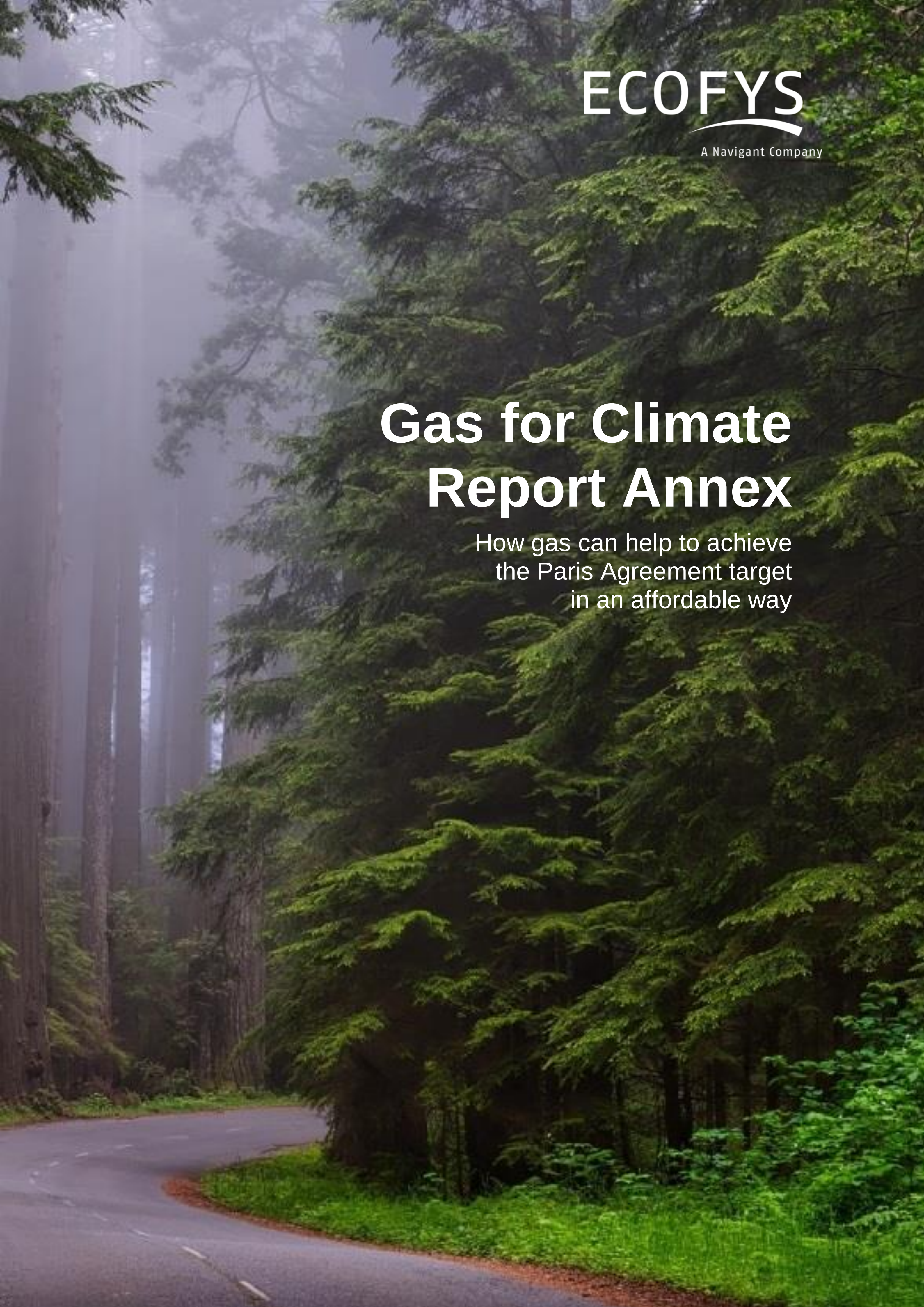

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Gas for Climate Report Annex

How gas can help to achieve the Paris Agreement target in an affordable way

Gas for Climate – Report Annex

How gas can help to achieve the Paris Agreement target in an affordable way

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This annex provides further details around the assumptions and the methodology for the Gas for Climate report. It is aimed at subject matter experts to provide full transparency.

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Abbreviations

CAPEX	Capital expenditures
CB	Commercial buildings
DR	Deep renovation
FOPEX	Fixed expenditures
MFH	Multi-family homes
NE	North-East Europe
NO	Northern Europe
OPEX	Operational expenditures
SE	South-East Europe
SFH	Single-family homes
SO	Southern Europe
SR	Shallow renovation
WACC	Weighted average cost of capital
WE	Western Europe

1 General assumptions on the quantification of the value of gas

All costs are calculated on an annual basis (using an annuity factor) per household and for the European Union (EU-28). The outcome reflects the overall annual costs in 2050, combining operational and capital costs in a single yearly amount. The value is expressed in 2017 euros.

$$Annual\ costs = Investment\ costs * Annuity\ factor + Fixed\ operating\ costs + Variable\ operating\ costs$$

The annuity factor corresponds to the economic lifetime of the investment and the weighted average cost of capital (WACC). In the analysis, a WACC of 5% for the energy system is assumed. The annuity factor is defined as:

$$Annuity\ factor = \frac{WACC}{1 - (1 + WACC)^{-n}}$$

With *n* corresponding to the economic lifetime.

The number of households in the EU is based on the projection of the population in the EU-28 based on the Eurostat “Convergence” scenario and the average household size for the most current year available which is 2015 (Eurostat). The “Convergence scenario” is based on the assumption that the population will rise by around 5% between 2010 and 2050. The population number is in line with the E-Highways 2050 scenarios.[1]

Table 1 (see next page) summarises the most relevant assumptions taken in this report and their influence on the results.

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[1] Please keep in mind that in this analysis only all current members of the European Union were taken into account whereas the EU Energy Roadmap 2050 and the E-Highways 2050 also include Switzerland and Norway.

Table 1: General assumptions and influencing factors

Variable	Assumption	Sensitivity
Population growth rate	Assumed to be around 5% between 2010 and 2050 in line with the Eurostat “Convergence” scenario”	The population growth rate has the same impact on both scenarios and does not alter the cost differences between the scenarios.
Change in typology of the building stock (rural, intermediate, urban)	It was assumed that the trend of urbanisation which could be observed in the European Union between 2006 and 2015 will continue until 2050. The categorisation and historic developments are based on Eurostat data.	For now, the model only takes the typology into account when calculating the cost for the medium voltage distribution grid. The building analysis also considers differences in the building stock and typology, but the further described model uses these assumptions only indirectly by using the results as inputs (e.g. insulation cost per region for deep/ shallow renovation).
Change in the total power demand (not related to heat or mobility, used to scale the hourly load)	No change in power demand has been taken into account other than in the residential and related electricity sector. Forecasts regarding the future GDP, the impact of it on the energy consumption, changing demand patterns and improvements of energy efficiencies of appliances were left out for simplicity reasons.	A change of the total power demand would impact both scenarios equally. As a result, there would be no cost difference between the two scenarios.

2 Buildings sector analysis

2.1 General approach

To reflect the variety within Europe of building stock and climate conditions, based on previous studies such as the "Renovation tracks for Europe up to 2050" conducted in 2012 by Ecofys and a study for the Energy Performance of Buildings Directive (EPBD, 2016), the analysis is applied to five European regions (Northern, Western, North-Eastern, South-Eastern, Southern). The assumptions per region reflect the typical heat demand per type of building, and the typology and state of the building stock. This means that besides the geographical region, the technology cost depends on the type of dwelling. It is distinguished whether it is new build or not, and whether it is a multi-family-house or a single-family house.

Table 2: Building sector: General assumptions and influencing factors

Variable	Assumption	Sensitivity
New building rate, demolition rate	For all scenarios, a new building rate of 1.0% per year and a demolition rate of 0.1% per year are assumed.[2] [3] The building and demolition rate is related to the increase in surface area. This is not proportional to the increase in population because of changes in average household size and building size.	Over the 32 years until 2050 the new building and demolition rate has a great impact on the building stock. The technology prices differ greatly between retrofitted houses and new buildings
Efficiencies of the heating technologies	For renewable gas boilers only, a small efficiency improvement is assumed as the technology is already quite mature.	Impacting directly the energy demand for different technologies, proportional relationship.
Price decreases of technology cost	Based on two studies for the Department of Energy and Climate change as well as results from the Ecofys Urban Electrification report price decreases have been assumed for each of the heating technologies (reduction from 2015 to 2050): Gas boiler: 10%, electric air-sourced heat-pump: 20%, electric ground-sourced heat-pump: 18%, hybrid heat-pump: 15%, district heating: 0%.	Impacting directly the technology cost.
Price decreases of insulation cost	Based on results from available studies such as the Ecofys Urban Electrification report price decreases by around 30% of insulation cost have been assumed.	Impacting directly the insulation cost.
Technology/ insulation lifetime	Technology: 10 years (could be increased up to 20 years); Insulation: 40 years	Annuity factor for: 10 yrs.: 0.13; 20 yrs. 0.08; 40 yrs.: 0.06

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[2] Ecofys, 2012. Renovation tracks for Europe up to 2050. Available at: http://www.eurima.org/uploads/ModuleXtender/Publications/90/Renovation_tracks_for_Europe_08_06_2012_FINAL.pdf. Report established by Ecofys by order or Eurima.

[3] Study performed by GRTgaz and GRDf for the French situation assumed similar building (1.05% -1.75% depending on chosen scenario) and demolition rates (0.1%)

Table 3: Living area in Mio. m² per housing type and region (Ecofys, 2012: Renovation Tracks for Europe up to 2050. Building renovation in Europe- what are the choices?)

Housing type	NO	WE	NE	SE	SO	SUM
SFH	609	7,882	909	300	2,352	12,052
MFH	292	2,485	607	517	1,544	5,446
CB	321	5,974	666	567	1,115	8,642
Total	1,222	16,341	2,182	1,384	5,010	26,140

Table 4: Development of the living area up 2050 assuming a demolition rate of 0.1% and a new built rate of 1% according to Ecofys, 2012: Renovation tracks for Europe. The remaining buildings are retrofitted to meet increased insulation standards.

		Unit	NO	WE	NE	SE	SO
SFH	Existing	Mio m²	609	7,882	909	300	2,352
	Retrofit	Mio m²	590	7,634	880	291	2,278
	New built	Mio m²	195	2,522	291	96	753
MFH	Existing	Mio m²	292	2,485	607	517	1,544
	Retrofit	Mio m²	283	2,407	588	501	1,495
	New built	Mio m²	94	795	194	165	494
CB	Existing	Mio m²	321	5,974	666	567	1,115
	Retrofit	Mio m²	311	5,785	645	549	1,079
	New built	Mio m²	103	1,912	213	181	357
Total	SFH	Mio m²	784	10,156	1,171	387	3,030
	MFH	Mio m²	377	3,202	782	666	1,989
	CB	Mio m²	413	7,697	858	730	1,436

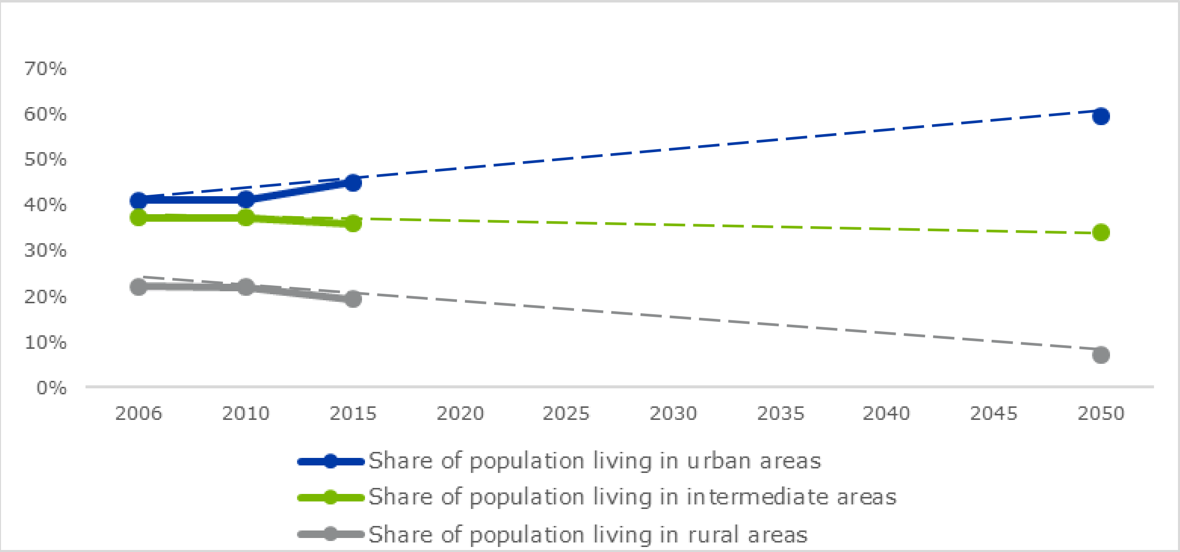

Figure 1: Development of the topology of the population in Europe (based on Eurostat data)

2.2 Space heating and insulation

In a climate friendly heating future, we assume no room for heavy fuel oil (HFO) heating. This means that this infrastructure will need to be replaced anyway, irrespective of whether a full electrification or electrification with renewable gas scenario is chosen.

The following table gives an overview of the main differences of technologies applied in the two scenarios. In both scenarios, the share of district heating is the same, so it does not contribute to the price difference between the two scenarios. The technology mix for the electrification with renewable gas scenario is set to allow a reasonable allocation of the available potential of renewable gas. It is ensured that sufficient renewable gas and solid biomass is available for industry. Any future updates of the renewable gas potential could impact the characteristics of the ‘Electrification with renewable gas’ scenario.

Table 5: Assumptions on heating technologies and insulation level

Technology	Electricity only scenario	Electricity & gas scenario with only biomethane(B)	Electrification scenario with biomethane and PtG (C)
ASHP	60%	48%	29%
GSHP	20%	15%	14%
HHP	0%	17%	37%
DH	20%	20%	20%
Insulation	DR for ASHP and GSHP (80%), SR for the rest	DR for ASHP and GSHP (63%), SR for the rest	DR for ASHP and GSHP (43%), SR for the rest

In the “electrification” scenario it is assumed that most of the heating demand (including domestic hot water) will be provided by electric heat pumps. As the use of electric heat pumps requires a high insulation, it is assumed that all buildings are compliant with the highest insulation standards (or “deep renovation”). For the houses which are connected to district heating a medium insulation level is sufficient (also called “shallow renovation”).

In the “electrification with renewable gas” scenario a high insulation is also needed in the case of electric heat pumps (with exemption of hybrid heat pumps), but these constitute a substantially lower share than in the electrification scenario. In the Ecofys EPBD study, the cost for deep and shallow renovations were calculated taking into account differences in the building stock and weather conditions. Therefore, the terms “shallow” and “deep” renovation have been defined for every region separately. The U-values for the various renovation levels in the different regions are given in the table below.[4]

Table 6: U-values (in W/m²K) for various renovation levels of the residential reference buildings

		Northern Europe	Western Europe	Southern Europe	North eastern Europe	South eastern Europe
Shallow renovation	**Ambient wall**	not replaced	not replaced	not replaced	not replaced	not replaced
	Roof	0.26	0.3	0.43	0.34	0.39
	Cellar	not replaced	not replaced	not replaced	not replaced	not replaced
	Windows	1.3	1.3	1.3	1.3	1.3
Deep renovation	**Ambient wall**	0.11	0.12	0.15	0.12	0.15
	Roof	0.11	0.12	0.15	0.12	0.15
	Cellar	0.11	0.12	0.15	0.12	0.15
	Windows	0.85	0.85	1.8	0.85	1.8
New building standards	**Ambient wall**	0.11	0.12	0.15	0.12	0.15
	Roof	0.11	0.12	0.15	0.12	0.15
	Cellar	0.11	0.12	0.15	0.12	0.15
	Windows	0.85	0.85	1.8	0.85	1.8

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[4] The U-values for deep renovated buildings and new building standards are identical however we are still assessing with the quantification group whether this is justified.

Table 7: Overview of annual insulation cost per region, building type and renovation level (Ecofys, 2012: Renovation Tracks for Europe up to 2050. Building renovation in Europe- what are the choices?)

Region	Building	Renovation level	Annuities Insulation
			€/(m²a)
Northern Europe	Single-family home	Shallow renovation	23.2
		Deep renovation	33.4
	Multi-family home	Shallow renovation	11.0
		Deep renovation	15.5
	Commercial building	Shallow renovation	11.0
		Deep renovation	15.5
Western Europe	Single-family home	Shallow renovation	7.8
		Deep renovation	11.4
	Multi-family home	Shallow renovation	3.6
		Deep renovation	5.2
	Commercial building	Shallow renovation	3.6
		Deep renovation	5.2
Southern Europe	Single-family home	Shallow renovation	7.5
		Deep renovation	9.7
	Multi-family home	Shallow renovation	3.5
		Deep renovation	4.6
	Commercial building	Shallow renovation	3.5
		Deep renovation	4.6
North-East Europe	Single-family home	Shallow renovation	3.8
		Deep renovation	4.8
	Multi-family home	Shallow renovation	2.2
		Deep renovation	2.7
	Commercial building	Shallow renovation	2.2
		Deep renovation	2.7
South-East Europe	Single-family home	Shallow renovation	4.6
		Deep renovation	6.0
	Multi-family home	Shallow renovation	2.3
		Deep renovation	2.9
	Commercial building	Shallow renovation	2.3
		Deep renovation	2.9

Table 8: Technology costs per region and square meter (Ecofys, 2012: Renovation Tracks for Europe up to 2050. Building renovation in Europe- what are the choices?)

Region	Technology	Unit	SFH		MFH		CB	
			Retrofit	New built	Retrofit	New built	Retrofit	New built
NO	GB	€/m² floor area	77	85	31	30	31	30
	ASHP	€/m² floor area	197	225	109	72	109	72
	GSHP	€/m² floor area	242	258	109	72	109	72
	HHP	€/m² floor area	99	113	55	36	55	36
	DH	€/m² floor area	73	144	36	20	36	20
WE	GB	€/m² floor area	60	66	24	23	24	23
	ASHP	€/m² floor area	154	176	85	56	85	56
	GSHP	€/m² floor area	189	202	85	56	85	56
	HHP	€/m² floor area	77	88	43	28	43	28
	DH	€/m² floor area	57	113	28	51	28	51
SO	GB	€/m² floor area	42	46	17	16	17	16
	ASHP	€/m² floor area	107	122	59	39	59	39
	GSHP	€/m² floor area	131	140	59	39	59	39
	HHP	€/m² floor area	54	61	30	20	30	20
	DH	€/m² floor area	39	78	20	11	20	11
NE	GB	€/m² floor area	39	42	15	15	15	15
	ASHP	€/m² floor area	89	112	54	36	54	36
	GSHP	€/m² floor area	98	129	54	36	54	36
	HHP	€/m² floor area	45	56	27	18	27	18
	DH	€/m² floor area	36	72	18	10	18	10
SE	GB	€/m² floor area	30	33	12	12	12	12
	ASHP	€/m² floor area	77	88	42	28	42	28
	GSHP	€/m² floor area	94	100	42	28	42	28
	HHP	€/m² floor area	39	44	21	14	21	14
	DH	€/m² floor area	28	56	14	8	14	8

Table 9: Cost reductions of heating technologies and insulation costs (based on the estimates in Ecofys, 2016: Urban Electrification Report, DECC, 2016: Potential Cost Reductions for Air Source Heat Pumps and DECC, 2016: Potential Cost Reductions for Ground Source Heat Pumps)

	Cost reduction multiplicator
GB	0.90
ASHP	0.80
GSHP	0.82
HHP	0.85
DH	1.00
Insulation	0.70

2.3 Transmission & distribution

Electricity infrastructure			**Unit**	**Source/ Assumption**
Medium voltage				
Avg. Cost for the development of the medium voltage electricity grid				Ecofys, 2016: Waarde van congestiemanagemen (Dutch), table 9
	urban	21	€/kW/a	
	suburban	27	€/kW/a	
	rural	57	€/kW/a	
Integration Cost Onshore wind and solar		6	€/MWh	Agora Energiewende, 2015: Integrations costs of wind and solar power
High voltage				
Integration Cost Offshore wind		30	€/MWh	Agora Energiewende, 2015: Integrations costs of wind and solar power
Annual investments into the transmission grid, scaled down to the population of EU-28 from EU-33				Approximated with the bulk investment costs from the E-Highway 2050 scenarios. Investments up to 2040 are the same for all scenarios and have not been taken into accou
100% RES	Strategy 2 (Overhead and underground transmission lines)	15	bn. €	
Small & Local		8	bn. €	
Lifetime electricity infrastructure		40	years	
Gas infrastructure				
Biomethane grid integration costs				
Number of injection points required		15833	#	Based on biomethane potential and typical biomethane plant size
Injection into transmission grid (max 40 bar)	Pipeline (for 1 km)	56,000	€/yr/injection point	DNV Kema, 2012: Injecting biomethane into the grid
	Injection point	66,000	€/yr/injection point	
	Compression	150,000	€/yr/injection point	
	Gas quality metering	16,000	€/yr/injection point	
Conventional gas infrastructure				
Gas infrastructure	CAPEX	65	€/yr per household	Nathan Parker, 2004: Using Natural Gas Transmission Pipeline Costs to Estimate Hydrogen Pipeline Costs Gasunie annual report, "replacement value"
Energy costs transport and balancing	OPEX	10	€/yr per household	Ecofys, 2016: Systeemkosten van warmte voor woningen
Maintenance and operations	OPEX	30	€/yr per household	
Lifetime gas infrastructure		50	years	
Heat infrastructure				
Cost for district heating grids				Ecofys, 2016: Urban Electrification Report
	Central Urban	1,096	€/kW	
	Suburban	1,149	€/kW	
	Rural	1,366	€/kW	Approximated with "leavy suburban"
Peak demand				Ecofys, 2016: Urban Electrification Report
Relation energy demand avg. housing house/ terraced house in NL		0.83	%	Avg. Electricity demand for high insulation level
Peak demand heat terraced house		14	kW_{th}	Medium insulation level
Peak demand heat scaled avg. House		12	kW_{th}	
Lifetime heat infrastructure		40	years	

2.4 Electricity production

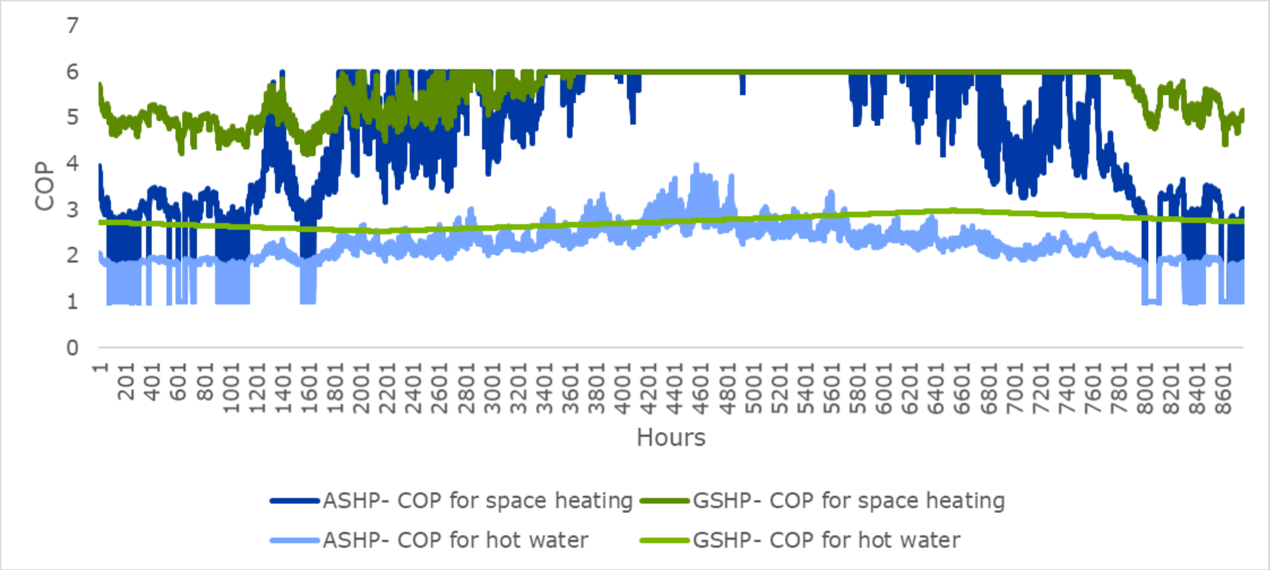

Figure 2: COPs for heat pumps in Western Europe (internal calculations using standard Carnot-Processes)

2.5 Costs

The total technology costs for each scenario are calculated by multiplying the share of each technology in the number of European households with the respective investment cost. To get the technology cost on an annual basis, the investment cost was multiplied with an annuity factor which takes the lifetime of the heating technology into account. Additionally, electric heat pumps incur system integration cost such as replacing existing radiators with low temperature radiators. These costs are included in the technology cost. An analogue approach was made for the insulation cost.

3 Detailed costs for the electricity only scenario

The annualized CAPEX is around 8% of the total CAPEX investments, which corresponds to an average lifetime of 20 years given the annuity factor with a WACC of 5%. The reasoning behind the value of the WACC and the cost comparison between the scenarios with and without renewable gas can be found in the report in chapter 4.2.

Table 10: Total and annual cost for the electricity only scenario

Investment	**Economic lifetime**	**Annuity**	**Total investments**	**Annual cost**			
			CAPEX	**CAPEX, FOPEX, OPEX**	**CAPEX**	**FOPEX**	**VOPEX**
	years		**bn. €**	**bn. €**	**bn. €**	**bn. €**	**bn. €**
Heating technologies	15	0.10	2178	210	210	0	0
Insulation	50	0.05	3283	180	180	0	0
Energy production for heating (gas & heat)				21	0	0	20.6
Electricity production			3982	426	266	69	91.6
Hereof:							
Wind offshore	25	0.07	1141	125	81	44	0
Wind onshore	25	0.07	303	28	22	6	0
Solar	30	0.07	442	33	29	4	0
Hydro	50	0.05	211	12	12	1	0
Biomass	30	0.07	1882	227	122	13	92
Battery storage	5	0.23	3	1	1	0	0
Electricity production for heating				*40*	*No split possible*		
Gas infrastructure cost	50	0.05	364	20	20	0	0
Electricity distribution	40	0.06	537	31	31	0	0
Electricity transmission	40	0.06	1199	70	70	0	0
Heat infrastructure	40	0.06	634	37	37	0	0
TOTAL			**12,177**	**995**	**814**	**69**	**112**

All in all, to build an electricity only scenario for the EU-28 would require investments of €12 trillion. These can be equally split between the power and the heating sector. Although in the ‘electricity only’ scenario renewable gas is not used in the power and building sector, a share of the renewable gas potential is allocated to the industry which leads to integration costs of biomethane. However, the largest share of the gas infrastructure costs can be allocated to the already existing gas infrastructure. The reasoning behind this is that the current gas transmission network has a financial lifetime that runs until 2070 and a technical lifetime that might run even longer. This means that the capital expenditure of these investments in 2050 is already committed, and cannot be avoided by not using it. Nonetheless, as the gas infrastructure is not actively used in this scenario, operation and maintenance costs can be neglected.

In the building sector, the energy costs can be split between heat and power demand for heating (in the electricity with renewable gas scenario also with renewable gas). The costs for the electricity production for the building sector are calculated as part of the whole power system costs and later allocated to the building sector. Therefore, between CAPEX, OPEX and FOPEX is available.

4 Sensitivities

The evaluation of the benefits that renewable gas can provide for the energy system largely depends on the availability and cost of biomethane. In order to assess the impact of these key assumptions and the validity of results, a sensitivity analysis of the biomethane costs (€52 /MWh) and the biomethane potential (98 bcm) was conducted.

The following graph shows the impacts on the savings if the biomethane price varies by 10% or if the biomethane potential varies by 20 bcm due to imports or exports (e.g. from/ to Ukraine, Belarus). Although these variations are significant their individual impact on the system savings is limited.

Price variations of biomethane of 10 % have only an impact of 4 % (or €5bn.) on the cost savings. Variations of the biomethane potential of 20 bcm (which constitute approximately 20 %) also have a limited impact. If an additional 20 bcm of biomethane can be imported to Europe the total system savings can be increased by 7% (€9bn.). A lower biomethane budget of 20 bcm due to exports outside Europe results in lower system savings by 5% (€7bn).

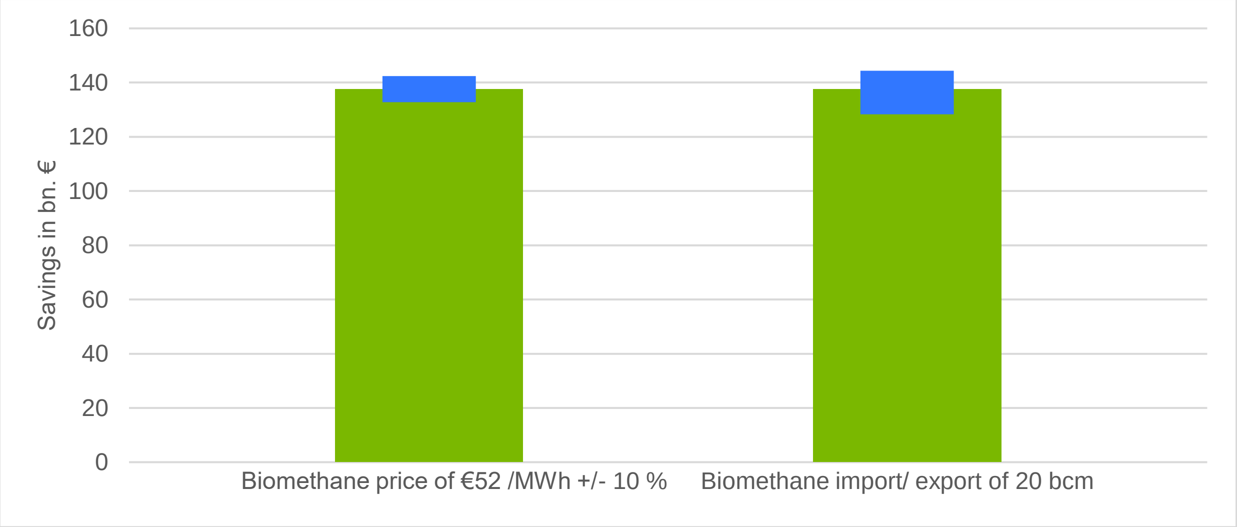

Figure 3: Results of biomethane price and availability sensitivities. Blue area shows the increase and decrease of societal cost savings depending on higher or lower estimates on biomethane price and supply.

The figures below show the impacts by category and show where the highest sensitivities occur.

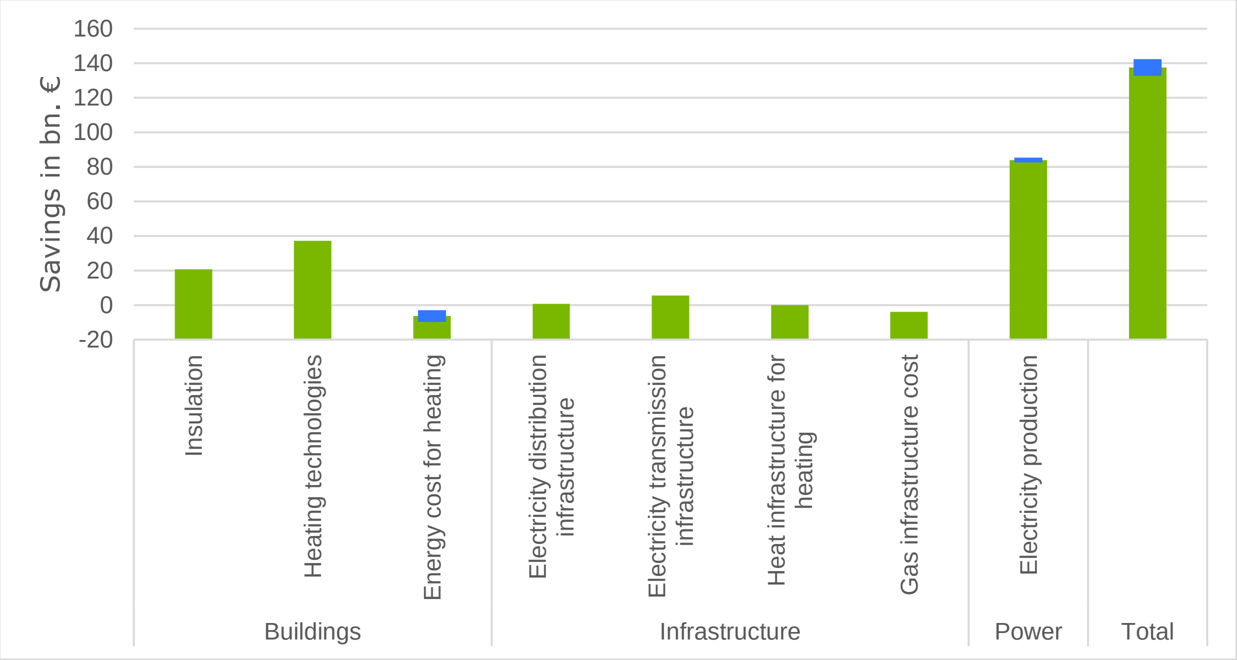

Figure 4: Impacts of changing the biomethane price of €52 /MWh by +/- 10%

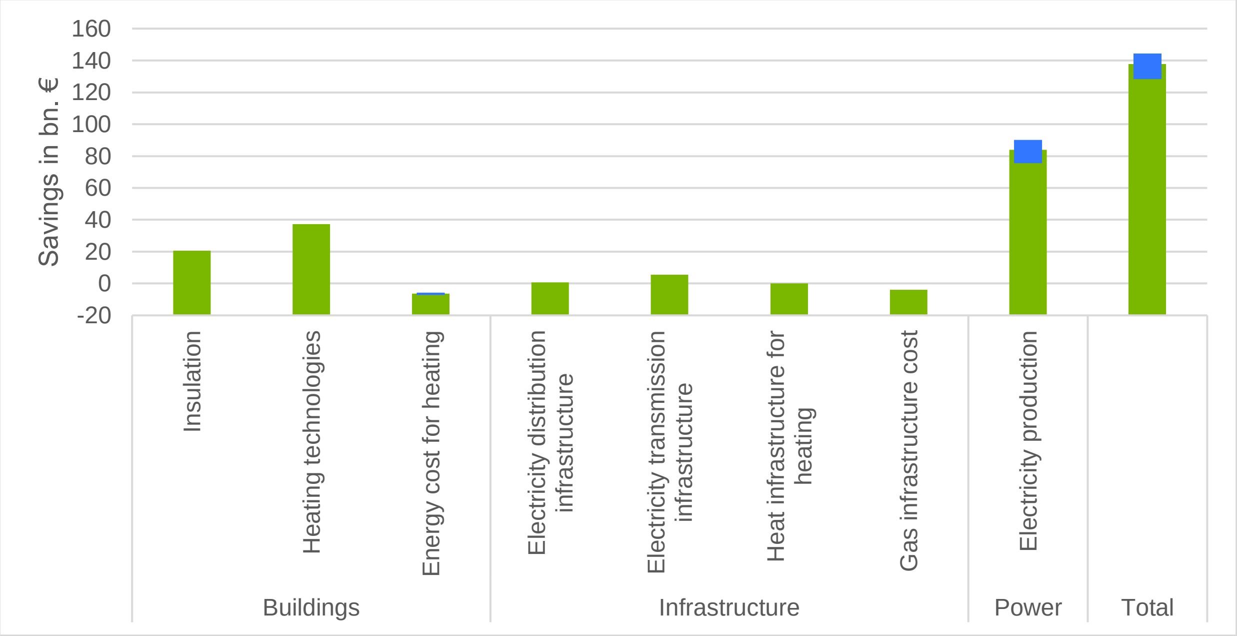

Figure 5: Impacts of assuming biomethane imports/ exports of 20 bcm

Literature list

The analysis uses some results from previous studies and applies them to Europe. Here is an overview of the key publications which provided data for the conducted analysis:

- **Agora Energiewende, 2015**: Integrations costs of wind and solar power. An Overview of the Debate on the Effects of Adding Wind and Solar Photovoltaic into Power Systems. Retrieved here: https://www.agora-energiewende.de/fileadmin/Projekte/2014/integrationskosten-wind-pv/Agora_Integration_Cost_Wind_PV_web.pdf
- **Bozzetto et al. 2017**. The development of biomethane: a sustainable choice for the economy and the environment. Notes for the elaboration of a road map for the development of biogas done right and biogas refinery technologies in Italy.
- **CEMBEREU & ERFO, 2015.** MARKETS FOR SOLID RECOVERED FUEL: Data and assessments on markets for SRF
- **DECC, 2014**. RHI Biomethane Injection to Grid Tariff Review.
- **DECC, 2016**: Potential Cost Reductions for Air Source Heat Pumps. Potential cost decreases in the case of a mass market. Retrieved here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498962/150113_Delta-ee_Final_ASHP_report_DECC.pdf
- **DECC, 2016**: Potential Cost Reductions for Ground Source Heat Pumps. Potential cost decreases in the case of a mass market. Retrieved here: https://www.gov.uk/government/uploads/system/uploads/attachment_data/file/498963/150113_Delta-ee_Final_GSHP_report_DECC.pdf
- **DNV Kema, 2012**: Injecting biomethane into the grid
- **Ecofys et.al. 2017, Batstorm.** Support to R&D Strategy for battery based energy storage (D7). *Cost and benefits for deployment scenarios of battery systems.*
- **Ecofys, 2013**. Low ILUC potential of wastes and residues for biofuels
- **Ecofys, 2015. Waarde van slimme netten** (Dutch).[5] The value of smart grids (English summary). *This study investigated the potential added value of smart grids through a case study of two existing and representative medium-voltage grids in the Netherlands. Investments costs for grid reinforcements are compared to costs for applying smart solutions in households.*
- **Ecofys, 2016**. Assessing the case for sequential cropping to produce low ILUC risk.
- **Ecofys, 2016. Systeemkosten van warmte voor woningen** (Dutch).[6] Total energy system costs of heat in the residential sector. *Other studies such as the Urban Electrification study are based on the results of this report. This report examines the system costs for heating for different scenarios, house types, insulation types and building stock topologies.*
- **Ecofys, 2016. Urban Electrification: Impact of electrification of urban infrastructure on costs and carbon footprint.**[7] *This study explored potential trajectories in the development of the urban energy infrastructure. Various scenarios incorporate different energy carriers for heating of residences and private transport were analysed and compared.*
- **Ecofys, 2016. Waarde van congestiemanagement** (Dutch).[8] The value of congestion management. *This study investigated the potential added value of flexibility options as alternative to grid reinforcements. System costs for distribution and transmission grid reinforcements are compared to system costs for applying demand side management.*

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[5] http://www.ecofys.com/files/files/ecofys-2014-summary-the-value-of-smart-grids-english.pdf; http://www.ecofys.com/files/files/ecofys-2014-the-value-of-smart-grids-dutch.pdf

[6] http://www.ecofys.com/files/files/the-total-costs-of-heat-in-the-residential-sector-summary.pdf; http://www.ecofys.com/files/files/ecofys-2015-systeemkosten-van-warmte-voor-woningen_02.pdf

[7] http://www.ecofys.com/en/projects/urban-electrification/

[8] http://www.ecofys.com/files/files/ecofys-2016-waarde-van-congestiemanagement.pdf

- **Ecofys, 2017, Public Consultation on the Evaluation of Directive 2010/31 EU**. *This study evaluated the Energy Performance of Buildings Directive (EPBD) and analysed the building stock and energy demand across Europe.*
- **Ecofys, 2017**. Beschikbaarheid houtige biomassa voor energie in Nederland (Dutch). Availability of woody biomass for energy in the Netherlands.
- **Ecofys, 2017. Translate COP21: 2045 Outlook and implications for offshore wind in the North Seas**. *This study investigated the required offshore wind capacity in the North Seas that is needed by 2045 to meet the* CO_2 *reduction targets set in the COP21.*
- **Elbersen et al. 2014**. Outlook for spatial biomass value chains in EU-28.
- **ENTSO-E, Technofi, RTE et.al. 2015, e-Highway 2050: Europe's future secure and sustainable electricity infrastructure.** *In a 3-year programme several partners developed several scenarios for 2050 and analysed the requirements for the pan-European transmission grid.*
- **European Climate Foundation 2010, Roadmap 2050.**[9] *The analysis includes estimations on the reduction of cost and increase of efficiencies of renewable energies. Moreover, the study makes some assumption on the cost and number of electric vehicles by 2050.*
- **Eurostat, 2017.** Crop statistics. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=apro_acs_a&lang=en
- **Eurostat, 2017**. Generation of waste by waste category. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasgen&lang=en
- **Eurostat, 2017**. Land use. http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ef_oluft&lang=en
- **Eurostat, 2017.** Municipal solid waste by operations.
- **Fraunhofer EU Longterm scenarios 2050 II, 2014**. *Cost estimates for renewables.*
- **Fraunhofer-Institute ISE, Agora Energiewende, 2015,** *Current and Future Cost of Photovoltaics* http://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=env_wasmun&lang=en
- **Iqbal et al. 2016.** Maximising the yield of biomass from residues of agricultural crops and biomass from forestry.
- **Kampman et al. 2017**. Optimal use of biogas from waste streams.
- **Low Carbon Innovation Coordination Group, 2012**. Technology Innovation Needs Assessment.
- **Ricardo, 2016.** *The role of natural gas and biomethane in the transport sector.*
- **USDA, 2018**. World Agricultural Production. https://apps.fas.usda.gov/psdonline/circulars/production.pdf

The costs of technology were updated and reviewed with more actual publications such as: Kosten des Ausbaus erneuerbarer Energien: Eine Metaanalyse von Szenarien, 2012, Potsdam-Institut für Klimaforschung. *The meta-analysis compares different study results regarding to the CAPEX developments of renewables by 2050. The study was commissioned by Germany's environmental protection agency commissioned the study.*

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[9] http://www.roadmap2050.eu/

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