952	Calculated value based on literature values and
4 - ToEnvironment	Methane, fossil	kg		7.02E-07	Calculated with average emissions from turbines for
4 - ToEnvironment	Nitrogen oxides	kg		3.042E-05	Calculated with average emissions from turbines for
4 - ToEnvironment	Dinitrogen monoxide	kg		1.56E-08	Calculated with average emissions from turbines for
4 - ToEnvironment	Carbon monoxide, fossil	kg		6.24E-06	Calculated with average emissions from turbines for
4 - ToEnvironment	Carbon dioxide, fossil	kg		0.008736	Calculated with average emissions from turbines for
4 - FromEnvironment	Water, salt, ocean	m3		0.0112	
5 - FromTechnosphere	port facilities	unit		7.23E-15	
5 - FromTechnosphere	freight ship, transoceanic	unit		2.43E-11	
5 - FromTechnosphere	natural gas, high pressure	m3		0.00429	includes return trip
5 - FromTechnosphere	maintenance, freight ship, transoceanic	unit		2.43E-11	
5 - FromTechnosphere	heavy fuel oil, burned in refinery furnace	MJ		0.068	includes return trip

Table 14: Exchanges of the activity dataset "transport, freight, sea, liquefied natural gas, GLO 2006".

3.4.2.3 Gasification (evaporation plant)

In the regasification terminals, LNG is evaporated at pipeline pressure. Key figures for the evaporation plant in Ecoinvent v2.2 (Faist Emmenegger et al. 2007; Schori and Frischknecht 2012) stem from data of an Italian company in a report dating from 2002. Here we use data based on a more recent European study (Sevenster and Croezen 2006), as in Del Duce and Faist Emmenegger (2014),.

	Ecoinvent v2.2	Updated values
fugitive emissions	0 %	0.01 %
combustion rate	1.6 %	0.43 %
Electricity (MJ/Nm^3)	-	0.042

Table 15: Fugitive emissions, combustion rate and electricity rate at the evaporation plant. Sources: Faist Emmenegger et al. (2007) and Sevenster and Croezen (2006) for the energy consumption and Del Duce and Faist Emmenegger (2014) for the fugitive emissions.

3.4.2.4 Updated datasets

Dataset v2.2	Location	Activity name (new)	Reference flow
natural gas, liquefied, at liquefaction plant	GLO	natural gas production, liquefied, GLO, 2012 - 2012	natural gas, high pressure
natural gas, at liquefaction plant	DZ	natural gas production, liquefied, DZ, 2012 - 2012	natural gas, high pressure
natural gas, liquefied, at liquefaction plant	RME	natural gas production, liquefied, RME, 2012 - 2012	natural gas, high pressure
transport, liquefied natural gas, freight ship	OCE	transport, freight, sea, liquefied natural gas, GLO 2006	transport, freight, sea, liquefied natural gas
natural gas, at evaporation plant	CH	Evaporation of natural gas, GLO, 2012 - 2012	natural gas, high pressure

Table 16: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3.

3.5 Representation of the trade movements

The country of origin of the natural gas imported in various European countries is calculated based on the trade movements of the natural gas in 2013 as described in (BP Amoco 2014) and, for the import from Norway and the Russian Federation to Switzerland, on the statistics of the Swiss natural gas industry for 2012 (Del Duce and Faist Emmenegger 2014).

The trade movements are modelled as following in the ecoinvent v3 database. The regional market (e.g. market for natural gas (NG), high pressure, CH) imports high pressure natural gas according to the production volumina of the datasets “natural gas (NG), high pressure, import from XX (CH)”, where XX here symbolises an origin country for the natural gas imported in Switzerland. The “production volumina” correspond to the import quantity of natural gas. The datasets “natural gas (NG), high pressure, import from XX (CH)” have a fixed link to the corresponding production country of the natural gas. The supply mix corresponds to the imports plus the domestic production. If a country has no specific dataset for its production, the supply mix consists only of the import shares. This is the case for Italy and Poland.

The imported quantities are described in the following chapters. In ecoinvent v2, only one dataset per origin was available, using an average distance. In ecoinvent v3, each market refers to specific import datasets, which use specific distances from the country of origin to the market. The datasets were created for all countries shown in Table 17 and Table 18.

3.5.1 European countries (1)

	Switzerland		Austria		Belgium		Czech Republic		Denmark		Finland		France		Germany		Greece	
PIPELINE	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3
Germany	5.2%	0.176	0.2%	0.02	0.0%	0.00	0.0%	0.00	0.3%	0.00	0.0%	0.00	0.0%	0.01	0.0%	8.22	0.7%	0.02
Netherlands	35.8%	1.203	0.3%	0.02	18.2%	5.40	0.0%	0.00	0.7%	0.01	0.0%	0.00	21.4%	6.51	23.4%	22.41	0.7%	0.02
Russian Federation	23.8%	0.800	79.4%	5.41	41.4%	12.25	65.2%	7.20	1.0%	0.01	100.0 %	3.50	27.1%	8.27	41.6%	39.84	89.0%	2.67
France	0.3%	0.010	0.0%	0.00	0.0%	0.00	0.0%	0.00		0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
Italy	0.3%	0.010	0.0%	0.00	0.0%	0.00	0.0%	0.00		0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
United Kingdom	0.4%	0.014	0.0%	0.00	8.5%	2.52	0.0%	0.00	0.1%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00
Norway	24.9%	0.835	20.1%	1.37	31.9%	9.45	34.8%	3.84	97.9%	1.33	0.0%	0.00	51.3%	15.66	35.0%	33.56	7.7%	0.23
Denmark				0.00		0.00		0.00		0.00		0.00		0.00		0.00		
Qatar	1.1%	0.035	0.0%	0.00	0.0%	0.00	0.0%	0.00		0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
Algeria	5.8%	0.195	0.0%	0.00	0.0%	0.00	0.0%	0.00		0.00	0.0%	0.00	0.1%	0.04	0.0%	0.00	2.0%	0.06
Nigeria	2.4%	0.082	0.0%	0.00	0.0%	0.00	0.0%	0.00		0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
Total import	100.0 %	3.360	100.0 %	6.81	100.0 %	29.62	100.0 %	11.04	100.0 %	1.36	100.0 %	3.50	100.0 %	30.50	100.0 %	95.80	100.0 %	3.00
LNG	%	bn m^3		bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3
Qatar	0 %	0.00	0 %	0.00	100.0 %	3.20	0 %	0.00	0 %	0.00	0 %	0.00	21.2%	1.75	0 %	0.00	0 %	0.00
Algeria	0 %	0.00	0 %	0.00	0.0%	0.00	0 %	0.00	0 %	0.00	0 %	0.00	64.3%	5.31	0 %	0.00	0 %	0.00
Nigeria	0 %	0.00	0 %	0.00	0.0%	0.00	0 %	0.00	0 %	0.00	0 %	0.00	14.5%	1.20	0 %	0.00	0 %	0.00
Total	0 %	0.00	0 %	0.00	100.0 %	3.20	0 %	0.00	0 %	0.00	0 %	0.00	100.0 %	8.26	0 %	0.00	0 %	0.00
Own production		0.00		0.00		0.00		0.00		2.61	0 %	0.00	0 %	0.00		7.51		0.00

Table 17: Supply mix based on (BP Amoco 2014) and corresponding amounts of imported natural gas from the origin countries. In the datasets, Denmark is approximated with Norwegian production, as the Danish production is also situated in the North Sea. Own production is shown in the corresponding row. All values in Sm^3.

3.5.2 European countries (2)

	Hungary		Ireland		Italy		Netherlands		Poland		Slovakia		Spain		Sweden		United Kingdom	
PIPELINE	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3
Germany		0.00	0.0%	0.00	0.0%	0.01	3.9%	0.83	0.5%	0.06	0.0%	0.00	0.3%	0.04	0.0%	0.00	0.0%	-
Netherlands	0.0%	0.00	0.0%	0.00	18.6%	9.58		-	0.5%	0.06	0.0%	0.00	0.3%	0.04	0.0%	0.00	24.0%	10.05
Russian Federation	100.0 %	5.90	0.0%	0.00	54.0%	27.88	38.1%	8.20	91.7%	10.48	100.0 %	5.33	3.9%	0.60	0.0%	0.00	3.7%	1.54
France		0.00	0.0%	0.00	0.0%	0.00	0.0%	-	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
Italy		0.00	0.0%	0.00	0.0%	0.00	0.0%	-	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-
United Kingdom	0.0%	0.00	100.0 %	4.87	0.0%	0.00	7.3%	1.56	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	0.00
Norway	0.0%	0.00	0.0%	0.00	2.7%	1.39	45.0%	9.69	5.8%	0.67	0.0%	0.00	21%	3.16	0.0%	0.00	72.4%	30.33
Denmark		0.00		0.00		0.00				0.00		0.00		0.00	100.0 %	1.09		
Qatar	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-	0.0%	0.00	0.0%	0.00	0%	0.00	0.0%	0.00	0.0%	-
Algeria	0.0%	0.00	0.0%	0.00	24.7%	12.75	5.7%	1.22	1.5%	0.17	0.0%	0.00	75%	11.48	0.0%	0.00	0.0%	-
Nigeria	0.0%	0.00	0.0%	0.00	0.0%	0.00	0.0%	-	0.0%	0.00	0.0%	0.00	0%	0.00	0.0%	0.00	0.0%	-
Total import	100.0 %	5.90	100.0 %	4.87	100.0 %	51.61	100.0 %	21.51	100.0 %	11.43	100.0 %	5.33	100.0 %	15.33	100.0 %	1.09	100.0 %	41.91
LNG	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3	%	bn m^3
Qatar	0 %	0.00	0 %	0.00	99.2%	5.20	0 %	0.00	0 %	0.00	0 %	0.00	35.5%	3.49	0 %	0.00	95.5%	8.61
Algeria	0 %	0.00	0 %	0.00	0.8%	0.04	0 %	0.00	0 %	0.00	0 %	0.00	32.9%	3.24	0 %	0.00	4.5%	0.41
Nigeria	0 %	0.00	0 %	0.00	0.0%	0.00	0 %	0.00	0 %	0.00	0 %	0.00	31.6%	3.11	0 %	0.00	0.0%	-
Total	0 %	0.00	0 %	0.00	100.0 %	5.24	0 %	0.00	0 %	0.00	0 %	0.00	100.0 %	9.83	0 %	0.00	100.0 %	9.01
Own production		0.00		0.00		7.09		68.68		4.18		0.00		0.00		0.00		36.48

Table 18: Supply mix based on (BP Amoco 2014) and corresponding amounts of imported natural gas from the origin countries. In the datasets, Denmark is approximated with Norwegian production, as the Danish production is also situated in the North Sea. Own production is shown in the corresponding row. All values in Sm^3.

3.5.3 Updated datasets

Dataset v2.2	Location	Activity name (new)	Reference flow	Unit
natural gas, production DE, at long-distance pipeline	RER	natural gas, high pressure, import from DE, XX, 2012 - 2012	natural gas, high pressure	m^3
natural gas, production DZ, at long-distance pipeline	RER	natural gas, high pressure, import from DZ, XX, 2012 - 2012	natural gas, high pressure	m^3
natural gas, production GB, at long-distance pipeline	RER	natural gas, high pressure, import from GB, XX, 2012 - 2012	natural gas, high pressure	m^3
natural gas, production NL, at long-distance pipeline	RER	natural gas, high pressure, import from NL, XX, 2012 - 2012	natural gas, high pressure	m^3
natural gas, production NO, at long-distance pipeline	RER	natural gas, high pressure, import from NO, XX, 2012 - 2012	natural gas, high pressure	m^3
natural gas, production RU, at long-distance pipeline	RER	natural gas, high pressure, import from RU, XX, 2012 - 2012	natural gas, high pressure	m^3

Table 19: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3. XX in the new activity name makes clear that the dataset is specific and exists for each importing country of Table 17 and Table 18. 2012-2012 indicates the time range of the data in the dataset.

3.6 Natural gas distribution in Switzerland

3.6.1 Infrastructure of the Swiss high and low pressure network

Between 1998 and 2012, several changes took place in the Swiss distribution network: the length of the pipelines for distribution in the Swiss network grew from around 14600 km to almost 19000 km. Furthermore, the cast iron pipelines were continuously replaced by polyethylene pipelines which have a lower methane leakage rate.

The new datasets developed within this study are based on the updated length of the distribution network according to the 2014 study (Del Duce and Faist Emmenegger 2014) using the 2012 statistics from the Swiss natural gas industry. A description of the pipe materials and lengths in the Swiss distribution network is shown in Table 20. We assume a life span of 40 years for both high pressure and low pressure networks as in Faist Emmenegger et al. (2007).

	Low pressure connection	Medium pressure connection	High pressure connection	Low pressure	Medium pressure	High pressure	Transit transport
	km	km	km	km	km	km	km
Cast iron	66.1	0.0	0.6	142.9	0.0	7.0	
Ductile cast iron	846.3	16.7	7.5	1830.2	68.9	93.0	
Steel, not cathodically protected	893.1	36.0	31.9	1931.4	148.6	395.0	
Steel, cathodically protected	4.8	24.4	105.4	10.4	100.6	1304.0	2161.0
Polyethylene	3079.3	226.2	206.5	6659.3	933.7	2554.0	
Other materials	44.4	5.8	2.0	96.0	24.0	25.0	
Rehabilitated - Polyethyleneor hose relining	126.3	7.1	0.1	273.0	29.4	1.3	
Rehabilitated - other methods	11.4	2.2	0.9	24.6	9.0	11.7	
Total	5071.6	318.4	355.0	10967.9	1314.1	4391.0	2161.0

Table 20: Pipeline length of the Swiss distribution network according to the 2012 statistics of the Swiss gas industry (Del Duce and Faist Emmenegger 2014).

Data for the calculation of the infrastructure requirements (see following sections) is based on the ecoinvent dataset from v2.2 (Faist Emmenegger et al. 2007). Further, we use the specific material requirements per kilometre pipeline as in Faist Emmenegger et al. (2007) with regard to the specific weight of the pipelines per kilometre, the requirements of polyethylene foil and pitch (bitumen) for the coating of metallic pipelines as well as the sand and gravel requirements for the bedding of the pipelines. Separate datasets address the low- and high-pressure part of the network.

3.6.1.1 Material requirements of the low-pressure network

The following table shows the specific and the overall material requirements for the pipelines in the low-pressure distribution network. The new data is integrated in the dataset "pipeline construction, natural gas, low pressure distribution network, CH, 2012 – 2012".

	Pipeline length	Specific material requirements	Total material requirements
Low-pressure network	**km**	**kg/km**	**t**
Steel	1'942	18'300	35'535
Ductile cast iron	1'830	34'700	63'507
Cast iron	143	25'200	3'602
High density polyethylene	6'659	9'600	63'929
Low density polyethylene foils	273	1'000	273
Other materials	121	18'300	2'208
Household connecting network	**km**	**kg/km**	**t**
Steel	898	4'500	4'041
Ductile cast iron	846	34'700	29'366
Cast iron	66	25'200	1'666
High density polyethylene	3'079	1'200	3'695
Low density polyethylene foils	126	1'000	126
Other materials	56	4'500	251

Table 21: Pipeline length, specific and total material requirements of the low pressure network. The values of the category "other materials" are added to the steel. The total material requirements were calculated with unrounded values for pipeline length. Data sources: Faist Emmenegger et al. (2007) and Del Duce and Faist Emmenegger (2014).

The sand and gravel requirements are adapted to the 2012 length of the pipelines.

		Low-pressure network	Household connecting network
Length of pipes	km	10‘968	5‘072
Specific sand requirements	kg/m	500	350
Specific gravel requirements	kg/m	150	100
Total sand (80 % of pipelines)	Mio t	4.39	1.42
Total gravel (20 % of pipelines)	Mio t	0.33	0.10

Table 22: Pipeline length, specific and total material requirements for the pipeline beddings. The total material requirements were calculated with unrounded values for pipeline length. Data sources: Faist Emmenegger et al. (2007) and Del Duce and Faist Emmenegger (2014).

The updated values (Table 23) show a diminution of the steel and cast iron requirements in favour of polyethylene use. The polyethylene value decreases between version 2.2 and the updated value. However, according to our new calculations and the data collected in Del Duce and Faist Emmenegger (2014), the v2.2 value should read 3’900 kg, which would result in an increase of the kg HDPE per km of pipeline between 2000 and 2012.

		Material requirements per km network (updated)	*Ecoinvent v2.2*
Reinforcing steel, at plant/RER U	kg	3‘310	*5‘240*
Cast iron, at plant/RER U	kg	6‘120	*6‘300*
Polyethylene, HDPE, granulate, at plant/RER U	kg	4‘220	*4‘630*
Polyethylene, LDPE, granulate, at plant/RER U	kg	25	*490*
Gravel, round, at mine/CH U	kg	26‘800	*28‘000*
Sand, at mine/CH U	kg	362‘000	*376‘000*
Transport	pkm	27‘200	*37‘700*

Table 23: Average material requirements per km network, updated values and values from the ecoinvent v2.2. Data sources: own calculations; (Faist Emmenegger et al. 2007).

3.6.1.2 Material requirements of the high-pressure network

The following table shows the specific and the overall material requirements for the pipelines in the high-pressure distribution network. The new data is included in the ecoinvent v3.X dataset “pipeline construction, natural gas, high pressure distribution network, CH, 2012 – 2012”.

	Pipeline length	Specific material requirements	Total material requirements
	km	kg/km	t
Transit transport			
Steel	2'161	42'000	90'762
High pressure			
Cast iron	8	36'200	274
Ductile cast iron	101	36'200	3'639
Steel, not cathodically protected	427	31'500	13'448
Steel, cathodically protected	1'409	31'500	44'397
HD Polyethylene	2'760	4'600	12'698
Other materials	27		
Medium pressure			
Cast iron	-		-
Ductile cast iron	86	25'200	2'157
Steel, not cathodically protected	185	19'200	3'544
Steel, cathodically protected	125	19'200	2'400
HD Polyethylene	1'160	3'300	3'828

Table 24: Pipeline length, specific and total material requirements of the high pressure network. The values of the category “other materials” are added to the steel. Data sources: (Faist Emmenegger et al. 2007; Del Duce and Faist Emmenegger 2014).

As for the low-pressure network, the values for the coating and bedding of the pipelines were adapted to the new length of the network.

The following table shows the original and the updated values, which have similarly to the low pressure network a distinct diminution of the steel and cast iron requirements in favour of polyethylene use.

		Material requirements per km network (updated)	*Ecoinvent v2.2*
Steel	kg	19'648	*23'400*
Cast iron	kg	772	*949*
HD Polyethylene	kg	2'101	*938*
LD Polyethylene	kg	1'200	*1'090*
Bitumen	kg	600	*769*
Sand, at mine/CH U	kg	793'200	*786'000*

Table 25: Average material requirements per km network, updated values and values from the ecoinvent v2.2. Data sources: own calculations; (Faist Emmenegger et al. 2007).

3.6.2 Emissions due to leakage in the natural gas distribution system

The change from cast iron pipelines to polyethylene reduced the leakages of natural gas from the Swiss distribution network. The emissions of the distribution network were updated multiplying the length of each pipeline type in the Swiss network (Table 20) with the specific leakage rates of pipeline types (see also Table 38) presented in Xinmin (Xinmin 2004), which was based on Battelle (1994). The following table summarizes the leakages for the year 2012 in the Swiss distribution networks as calculated in Del Duce and Faist Emmenegger(2014).

	Leakages (2012)
	Nm^3 natural gas/year
Leakages high / middle pressure network	4.3E+05
Leakages low pressure network	6.7E+06
Leakages transit	5.4E+05
Total	7.1E+06

Table 26: Leakages 2012 in the Swiss distribution network.

The specific emissions of the different gases contained in natural gas are calculated according to following formula:

$$E_{i,Pl}[\frac{kg}{MJ, Hu}] = L_{tot,Pl}[\frac{kg}{a}] * C_i[\frac{kg}{Nm^3}]/(Q_{tot}\left[\frac{GWh, Ho}{a}\right] * 1'000'000\left[\frac{kWh}{GWh}\right] * 3.6\left[\frac{MJ}{kWh}\right] * {}^{36.4}/_{40.5})$$

Where:

$E_{i,Pl}[\frac{kg}{MJ,Hu}]$: specific emission of gas *i* for the pressure level Pl (in proportion to 1 MJ, net calorific value.

$L_{tot,Pl}[\frac{kg}{a}]$: total natural gas leakages per year in pressure level Pl

$C_i[\frac{kg}{Nm^3}]$: Concentration of gas *i* in the natural gas CH (Table 1)

$^{36.4}/_{40.5}$: Proportion of net to gross calorific value of natural gas CH.

The specific gas consumption at the different pressure level (low / high-middle) were calculated with the same methodology as in (Faist Emmenegger et al. 2007), using the statistics on total specific consumption of the different consumer categories (Del Duce and Faist Emmenegger 2014) and assumption on their repartition in the networks (Faist Emmenegger et al. 2007).

	Total consumption 2012	**Pressure level**		**Consumption in network**	
		Low	Middle / High	Low	Middle / High
	GWh	%	%	GWh	GWh
Households	14’577	100 %	0 %	14’577	0
Commerce, agriculture, services	9’136	95 %	5 %	8’679	457
District heating	2’479	0 %	100 %	0	2’479
Industry	10’997	63 %	37 %	6’928	4’069
Total	33’871			30’184	7’005

Table 27: Total consumption in the low and middle/high pressure network 2012 according to statistics (Del Duce and Faist Emmenegger 2014), repartition on the low and middle/high pressure network (assumption according to (Faist Emmenegger et al. 2007)) and calculated consumption in the different networks.

3.6.2.1 Energy use and emissions in the low-pressure network

The new data is integrated in the ecoinvent v3.X dataset “market for natural gas, low pressure, CH, 2012 - 2013” (Table 28). The updated values were scaled to 1 MJ instead of m^3 (as in the original v3 dataset) to allow comparison with the former data.

Materials/fuels	Updated values	*Values Schori and Frischknecht (2012)*	*Values v2.2*	Unit
Reference flow				
natural gas, low pressure	1			MJ
Technosphere inputs				
heat, central or small-scale, natural gas	1.48E-03			MJ
natural gas, low pressure	1.002			MJ
pipeline, natural gas, low pressure distribution network	3.78E-09			km
Emissions to air				
Methane, fossil	4.44E-05	*7.85E-05*	*1.34E-04*	kg
Ethane	2.25E-06	*3.80E-06*	*6.47E-06*	kg
Propane	9.75E-07	*1.45E-06*	*2.47E-06*	kg
Butane	4.50E-07	*6.58E-07*	*1.12E-06*	kg
Carbon dioxide, fossil	8.25E-07	*1.25E-06*	*2.13E-06*	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	2.25E-07	*3.63E-07*	*6.18E-07*	kg

Table 28: Main exchanges of the new "natural gas, low pressure" dataset and values in the former datasets.

The reduction in the emissions is mainly due to the replacement of cast iron with polyethylene in pipelines, which result in less leakages.

3.6.2.2 Energy use and emissions in the high-pressure network

The new data is integrated in the ecoinvent v3.X dataset “market for natural gas, high pressure, CH, 2012 - 2013” (Table 29). The updated values were scaled to 1 MJ instead of m^3 (as in the original v3 dataset) to allow comparison with the former data.

Materials/fuels	Updated values	*Value Schori and Frischknecht (2012)*	*Values v2.2*	Unit
Reference flow				
natural gas, high pressure	1			MJ
Technosphere inputs				
heat, central or small-scale, natural gas	5.93E-03			MJ
natural gas, high pressure	2.74E-02			m^3
electricity, medium voltage	7.12E-05			kWh
pipeline, natural gas, high pressure distribution network	1.45E-09			km
Emissions to air				
Methane, fossil	2.54E-06	*6.42E-06*	*8.70E-06*	kg
Ethane	1.29E-07	*3.11E-07*	*4.22E-07*	kg
Propane	5.58E-08	*1.19E-07*	*1.61E-07*	kg
Butane	2.58E-08	*5.38E-08*	*7.30E-08*	kg
Carbon dioxide, fossil	4.72E-08	*0.000000102*	*1.39E-07*	kg
NMVOC, non-methane volatile organic compounds, unspecified origin	1.29E-08	*2.97E-08*	*4.03E-08*	kg

Table 29: Main exchanges of the new "natural gas, high pressure" dataset and values in the former datasets.

In the high pressure network also, cast iron pipelines have been continuously replaced with polyethylene, which has less leakages.

3.6.3 Updated datasets

The following table is a list of the updated datasets.

Dataset v2.2	Location	Activity name (new)	Reference product	Unit
Pipeline, natural gas, low pressure distribution network	CH	pipeline construction, natural gas, low pressure distribution network, CH, 2012 - 2012	pipeline, natural gas, low pressure distribution network	km
Pipeline, natural gas, high pressure distribution network	CH	pipeline construction, natural gas, high pressure distribution network, CH, 2012 - 2012	pipeline, natural gas, high pressure distribution network	km
Natural gas, low pressure, at consumer	CH	market for natural gas, low pressure, CH, 2012 - 2013	natural gas, low pressure	MJ
Natural gas, high pressure, at consumer	CH	market for natural gas, high pressure, CH, 2012 - 2013	natural gas, high pressure	MJ

Table 30: Updated datasets (names v2.2) and their equivalent (activity name and reference flow) in ecoinvent data version 3.

4 Biogas from biowaste, SNG from wood and electricity based fuels

With respect to biogas, SNG from wood and electricity based fuels, the aim was to gather the available datasets – mostly from ecoinvent v2.2 and from new data generation projects – and to harmonize these and bring them together into a common platform.

4.1 Biogas from biowaste

A biogas plant fed with biowaste fulfils 3 services (Figure 5).

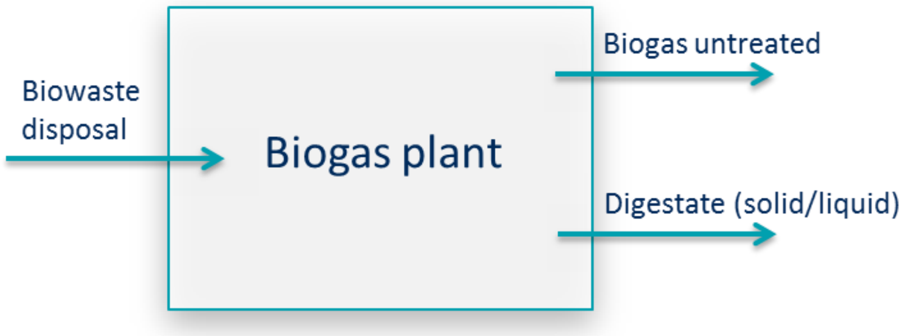

Figure 5: Products and services of a biogas plant.

It performs the service of biowaste disposal and produces biogas as well as liquid and solid digestate which is used in agriculture as fertilizer. The biogas, which can have a methane content of around

50-70 %, can be used directly in cogeneration units to produce heat and electricity or it can be upgraded to natural gas quality and then be fed into the natural gas system.

In ecoinvent v2.2, these 3 processes were modelled through the datasets:

- Biogas, from biowaste, at storage/CH U
- Disposal, biowaste, to anaerobic digestion/CH U
- Digested matter, application in agriculture/CH U

as documented in (Jungbluth et al. 2007). More recently, following datasets have been presented in conjunction with the study reported in Dinkel et al. (2012):

- biogas from biowaste/CH U
- disposal, biowaste, to anaerobic digestion/CH U
- digestate, solid, applicated on field/CH U
- digestate, liquid, applicated on field/CH U

together with further datasets required to model the digestate datasets. While, to the best of the authors' knowledge, little information on the modelling of the biogas production and the biowaste disposal service is available in the report by Dinkel et al, the data and processes behind the digestate datasets are very well documented. Moreover, as can be seen from the lists above, in Dinkel et al. (2012) separate datasets for solid and liquid digestate application have been realized whereas in ecoinvent v2.2 the two had been modeled together.

In the harmonization of the currently available data for a biogas/biowaste disposal plant, new datasets for biogas production and biowaste disposal were realized using the ecoinvent datasets as the starting point and updating these with specific entries from the datasets originating from Dinkel et al. (2012). Ecoinvent data was chosen as the starting point for the datasets due to the high amount of documentation available for these datasets. These datasets rely on an economic allocation with 31 % of the impacts on the biogas production and 69 % on the waste disposal. Data originating from Dinkel et al. (2012) was used when this was more complete or when the comparison with information from (Del Duce and Zah 2015a) suggested it being more appropriate. In the datasets from Dinkel et al. (2012), the allocation used is 30 % on biogas production, 64 % on the biowaste disposal and the rest on the digestate co-products.

An important aspect is the update of the methane leakage, since this is responsible for an important part of the impacts. Table 31 summarizes the ecoinvent value for methane leakage in biogas production, as well as the one from the dataset of Dinkel et al. (2012) and the value from Del Duce and Zah (2015a).

Emission	ecoinvent	Dinkel et al.	(Del Duce and Zah 2015a)
Methane leakage (kg methane/m^3 biogas)	0.0263	0.0101	0.00676

Table 31: Methane leakage data for biogas production.

Due to the closeness of the value originating from Dinkel et al. (2012) to the one from Del Duce and Zah (2015a), the one from Dinkel et al. (2012) was chosen for the biogas production dataset. For the biowaste disposal process, the average from the value proposed in the original ecoinvent dataset and the one from Dinkel et al. (2012) was chosen, since the value from Del Duce and Zah (2015a) lies between the two (Table 32).

Emission	ecoinvent	Dinkel et al.	Del Duce and Zah	This project
Methane leakage (kg methane/kg biowaste)	5.38E-03	6.69E-04	1.41E-03	3.03E-03

Table 32: Methane leakage data for biowaste disposal.

Also, all emissions to water were taken from the datasets originating from (Dinkel et al. (2012) since no emissions to water are included in the ecoinvent v2.2 datasets. Following the datasets released within Dinkel et al. (2012), all exchanges related to the digestate application were taken out of the biogas production and biowaste disposal processes. No modifications have been implemented on the digestate application datasets presented in (Dinkel et al. (2012), which describe the exchanges related to the application of liquid and solid digestate matter on an agricultural field as a fertilizer. Overall, the new biogas production and biowaste disposal datasets are based on an economic allocation with 31 % of the impacts of the biogas/biowaste disposal plant allocated to the biogas production, 63 % to the biowaste disposal service, with the rest of the impacts being accounted for in the digestate datasets (Jungbluth et al. 2007; Dinkel et al. 2012). The untreated biogas coming out of the anaerobic digestion plant is assumed to have a methane content of 67 %. The updated datasets (and the original ecoinvent values) for biogas production and biowaste disposal are shown in Table 33 and Table 34.

Exchanges	ecoinvent 2.2	Updated value	Unit	Comment/source
Reference flow				
Biogas, from biowaste, at storage	1.00E+00	1.00E+00	m3	
Resources				
Carbon dioxide, in air	3.27E+00	3.27E+00	kg	ecoinvent
Materials/fuels				
heat, biogas from biowaste, at cogen	1.83249	2.42E+00	MJ	(Dinkel et al. 2012)
electricity, biogas from biowaste, at cogen	1.23E-01	1.23E-01	kWh	ecoinvent
Anaerobic digestion plant, biowaste/CH/I U	1.234E-08	1.67E-08	p	(Dinkel et al. 2012)
Tap water, at user/CH U	0	2.60E-01	kg	(Del Duce and Zah 2015a)
Transport, lorry 20-28t, fleet average/CH U	0.030613	3.06E-02	tkm	ecoinvent
Transport, municipal waste collection, lorry 21t/CH U	0.027011	2.70E-02	tkm	ecoinvent
Emissions to air				
Methane, biogenic	2.63E-02	1.01E-02	kg	(Dinkel et al. 2012)
Dinitrogen monoxide	3.08E-04	3.30E-04	kg	ecoinvent
Hydrogen sulfide	7.56E-04	7.56E-04	kg	ecoinvent
Heat, waste	4.44E-01	4.44E-01	MJ	ecoinvent
Carbon dioxide, biogenic	1.26E+00	1.26E+00	kg	ecoinvent
Ammonia	7.05E-04	7.05E-04	kg	ecoinvent
Emissions to water				
Ammonium, ion	0	9.28E-08	kg	(Dinkel et al. 2012)
COD, Chemical Oxygen Demand	0	1.28E-05	kg	(Dinkel et al. 2012)
Nitrate	0	2.97E-06	kg	(Dinkel et al. 2012)
Nitrite	0	9.28E-08	kg	(Dinkel et al. 2012)
Nitrogen, organic bound	0	1.09E-07	kg	(Dinkel et al. 2012)
Phosphorus	0	7.04E-08	kg	(Dinkel et al. 2012)

Exchanges	ecoinvent 2.2	Updated value	Unit	Comment/source
Waste to treatment				
Disposal, municipal solid waste, 22.9 % water, to municipal incineration/CH U	3.09E-02	3.09E-02	kg	ecoinvent

Table 33: Main exchanges of the biogas production dataset.

In the table below, a fixed deviation can be noted in the updated values as opposed to the original ecoinvent values, even when the original source indicated is ecoinvent. This is related to the slightly different allocation factor of 63% used here compared to the original value of 69%. Moreover, the original ecoinvent dataset also included a list of soil emissions due to the application of digestate matter as a fertilizer. These have been omitted from the list since, as mentioned above, in the new models presented in Dinkel et al. (2012), all exchanges related to the application of digestate in agriculture are taken into account in specific processes (“digestate, liquid, applicated on field/CH U” and digestate, solid, applicated on field/CH U”).

Exchange	ecoinvent 2.2	Updated value	Unit	Comment/source
Reference flow				
Disposal, biowaste, to anaerobic digestion	1.00E+00	1.00E+00	kg	
Materials/fuels				

Exchange	ecoinvent 2.2	Updated value	Unit	Comment/source
heat, biogas from biowaste, at cogen	4.11E-01	3.75E-01	MJ	ecoinvent
electricity, biogas from biowaste, at cogen	2.77E-02	2.53E-02	kWh	ecoinvent
Anaerobic digestion plant, biowaste/CH/I U	2.77E-09	2.53E-09	p	ecoinvent
Tap water, at user/CH U	0	4.38E-02	kg	(Del Duce and Zah 2015a)
Transport, lorry 20-28t, fleet average/CH U	6.86E-03	6.27E-03	tkm	ecoinvent
Transport, lorry 3.5-20t, fleet average/CH U	7.50E-03	6.85E-03	tkm	ecoinvent
Solid manure loading and spreading, by hydraulic loader and spreader [9]	5.00E-01	0	kg	See footnote 9.
Electricity/heat				
Transport, municipal waste collection, lorry 21t/CH U	6.05E-03	5.53E-03	tkm	ecoinvent
Emissions to air				
Methane, biogenic	5.90E-03	3.03E-03	kg	Average of values presented in ecoinvent and in the datasets from Dinkel et al.
Dinitrogen monoxide	6.90E-05	6.30E-05	kg	ecoinvent
Hydrogen sulfide	1.69E-04	1.55E-04	kg	ecoinvent
Heat, waste	9.96E-02	9.09E-02	MJ	ecoinvent
Carbon dioxide, biogenic	5.79E-01	5.29E-01	kg	ecoinvent
Ammonia	2.03E-04	1.85E-04	kg	ecoinvent
Emissions to water				

[9] Not taken into account in the updated dataset, since, as mentioned above, 2 additional datasets have been introduced in Dinkel et al. (2012) for the application of digestate as fertilizer.

Exchange	ecoinvent 2.2	Updated value	Unit	Comment/source
Ammonium, ion	0	1.94E-07	kg	(Dinkel et al. 2012)
COD, Chemical Oxygen Demand	0	2.69E-05	kg	(Dinkel et al. 2012)
Nitrate	0	6.20E-06	kg	(Dinkel et al. 2012)
Nitrite	0	1.94E-07	kg	(Dinkel et al. 2012)
Nitrogen, organic bound	0	2.27E-07	kg	(Dinkel et al. 2012)
Phosphorus	0	1.48E-07	kg	(Dinkel et al. 2012)
Waste to treatment				
Disposal, municipal solid waste, 22.9 % water, to municipal incineration/CH U	6.915E-3	6.31E-03	kg	ecoinvent

Table 34: Main exchanges of the biowaste disposal dataset.

For both processes it is assumed that internal electricity and heat requirements are covered through combustion of the biogas produced in the plant in a cogeneration unit. About 0.0853m^3 of biogas are required per m^3 of biogas produced while 0.0155m^3 of biogas are allocated on the disposal of 1kg of biowaste. The emissions of the cogeneration unit have been modelled based on the dataset “operation, biogas combustion, in cogen with biogas engine” proposed in Stucki et al. (2011).

4.1.1 Upgrade of biogas to natural gas quality

Stucki et al. presented data on 3 biogas upgrading processes in Stucki et al. (2011). The data addresses upgrading through amino-washing, glycol-washing and pressure swing adsorption (PSA). However, in the dataset proposed by Stucki et al. (2011), only the material, infrastructure and energy resources required for the upgrading processes are considered and not the untreated biogas input. The corresponding datasets are termed:

- biogas purification to methane, 96 vol- %, pressure swing adsorption/CH U
- biogas purification to methane, 97 vol- %, glycol washing process/CH U
- biogas purification to methane, 99 vol- %, amino washing process/CH U

The reader is referred to Stucki et al. (2011) for the documentation concerning these processes and the related exchanges.

In order to use these datasets with the developed untreated biogas datasets, 3 new datasets were here implemented which use all the exact exchanges defined in Stucki et al. (2011) but also include the untreated biogas from biowaste input. An input of 1.5m^3 of untreated biogas is assumed for each m^3 of natural-gas-quality upgraded biogas. The new datasets are termed:

- biogas from biowaste purified to methane, 96 vol- %, pressure swing adsorption/CH U
- biogas from biowaste purified to methane, 97 vol- %, glycol washing process/CH U

- biogas from biowaste purified to methane, 99 vol- %, amino washing process/CH U

4.2 Synthetic natural gas from wood

Synthetic natural gas (SNG) from wood can be obtained by gasifying wood with a subsequent methanation step (Jungbluth et al. 2007). In ecoinvent v2.2 two gasification steps were considered: fixed bed and fluidized bed gasification. However, only one dataset for the production of synthetic natural gas based on fluidized bed gasification is available in ecoinvent v2.2. In Del Duce and Zah (2015b) a hot-spot analysis of the ecoinvent SNG dataset was performed which led to the development of a new dataset featuring some minor changes compared to the original process and a new dataset for the production of SNG with fixed bed gasification. The two datasets are termed:

- Synthetic natural gas, fixed bed gasification, CH
- Synthetic natural gas, fluidized bed gasification, CH

Their main exchanges are shown in Table 35. The datasets cover the infrastructure and resources required for the preparation of the wood, the gasification, the cleaning of the syngas, the methanation and the upgrade of the SNG to natural gas quality. More information about the processes is available in Del Duce and Zah (2015b). As mentioned above and visible in the table below, some small changes were implemented in the updated fluidised bed SNG dataset compared to the original ecoinvent dataset. These are mainly due to some open points in the ecoinvent report on biofuels (Jungbluth et al. 2007) with respect to the data presented for a gasification process when addressing synthetic gas production only as opposed to the complete SNG production process. To overcome these small open points, the modeling was based on the more specific data on gasification for synthetic gas production which was then scaled with the amount of synthetic gas ($3.906m^3$) required for the production of $1m^3$ SNG (Jungbluth et al. 2007).

Production of 1m3 of SNG from wood	ecoinvent 2.2	Fluidized bed SNG	Fixed bed SNG	Unit
Reference flow				
Synthetic natural gas, fixed bed gasification		1		m^3
Synthetic natural gas, fluidised bed gasification			1	m^3
Methane, 96 vol.-%, from synthetic gas, wood, at plant (ecoinvent 2.2)	1			m^3
Materials/fuels				
Wood chips, mixed, u=120 %, at forest/RER U	1.26E-02	1.26E-02	1.30E-02	m^3
Wood chips, mixed, from industry, u=40 %, at plant/RER U	4.32E-03	4.32E-03	4.46E-03	m^3
Waste wood chips, mixed, from industry, u=40 %, at plant/CH U	2.75E-03	2.75E-03	2.84E-03	m^3
Electricity, medium voltage, at grid/CH U	8.29E-01	8.29E-01	8.36E-01	kWh
heat, SNG combustion for gasification[10]	0.00E+00	7.40E+00	7.65E+00	MJ
Industrial furnace, natural gas/RER/I U	2.06E-08	0.00E+00	0.00E+00	p
Tap water, at user/CH U	1.05E+00	5.59E-01	5.77E-01	kg
Sodium hydroxide, 50% in H2O, production mix, at plant/RER U	1.22E-03	3.28E-03	3.28E-03	kg
Sulphuric acid, liquid, at plant/RER U	1.03E-02	1.03E-02	1.30E-02	kg
Aluminium oxide, at plant/RER U	4.29E-10	4.29E-10	4.29E-10	kg
Zinc, primary, at regional storage/RER U	1.87E-03	1.87E-03	1.87E-03	kg
Nickel, 99.5, at plant/GLO U	4.29E-10	4.29E-10	4.29E-10	kg
Light fuel oil, burned in boiler 100kW, non-modulating/CH U	6.13E-04	6.13E-04	6.13E-04	MJ
Rape methyl ester, at esterification plant/CH U	1.46E-02	1.46E-02	1.46E-02	kg
Charcoal, at plant/GLO U	1.98E-02	1.98E-02	1.98E-02	kg
Dolomite, at plant/RER U	0.00E+00	3.96E-02	0.00E+00	kg
Zeolite, powder, at plant/RER S	0.00E+00	8.12E-03	0.00E+00	kg
Silica sand, at plant/DE U	3.52E-02	3.52E-02	0.00E+00	kg
Synthetic gas plant/CH/I U	2.90E-09	2.90E-09	2.90E-09	p

[10] This process models the combustion of biogas for heat purposes in the production (industrial furnace, emissions, etc.). In the ecoinvent model, these exchanges were taken into account in the production dataset itself. This is why the ecoinvent process has an industrial furnace input while in the datasets here presented it is not directly visible. It is included in the “heat, SNG combustion for gasification” process.

Production of 1m3 of SNG from wood	ecoinvent 2.2	Fluidized bed SNG	Fixed bed SNG	Unit
Transport, lorry 3.5-20t, fleet average/CH U	3.54E-01	3.54E-01	3.54E-01	tkm
Transport, lorry 20-28t, fleet average/CH U	4.15E-03	4.15E-03	4.15E-03	tkm
Transport, freight, rail/CH U	5.39E-02	5.39E-02	5.39E-02	tkm
Waste to treatment				
Disposal, wood ash mixture, pure, 0% water, to municipal incineration/CH U	1.99E-02	1.70E-02	1.70E-02	kg
Disposal, wood ash mixture, pure, 0 % water, to sanitary landfill/CH U	1.51E-02	1.28E-02	1.28E-02	kg
Disposal, used mineral oil, 10 % water, to hazardous waste incineration/CH U	1.46E-02	1.46E-02	1.46E-02	kg
Treatment, sewage, from residence, to wastewater treatment, class 2/CH U	1.08E-03	3.96E-04	3.96E-04	m^3

Table 35: Main exchanges of the SNG production datasets.

4.3 Power-to-Gas

Power-to-gas (PTG) means the production of hydrogen from water using electrolysis and the subsequent methanation of the hydrogen (Figure 6). The resulting energy gases are Hydrogen and Methane.

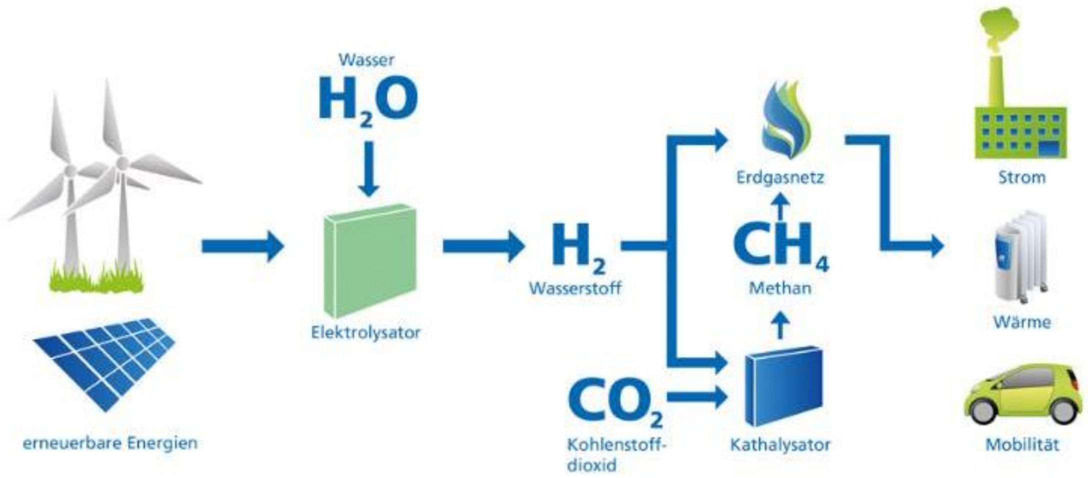

Figure 6: Simplified scheme of the power-to-gas production chain.

4.3.1 Power-to-Hydrogen

4.3.1.1 Elektrolysis-Process

Nowadays, hydrogen production via electrolysis is a niche market compared to the reforming of H_2 from hydrocarbons. According to IEA the current production of H_2 by electrolysis amounts only to 4 % of global production due to the high electricity costs for electrolysis (Kasten et al. 2013).
In general, three different technologies are available for the H_2 production by (Kasten et al. 2013):

- alkaline electrolysis
- Polymer electrolyte membrane (PEM) electrolysis
- High temperature electrolysis (SOEL)

In the frame of this study we are focusing on technologies already available on the market - alkaline electrolysis and PEM electrolysis.
According to the study of the Ökoinstitut 2013 (Kasten et al. 2013), alkaline electrolysis and PEM electrolysis are similar applications, while PEM electrolysis needs less space. The partial load characteristics of both technologies are not restricted by the electrolysis itself, but by the system components. A partial load of 20 % of the nominal load is possible for both technologies and load change occurs within seconds. Both technologies are also suitable for storing excess electricity, since a cold start of the electrolysis system takes only about half an hour. Because of the relatively similar properties there is no distinction in this study between PEM and alkaline electrolysis.
The efficiency for both technologies in the MW-scale, is given between 62 % and 70 % (Kasten et al. 2013). In addition, power conditioning when taken from the AC power must be carried out as electrolysers are operated with direct current. In this study, therefore a conservative efficiency of 62 % is assumed for the reference scenario (Lo). In a sensitivity analysis, we examined the influence of a higher efficiency of 70 % (Hi) on the GHG emissions and the overall environmental impact (Frischknecht and Steiner 2006).

4.3.1.2 Sources of power supply for electrolysis and subsequent process steps

The following energy sources for electricity production are considered: Photovoltaic (PV), wind power (WK) and the European energy mix based on ENTSO-E (European Union). In addition, an initial estimate for the production of methanol with the use of electricity from geothermal energy is performed.
Power sources (wind, PV, EU Mix) are selected as examples to cover a large range of potential environmental impacts. Therefore, a renewable power source with low CO2 emissions and low environmental impacts (Frischknecht and Steiner 2006) has been selected (Wind), a renewable power source compared to wind power with higher CO2 emissions and higher environmental impact

(PV) and a predominantly fossil source with high CO2 emissions and a high total environmental impact (EU electricity mix). Hydropower, which is comparable from the environmental profile with wind power is not considered, since no additional insights can be expected. The consideration of a scenario "waste power" (GHG potential and overall environmental impact = 0) is waived for the following reasons:

- Such a scenario was not the aim of this study in identifying the major inputs and lifecycle phases.
- The concept of "waste power" is not compatible with today's electricity LCAs. Even excess power cannot be regarded as waste, since the entire amount of electricity generated is allocated to the respective inventory..
- There is at the present time in Switzerland no definition of waste power.

new dataset	location	reference flow
hydrogen, electrolysis, PV at storage/CH U	CH	hydrogen, high pressure
hydrogen, electrolysis, wind power at storage/CH U	CH	hydrogen, high pressure

Table 36: New electrolysis datasets generated for the PtX value chain.

4.3.2 Power-to-Methane

4.3.2.1 CO_2-Capture

The routes Power-to-methane and power-to-methanol require carbon dioxide (CO_2) as a carbon source. In principle, different sources of concentrated $CO_2$are possible, as shown in Figure 7:

a. fossil, production-related $CO_2$from exhaust gas (e.g. from coal power plant or cement production)
b. biogenic $CO_2$from the CO_2capture of biogas plants
c. atmospheric CO_2 (Air Capture, atmospheric CO_2)

The CO_2-feedstock is defined as a waste, as the economic value of all three CO_2-sources is currently 0. This might change however in the future, where a certain demand for concentrated CO2 from biogas plants could start.

Depending on the CO_2concentration in the medium, the energy consumption needed for the CO2 capture varies greatly. Biogenic CO_2stemming from the methane upgrade process of a biogas plant does already exhibit a concentration of > 99 % and can be used without additional effort. Exhaust gases of combustion processes require a low energy consumption for capture as the CO_2content is already at about 12 %. The CO_2capture from ambient air (CO_2content: 0.04 %) is most energy demanding but also most flexible with respect to location.

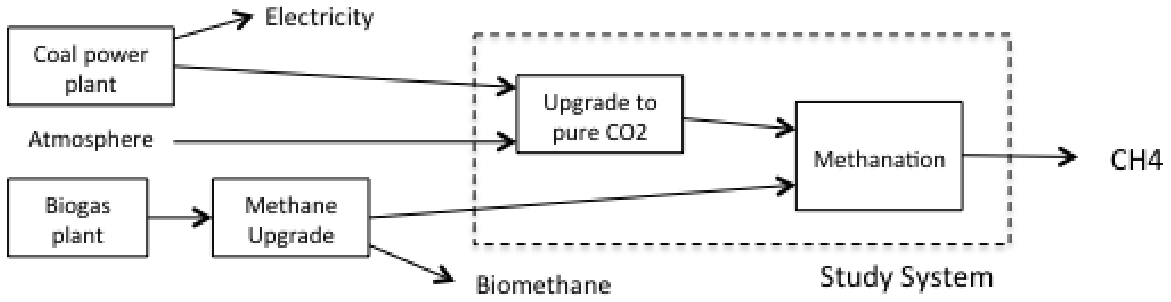

Figure 7: System boundaries for the assessment of CO2 capture and methanation.

The CO_2capture from the flue gas stream is done via leaching with monoethanolamine (MEA). The regeneration of the scrubbing and separation of $CO_2$is done using heat. In addition, electricity is required to operate pumps and fans. Then the $CO_2$is compressed from ambient pressure to 0.5 MPa. If CO_2capture and methanation take place at the same location, the heat demand can be at least partially covered by the heat released during the methanation. In this study, we assume that only electricity is required (23,6 kWh/t CO_2 (Koornneef et al. 2008)) and that the heat demand can be fully covered by the surplus heat from other manufacturing processes. The calculated greenhouse gas emissions and overall environmental impact (Frischknecht and Steiner 2006) thus represent the lower limit for the CO_2provision.

In the recovery of $CO_2$from the ambient air with the air capture technology, CO_2separation is carried out through leaching with potassium hydroxide (KOH) and regeneration of the scrubbing through electrodialysis. Air capture systems function as closed circuits without adding chemicals. In this study, a power requirement of 2,000 kWh / t CO_2will be used as basis (Specht et al. 2000). When implementing a possible thermal energy supply for the regeneration process the electricity demand could be lowered to approximately one quarter (= 500 kWh_{el}/t CO2) (Kasten et al. 2013). The company Climeworks defined a development target of 95 % heat (= 100 KWh_{el}/t CO_2) (Wurzbacher 2013).

4.3.2.2 Methane Production

For methanation it is assumed that it is realized on the basis of the Sabatier process: In a chemical process carbon and hydrogen are converted into methane and water. When hydrogen and carbon dioxide are available in sufficient quantity and purity, there are various technical methods to realize this process. In so-called fixed bed or fluidized bed reactors a heterogeneous catalysis may be performed, wherein the synthesis of hydrogen and carbon dioxide takes place under controlled conditions. Based on the current Fraunhofer study (Jentsch and Trost 2014) we assume in this study the use of a fixed bed reactor.

The following assumptions were applied:

- ixed-bed reactor with nickel / aluminium oxide catalyst.
- Provision of electricity through renewable energy sources (wind and PV) and from grid (ENTSO-E)
- Transport via the gas network and compression at the gas station in Switzerland

4.3.2.3 *Resulting datasets*

new dataset	location	reference flow
methane, 99.9 %, at storage, CH U, electrolysis PV, atmospheric CO_2 capture	CH	methane, high pressure
methane, 99.9 %, at at storage, CH U, electrolysis wind power, atmospheric CO_2 capture	CH	methane, high pressure
methane, 99.9 %, at at storage, CH U, electrolysis PV, coal power CO_2 capture	CH	methane, high pressure
methane, 99.9 %, at at storage, CH U, electrolysis wind power, coal power CO_2 capture	CH	methane, high pressure
methane, 99.9 %, at at storage, CH U, electrolysis PV, biogas plant waste CO_2	CH	methane, high pressure
methane, 99.9 %, at at storage, CH U, electrolysis wind power, biogas plant waste CO_2	CH	methane, high pressure

Table 37: New methane production datasets generated for the PtX value chain.

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6 Appendices

6.1 Tables

	[Nm^3/(h·km)]	m^3/(a km)
Cast iron low pressure	0.8	7008
Cast iron medium pressure	1.2	10512
Cast iron high pressure	0.192	1681.92
Cast iron Transport	0	0
Ductile cast iron low pressure	0.088	770.88
Ductile cast iron medium pressure	0.132	1156.32
Ductile cast iron high pressure	0.0023	20.148
Ductile cast iron Transport	0	0
Steel, not cathodically protected low pressure	0.088	770.88
Steel, not cathodically protected medium pressure	0.0132	115.632
Steel, not cathodically protected high pressure	0.00062	5.4312
Steel, not cathodically protected Transport	0	0
Steel, cathodically protected low pressure	0.008	70.08
Steel, cathodically protected medium pressure	0.012	105.12
Steel, cathodically protected high pressure	0.00002	0.1752
Steel, cathodically protected Transport	0.028424658	249
Polyethylene low pressure	0.008	70.08
Polyethylene medium pressure	0.016	140.16
Polyethylene high pressure	0.00062	5.4312
Polyethylene Transport	0	0
Relined polyethylene low pressure	0.008	70.08
Relined polyethylene medium pressure	0.016	140.16
Relined polyethylene high pressure	0.00002	0.1752
Relined polyethylene Transport	0	0
Relined other low pressure	0.012	105.12
Relined other medium pressure	0.024	210.24
Relined other high pressure	0	0
Relined other Transport	0	0

Table 38: Emission factor of pipelines depending on their material and network type (Xinmin 2004).

6.2 Replies to review comments

The report was revised by Christian Bauer, PSI.

6.2.1 introduction / natural gas

Chapter (Nr)	Reviewer's comment	Reply
Table of contents	Not so important, but I'd change the order in chapter 3; production first, then transport, distribution, infra	Changed
Introduction 1.1 Energy gases	Specification of the term "energy gases" would help	We added a paragraph defining energy gases.
	1st sentence: In ecoinvent, or in general, for which regions. etc??	Added: "in the ecoinvent database"
	Legend of Fig. 1: To Europe? To CH?	Added: "global import shares"
	A little more context would help: commissioner? Purpose of the update? Geographical and temporal scope of the new data? Data formats? Who are the intended users? What's the "product" of your work? Which new/updated DS in which formats? Are the DS openly accessible?	We think the chapters "approach" and "methodology" provide the information which was missed here. We moved therefore the sentence beginning with "aim of this project was…" to the chapter "approach".and renamed the latter "aim of the project"
	For all data from this site: please refer to a specific documentation (report), if available.	done
2.1.1	Please provide a list of old and new corresponding DS. And additional DS, if any. As appendix, I guess	The lists are provided in each chapter for more clarity. A sentence was added to make this more clear: "The new datasets and the datasets they replace are described in the following chapters."
	Which ones (were updated)? Please more specific	We changed the wording of this paragraph to "The original datasets were published in the natural gas ecoinvent report (Faist Emmenegger et al. 2007) and had been partlyupdated in (Schori and Frischknecht 2012). We based our update on these datasets, together with the newest publication like the one on methane emissions (Del Duce and Faist Emmenegger 2014) as well as further literature (see reference list at the end of this document)."
	Is there a difference between m3 and Nm3?	Nm^3 stands for "Norm cubic meter". The N had been omitted at this place and was added.
2.2.2 Standardized calorific value for	HHV, right?	Yes

Chapter (Nr)	Reviewer's comment	Reply
natural gas in ecoinvent v3		
	This needs to be discussed. The standardization was introduced by Bo without asking anybody. I would be in favour of reintroducing country-specific values, if not too much effort.	We think that this should indeed be discussed within the ecoinvent expert group. However, we cannot decide this for ourselves as this might influence other supply chains.
3.1 Overview	For re-compression?	Yes, added.
3.2 Natural gas production	Please be explicit in which countries we have joint production of oil and gas and in which "gas only"	Done.
3.2.1 Joint oil and natural gas production in Norway	Table 2.What's NGL?	NGL = Natural Gas Liquids. Explained in the legend and added to the abbreviations.
	Is that joint production? What's the reference product?	Yes, it is joint production. Added.
	What's the difference between Nm3 and Sm3?	This corresponds to different volume measurements based on different temperature and pressure. We added this precision and the abbreviations in the table.
	Zero losses for gas resource	Same assumption as in ecoinvent until now.
3.2.4 Natural gas production in Algeria, Middle East, Germany, Petroleum and gas production in the United Kingdom	Please be explicit concerning data content: North Africa is represented by Algeria, which is almost entirely a copy of RU. And middle east in turn is equivalent to Algeria.	Added: "The dataset for North African Countries is based on the Algeria data, where most of the flows are approximations from the Russian dataset. The Middele East dataset is the copy of the Algerian dataset. We use this data as they base on 2010 data and no more recent or more accurate data are was readily available."
3.4.1.4 Updated datasets	Wrong DS in this table	Corrected
3.4.2.2 LNG carriers	Table Empty (Return trip)?	Yes, we assume an empty return trip with a similar consumption as in the loaded trip.
	What does it mean in terms of %?	The figures are based on the scenario of Heede 2006 and take his % over.
3.5 Representation of the trade movements	Which year is represented?	We changed the text to: "The country of origin of the natural gas imported in various European countries is calculated based on the trade movements of the natural gas in *2013* as described in (BP Amoco 2014) and, for Switzerland, on the statistics of the Swiss natural gas industry for *2012* (Del Duce and Faist Emmenegger 2014)."
3.5.1 Switzerland	Can you explain, please, the meaning of "direct import" and "country of origin"? Cannot reconstruct the numbers: e.g. why is import quantity = 0 for NO; why is it higher for Nigeria than for Algeria? Etc…	The table was wrong and was corrected.

Chapter (Nr)	Reviewer's comment	Reply
	Numbers are different from those for CH in next table	
3.5.2 European countries (1)	Does that mean we'll have markets for high and low pressure nat gas for all these countries? What about the NG losses and the transport distances?	Only market for high pressure natural gas. No new data for the losses in the high pressure network. The explanation about the transport distance was moved to the chapter 3.5 beginning.
3.5.4 Updated datasets	DE? (as a location for the dataset "	No, the location for the dataset "natural gas, production DE, at long-distance pipeline" in ecoinvent 2 is "RER", whereas in ecoinvent 3 the dataset "natural gas, high pressure, import from DE, XX, 2012 – 2012" is specific for each importing country.
3.6.1 Infrastructure of the Swiss high and low pressure network	Could you specify the assumed lifetime somewhere?	Added (40 years, as in ecoinvent 2)
	I don't get it, sorry. The table above shows new data and in this paragraph you describe using old ones from v2.2. Which data in your new DS are based on v2.2 and which ones are new, exactly?	We add in the text "Data for the calculation of the infrastructure requirements **(see following chapter)** is based on the ecoinvent dataset from v2.2 (Faist Emmenegger et al. 2007)" as it seems that it was not clear that the sentence referred to the following calculations and tables.
3.6.1.1 Material requirements of the low-pressure network	for all DS: can you provide the reference product and its unit along with the activity name? (either in the text or the appendix table) - What about the GLO activites? Same inputs as for CH? I'd mention it at least in a footnote, similar for other DS	Added
3.6.2 Emissions due to leakage in the natural gas distribution system	How is this accounted for?	The emissions of the distribution network were updated multiplying the length of each pipeline type in the Swiss network (Table 3 and Table 5) with the specific leakage rates of pipeline types presented in (Battelle 1994; Del Duce and Faist Emmenegger 2014). However, the transit emissions are excluded from the emissions of the high pressure natural gas network, as they do not belong to the same network.
3.6.2.1 Energy use and emissions in the low-pressure network	Where is the energy for gas distribution (compression?) accounted for? Same for high pressure	Explanation will be added. This part of the data was taken over from ecoinvent 2.
	What is the heat needed for? Same for high pressure	Explanation will be added. This part of the data was taken over from ecoinvent 2.
3.6.2.2 Energy use and emissions in the	Why m3? (natural gas flow)	It was an typing error; changed to MJ

Chapter (Nr)	Reviewer's comment	Reply
high-pressure network		
3..6.2.3 Updated datasets	Ok, now there is a list I was asking for before. Please mention that already in the beginning	See comment above
	You'll need GLO activities for DS submission. Probably not relevant in this context	Not expected to be needed.
	Unit of the reference product would help	Added in the respective tables.

6.2.2 Replies to review comments: biogas/SNG part

Reviewer's comment	Reply
Concerning paragraph 1.2.2: Please refer to specific references, which are 1:1 in the reference list in case the data were available from previous studies	References are described in another paragraph (Chapter 4). A comment on where the information will be found has been introduced.
Concerning paragraph 1.2.2: Any source for this statement? Are there wood methanation plants right now operating in CH?	Data on the most relevant technology in Switzerland is unclear. The text has been changed so that the new datasets represent a new possible option.
Concerning chapter 4.1.: It's confusing that we're back in ev2 logic. Can you add a paragraph explaining, please?	A comment on the specific aim of the biogas/SNG part of the project and its data sources has been introduced which explains the link to ecoinvent version 2.
Concerning Table 26 on biogas leakage in biogas production: Don't get it, sorry. There is one process, biowaste disposal or biowaste treatment. This joint production activity has 2 products: biogas and digestate. You present it here as separate independent products/activities. Does this include implicit allocation?	Yes, economic allocation is assumed. A comment on the allocation system in the various datasets has been introduced before the table.
Concerning the function of the digestate datasets: What's the purpose of these? What's the product?	A comment has been introduced which specifies what is covered by these datasets.
Concerning Table 28: Don't you want to show the joint production DS here instead of the DS after allocation?	The source datasets were already separated. It was therefore preferred to continue the comparison on the separated datasets.
Concerning the own biogas consumption for heat and electricity processes in the biogas plant: Which fraction of gas is required?	The required quantity of consumed biogas per m^3 of produced biogas (and per kg of disposed biowaste) have been calculated and added in the text.

6.2.3 Replies to review comments: PtX

Chapter	Reviewer's comment	Reply
4.3.2.1 CO2-Capture	Sorry, but this is not acceptable from my perspective. There's a methodological inconsistency. Separation of co2 from power plants needs to be considered as joint production of electricity and CO2. I'd recommend this paper to read: "von der Assen et al. (2013) Life-cycle assessment of carbon dioxide capture and utilization: avoiding the pitfalls". You can either apply allocation or system expansion including the whole process of power plant operation with CO2 capture. Your procedure seems to be incorrect, or is not sufficiently described.	This point was thoroughly discussed in a separate telephone conference which showed that there were no disagreements on the method but rather a misunderstanding. The chapter was consequently re-written and a Figure has been added to show the system boundaries
4.3.2.3 Resulting datasets	Not compatible with the way you deal with/describe the CO2 capture in the previous chapter	It is more clearly described now!
4.3.2.3 Resulting datasets	Contradicts your statement above: "Biogenes CO_2 als CO_2-Quelle wird im Rahmen dieser Studie nicht explizit betrachtet"	You are right. I deleted the sentence saying (wrongly) that it will not be assessed

6.2.4 Replies to review comments: References

Chapter	Reviewer's comment	Reply
References	For all reports which are available on the web: please provide the link for download	Done where possible
	In general: most of these reports are not accessible. A reviewer should have access to the majority of primary sources.	The references were missing in the report due to a problem with the library system. This was corrected.