Overview of Distributed Generation in Germany

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Introduction

The German "Energiewende" (Energy Transition) serves as a model for promoting renewable energy, energy efficiency and innovative energy supply solutions worldwide. In 1990, renewable energy accounted for only 3.4% of the gross electricity consumption in Germany. With around 30 years of development, in 2016, 29% of the power generated in the entire country was from renewable energy.[1] At certain times of strong wind and sunshine, renewable energy could even fulfill more than 80% of the country's total electricity demands for several hours. [2]

This new era of energy generation comes hand in hand with a shift from centralized energy generation towards distributed generation. As Germany is leading the trend in the area of distributed generation, this briefing shall define distributed energy generation in the German context and discuss the development of the most relevant distributed energy sources in Germany. The policies in support of distributed generation and the challenges and opportunities of distributed generation in Germany are also analysed.

Definition of Distributed Electricity Generation

Although there is not quantitative definition of distributed generation in Germany, a quantitative boundary of distributed generation is given for this briefing based on diverse articles and availabitlity of data (see Table 1).

The Energy Economics Act (EnWG) of Germany defines a distributed energy conversion unit as a power plant connected to the distribution grid and close to the consumer and demand side.[3] As shown in Table 2, there are total of four voltage level categories in Germany, distribution grid includes medium and low voltage level grids (i.e. 230V, 400V, 10kV, 20kV and 30kV), which serves the regional electricity supply. [4]

Apart from locally generated and connect to middle and low voltage power grids, scale of generator is also an important criteria to distinguish centralised and distributed generation. To take the capacity standard of distributed PV in China as a reference and to conform to the statistical categories of installed capacity of power generation in Germany, this briefing will focusing on power generation units that equal or less than 10MW.

Table 1: Boundary of Distributed Generation of Germany versus Chinese Definition in this Briefing

Boundary of German Distributed Generation in this Briefing	Definition of Distributed PV in China
a) Close to consumer	a) Locally-generated and consumed
b) Connected to ≤ 30kV power grids*	b) connected to ≤10kV voltage power grid, for agriculture and fishery integrated projects ≤350kV, in Heilongjiang, Liaoning and Jilin provinces ≤660kV
c) Installed capacity of single unit ≤ 10MW**	c) installed capacity of single project ≤6MW, for agriculture and fishery integrated project ≤20MW per point of grid connection

Notice: *As there is no data available to qualify both b) and c) in Germany, the data analysis will be done to satisfy either b) or c); ** The statistic data of power generation capacity in Germany is based on number of units but not projects.

1 BMWi (2017)
2 GIZ (2016)
3 BMJV (2017b)
4 ewi Energy Research & Scenarios GmbH(2016)

Table 2: Four Voltage Level Categories of Power Grids in Germany and China5 6 7

Voltage-level Category		Germany	China
Centralised Power Grid	Extra-high Voltage	220kV, 380kV	500kV
	High Voltage	110kV	110kV, 220kV, 330kV
Distributed Power Grid	Middle Voltage	10kV, 20kV, 30kV	10kV, 35kV
	Low Voltage	230V, 400V	220V, 380V

Distributed Generation by Different Technology

Based on the definition of distributed power generation given earlier, this section gives an overview of German distributed electricity generation by different sources. A detailed overview of solar photovoltaic (PV), biomass and Combined Heat and Power (CHP) generation will be provided separately.

Renewable Distributed Generation

By the end of 2015, the installed capacity of the three most important renewable sources in Germany, which were onshore wind, solar PV, and biomass, were accumulated to 41.2 GW (44%), 39.3 GW (42.2%) and 6.9 GW (7.4%) respectively. They were followed by offshore wind, which had 3.4 GW (3.7%) of installed capacity. Other relevant renewable sources combine (hydro, geothermal, sewer gas, landfill gas, mine gas) accumulated to 2.1 GW (2.2%) of installed capacity.[8] [9] Please see the full table in Appendix 1.

Regarding voltage level of grid connection only, solar PV is the dominant (non-hydro) renewable power source in distributed generation (see Figure 1). By 2015, it had 36.5GW of units fed into medium to low voltage grids, accounting more than half of total renewable distributed generation. This was followed by onshore wind (30.24%) and biomass (9.83%).

Regarding installed capacity of a single power generation unit only, as shown in Figure 2, by 2015, onshore wind showed the largest proportion in total distributed generation (99.2%). To follow was others (98.1%), solar PV (95.9%) and biomass (86.4%). In words, all renewable energy generation have large proportion of their installed capacities as distributed generation in Germany.

Distributed onshore wind will not be discussed further in details as it is not referential to China.[10]

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5 Grid connection levels in Germany, cf. DPG (2016)
6 Verivox
7 国内电压等级划分及全球各国电压一览表
8 BNetzA (2017a)
9 For renewable energies the statistics only include plants which are eligible to receive promotions through the EEG (Renewable Energy Act). It is assumed that this equals the overall number of installed plants.
10 By 2014, only 0.5% (523MW) of total wind installed capacity in China was counted as distributed generation.

Figure 1: Installed Capacity of Various Power Sources with Corresponding Voltage Level of Grid Connection in 2015 (MW)11

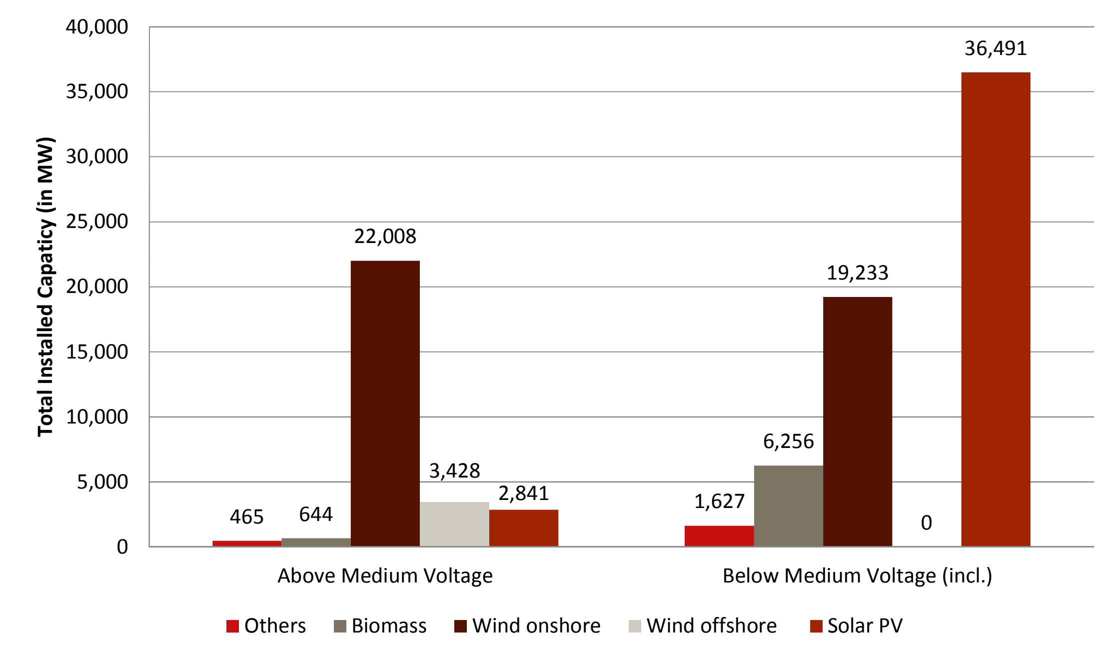
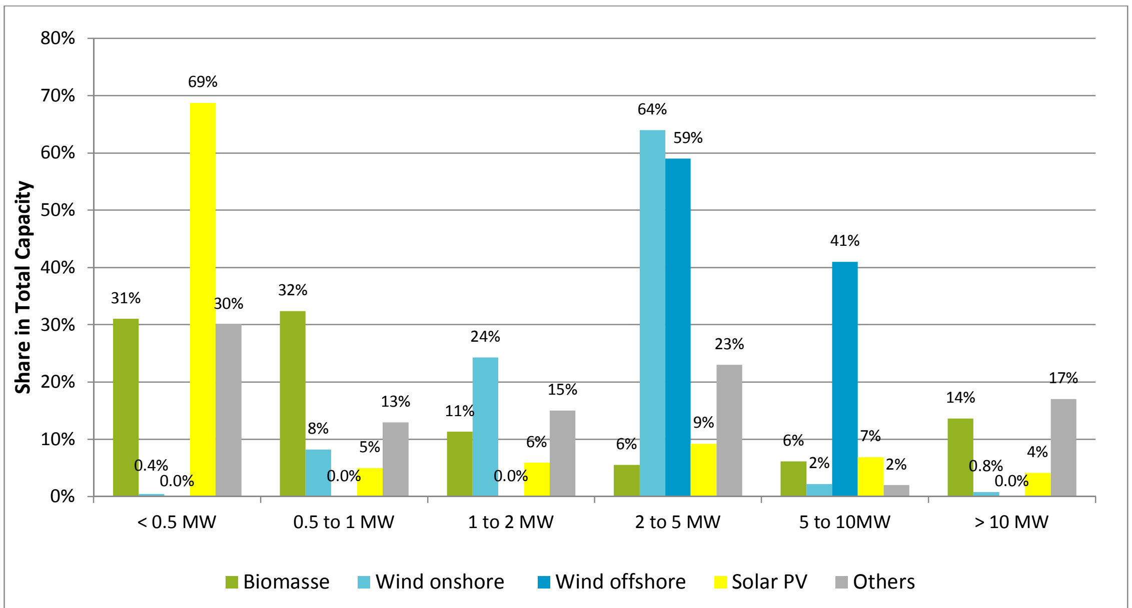


Figure 2: Share of installed capacity of biomass, onshore wind and solar PV in six capacity categories in 2015 12



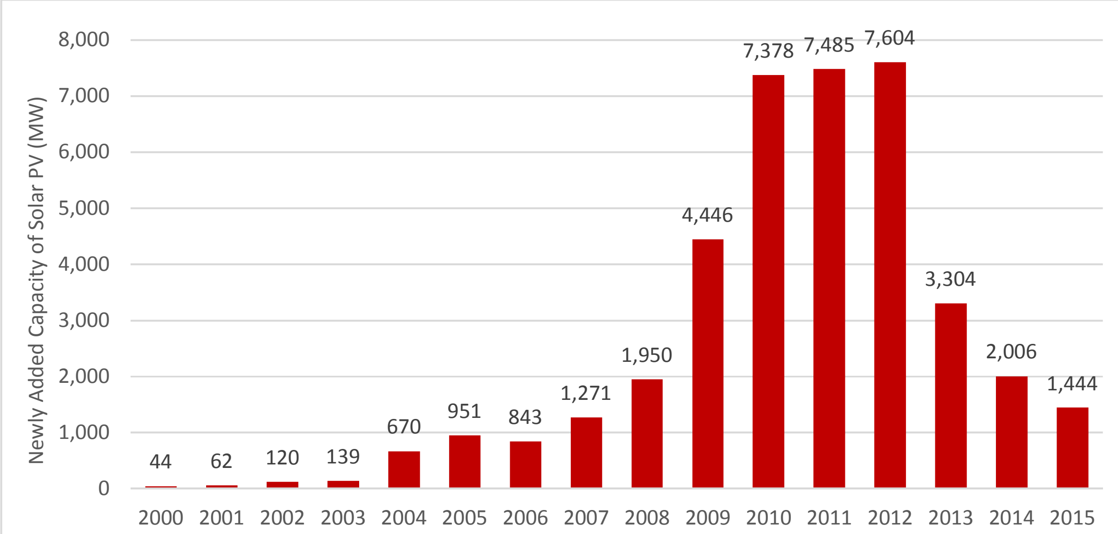
Notice: Others include Hydro, Geothermal, Landfill gas, Sewage gas and Mine gas.

Solar Photovoltaic

The development of solar PV experienced roller coaster in Germany (see Figure 3). It had a phenomenal growth between 2010 and 2012 but dropped sharply afterward. The annual growth was decreased by 43.5%, 60.7% and 28% in 2013, 2014 and 2015 respectively.[13]

11 BNetzA (2017a)
12 BNetzA (2017a)

Figure 3: Newly added installed capacity of solar PV between 2000 and 2015 (MW)



By 2015, a total of 39.3GW of solar PV units were installed in Germany, generating 35.2TWh of electricity. Of the total capacity, 71% were installed as roof-top units and 27% were installed as ground-mounted PV units.

As shown in the last chapter, 57% (22.5GW) of total solar installed capacity was connected to medium to low voltage grids. While data on grid connection levels of rooftop and ground-mounted PV plants is not available. Regarding the installed capacity of PV units, all roof-top (28GW) were smaller than 10MW, which 75% were between 10kW and 1MW. While for ground-mounted PV, 84.7% (10.5GW) of total were smaller than 10MW, which nearly 90% were between 1MW and 10MW (see Table 3). [14]

Table 3: Unit sizes of roof-top and ground-mounted solar PV applications in 2015 [15]

	< 0.01 MW		0.01 to 0.04 MW		0.04 to 1 MW		1 to 10 MW		>10 MW		Total
	MW	%	MW	%	MW	%	MW	%	MW	%	MW
Roof-top	5139.9	18.3	11082	39.5	11257.8	40.1	562.4	2	0	0	**28042**
Ground mounted	14.4	0.1	13.5	0.1	967.5	9.1	7997.6	75.4	1620.5	15.3	**10613.4**
Others*	281.3	41.6	135.6	20	119.3	17.6	130.1	19.2	10.6	1.6	**676.9**
Total	5435.6	60.0	11231.1	59.6	12344.6	66.8	8690.1	96.6	1631.1	16.9	**39332.3**

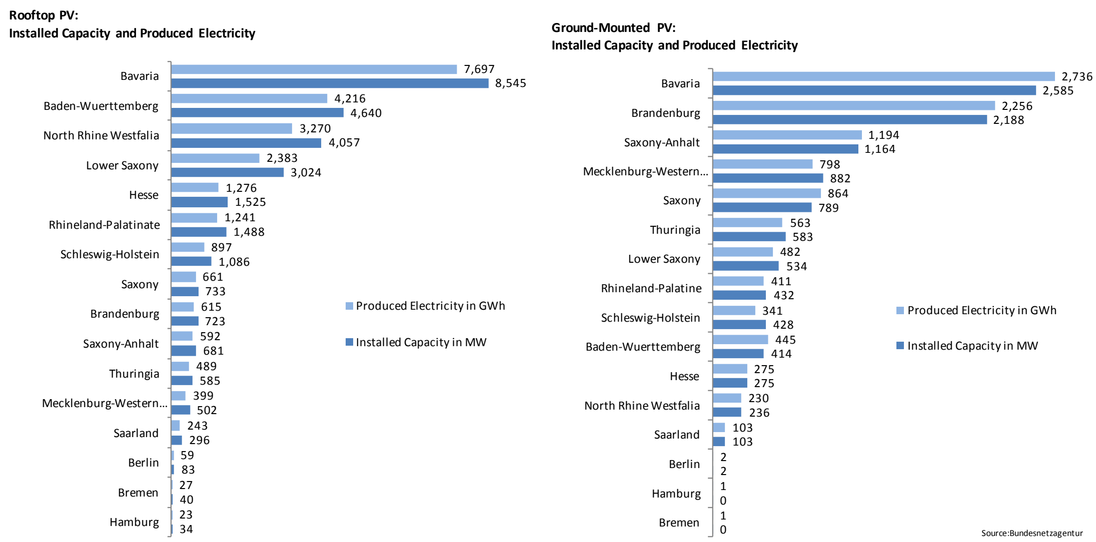
*Others: Solar PV application that are not classifiable

In aspect of geographical deployment, in 2015, Bavaria, the southern state of Germany, occupied the biggest share of solar PV installed capacity, i.e. 8.5 GW of roof-top and 2.6 GW of ground-mounted (see Figure 4). This is because Bavaria has the best solar resources within the whole country: the annual average solar irradiance from 1981 to 2010 in south Bavaria reached 1161-1180 kWh/m2 (see Appendix 2), which was comparable to the solar

13 BNetzA (2017a)
14 BNetzA (2017a)
15 BNetzA, P.25(2017a)

irradiance received in southeastern provinces of China, for example Zhejiang and Jiangsu (see Appendix 3). 63% of the ground-mounted PV with a total capacity of 830.6 MW in Bavaria was installed on farmland.[16] It was followed by the southwestern state of Baden-Wurttemberg for rooftop PV (4.6 GW) and the eastern state of Brandenburg for ground-ground mounted PV (2.2 GW), the majority of which being installed on former military areas.[17] [18] The three city states of Germany: Berlin, Hamburg, and Bremen, ranged lowest in the ranking and only accumulate to ca. 150 MW of installed rooftop capacity and 2 MW of ground-mounted PV capacity.[19]

Figure 4: Roof-top PV and ground-mounted PV capacity and power generation in 2015 by Federal State [20]



Biomass

In Germany, the installed capacity of biomass[21] power generation was increased by an average annual growth rate of 13.9% between 2007 and 2011. The pace of development has been slowing down since 2012 and by 2015, its annual growth rate already dropped to 1.4% only.

By 2015, 6.9GW of biomass units were totally installed in Germany, generating 40.6TWh of electricity. As shown in Chapter1, 90.7% (6.3GW) of total installed capacity was connected to medium to low voltage grids and 63.4% of units were smaller than 10MW. Table 4 illustrates six capacity categories of biomass units in Germany.

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16 ZSW (2014)

17 ZSW (2014)

18 After the Iron Curtain was lifted and allied and German Forces gradually reduced their numbers of barracks in Germany, many former military areas are now converted and used for e.g. public housing or the installation of renewable energies.

19 BNetzA (2017a)

20 BNetzA (2017a)

21 Include biomass liquid fuel, biogas, bio-methane and solid biomass

Figure 5: Newly Added Installed Capacity of Biomass Generation Stations between 2004 and 2015 (MW)

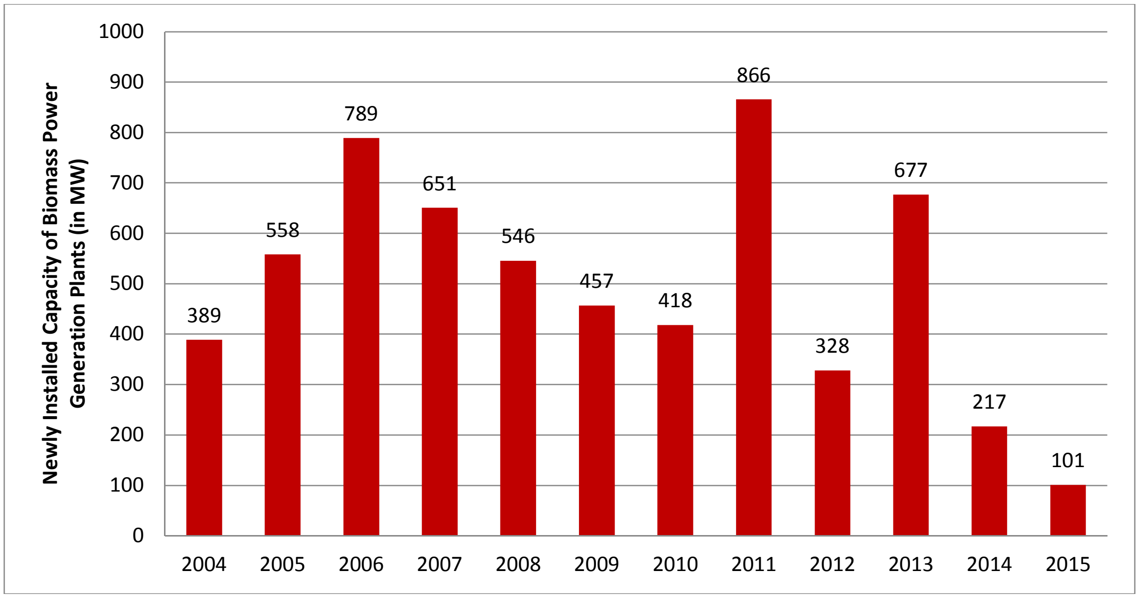


Table 4: Capacity Categories of Biomass Power Generation Units [22]

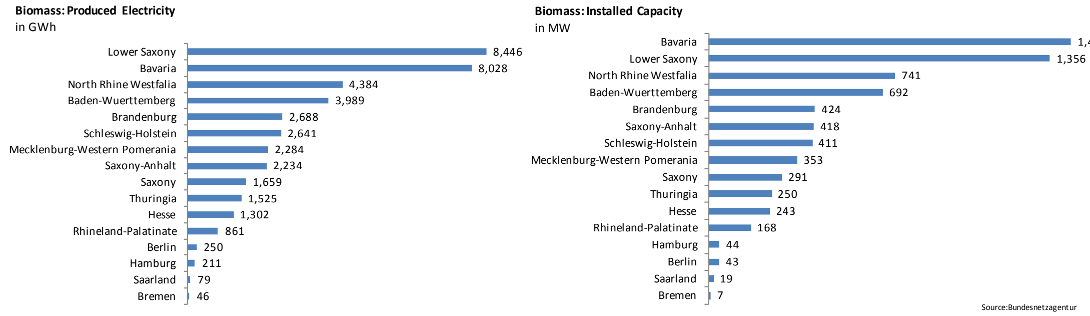
	< 0.5 MW		0.5 to 1 MW		1 to 2 MW		2 to 5 MW		5 to 10 MW		> 10 MW		Total
	MW	%	MW	%	MW	%	MW	%	MW	%	MW	%	MW
Biomass	2140.6	31.0	2232.5	32.4	782.8	11.3	380.4	5.5	423.5	6.1	940.3	13.6	**6900.1**

Similar to the solar PV, the biggest amount of biomass power installed capacity was installed in Bavaria, i.e. 1.4 GW and 20.9%, while the biggest amount of electricity generated from biomass was produced in Lower Saxony where was ranked the second in installed capacity, i.e. 8.5TWh and 20.8% (see Figure 6). [23]

Due to current alterations in the German Renewable Energy Sources Act (EEG) 2017, in the future biomass power plants shall be substituted by solar PV and wind units that are more cost-effective.[24] [25] The EEG expansion targets limit the newly installed capacity of biomass power generation units to be no more than 150 MW in the timeframe from 2017 to 2019 and 200 MW from 2020 to 2022.

[22] BNetzA(2017a)
[23] BNetzA (2017)
[24] BMWi (2016)
[25] DBFZ (2016)

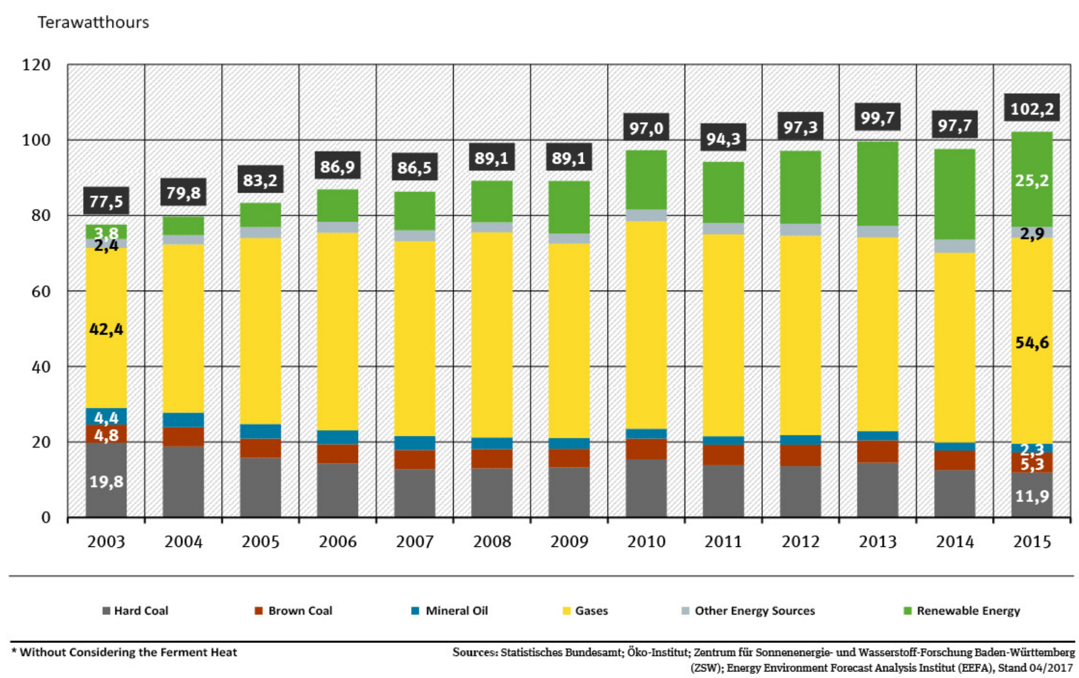
Figure 6: Installed Biomass Capacity and Power Generation in 2015 by Federal State [26]



Combined Heat and Power

The development of CHP generation had a steady but not big increase in Germany from 2003 to 2010, rose from 77.5TWh to 102.2TWh with an average yearly growth rate of 2.4%. Afterwards, it fluctuated up and down and ended up with 102.2TWh by 2015.[27] Regarding the electricity generation by different energy sources from CHP units, gases, renewables and hard coal were ranking the top three.

Figure 7: CHP Electricity Generation by Energy Sources (2003-2015). [28]



According the latest statistics of CHP installed capacity verses voltage level of grid connection, in 2013, a total of 12.8 GW of CHP units were installed in Germany. Among these, 32% were connected to medium and low voltage grids, which revealed the importance of CHP as a distributed generation energy source (see Table 5).[29]

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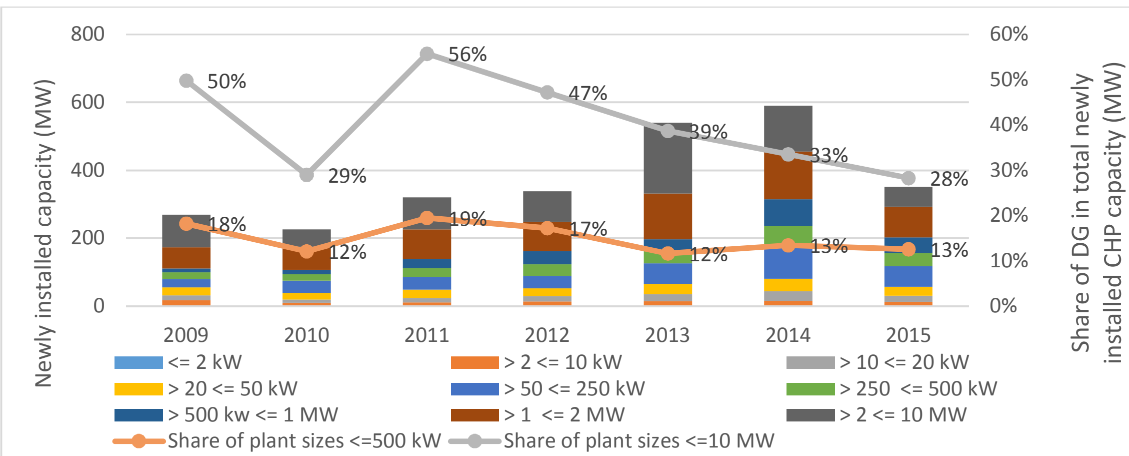
[26] BNetzA (2017a)
[27] Umweltbundesamt (2017): Kraft-Wärme-Kopplung (KWK);
[28] Umweltbundesamt (2017): Kraft-Wärme-Kopplung (KWK)
[29] BKWK (2014)

Table 5: Installed capacity of CHP units in Germany by grid connection level (in 2013)

	Low Voltage	Medium Voltage	High Voltage	Total
Number of units	50,000	1,500	300	**51,800**
Installed capacity	1.4GW	2.7GW	8.7GW	**12.8GW**
Share	10.9%	21.1%	68%	

Between 2009 and 2015, the installation growth of CHP units in all plant sizes witnessed a rough acceleration, although a drop-off in new installations appeared in 2015 (see Appendix 4).[30] Figure 8 shows the development of newly installed CHP with capacity smaller than 10 MW, as well as the shares of plant sizes of <10 MW and <500 kW in total newly installed CHP). As for the increasing number of CHP units, the unit size ranging from 2 (excl.) to 10 kW(incl.) have shown the largest jump, which summed up to 13,055 newly added units in 7 years. This were followed by CHP units that equal of less than 2kW (6,998), 10 (excl.) to 20kW (incl.) (5,885) and 20 (excl.) to 50kW (incl.) (3,719). It is obvious to see that the development of smaller size CHP units was promoted effectively, this is because of the relatively high Feed-in-Tariff indicated in the Combined Heat and Power Cogeneration Act (KWKG) which will be explain in the next chapter. Although the increasing number of small-scale CHP units was far more than large-scale units, its total newly added capacity within the 7 years was only a half of the large-scale.

Figure 8: Annual newly installed CHP units smaller 10 MW under the CHP law by size between 2009 and 2015 (in MW).[31]



Policies in Support of Distributed Generation

The development of distributed renewable generation and CHPs have been promoted by the Renewable Energy Sources Act (EEG) and the CHP Act (KWKG) respectively. Both of them will be briefly described in this section.

[30] Bafa (2017), these numbers also include any units which were newly registered, e.g. due to retrofit measures.
[31] Bafa (2017)

Renewable Energy Sources Act (EEG)[32]

Germany's Renewable Energy Sources Act (EEG) has served as a model for renewable energy promotion policies worldwide due to its success in promoting the development of renewable energies for electricity generation.

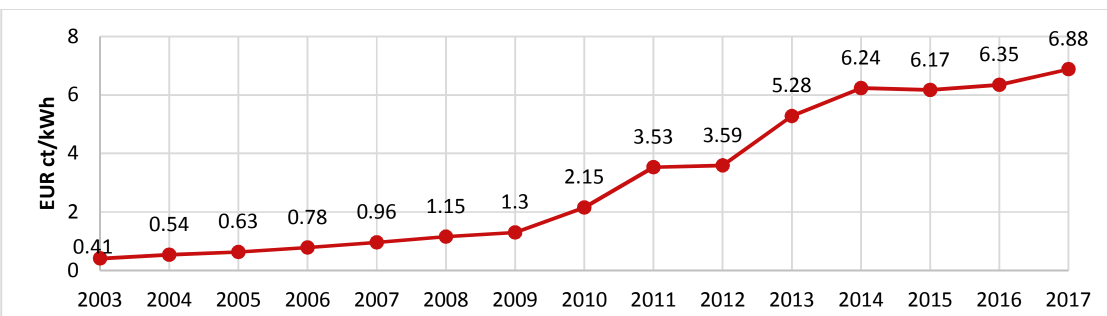
It is firstly guaranteed in the EEG legislation that all power generated from renewables would be utilized prior to electricity generated from conventional energy sources. Moreover, the EEG incentivizes the expansion of renewable energies through the two further key components, namely the Feed-in-Tariffs (FiTs), the EEG-surcharge and the priority grid access for renewables, which would be explained accordingly in the following text.

The FiTs was firstly introduced in the Germany's Regulation on Electricity Feed into the Public Grid (Stromeinspeisegesetz) adopted in 1990, which was also the predecessor of EEG. FiTs are the set payments that producers of renewable power receive per kilowatt-hour (KWh) and are guaranteed for 20 years.[33]

In order to finance the FiTs, a levy is imposed on the electricity price, which is the so-called EEG surcharge.[34] It is set on by the transmission grid operator on a annual basis and is paid by all consumers of electricity.[35, 36] The EEG surcharge in 2017 rose to around 6.88 EUR ct/kWh from 6.35 EUR ct/kWh in the previous year. Figure 9 shows the change of the EEG surcharge over the years.[37]

On January 1st 2017, the latest amendment of the EEG took effect and this amendment features a reform of FiTs away from statutory tariffs determined by the law to remunerations determined by the market bidding system.[38, 39]

Figure 9: Historical development of EEG Surcharge from 2003 to 2017[40]



[32] This section is taken and updated from the policy briefing "The German Renewable Energy Sources Act 2017" published by GIZ in November 2016. Refer to the publication for more detailed information on the Renewable Energy Sources Act EEG. Key data on the EEG can be found in the appendix.
[33] Appunn, Kerstine (2014): Defining features of the Renewable Energy Act (EEG), Clean Energy Wire
[34] Certain exemptions (for electricity storage and power-to-gas) and reductions of the EEG surcharge (for large electricity consumers of certain industries) apply (§61a).
[35] (with the exception of energy intensive industries (in order to avoid damage to international competitiveness) and operators of renewable and small conventional power plants that use electricity they generate themselves.
[36] Appunn, Kerstine (2014)
[37] BNetzA (2017b)
[38] BMWi (2017c): Das Erneuerbare-Energien-Gesetz, Erneuerbare-Energien-Gesetz 2017 (EEG 2017)
[39] Applicable for Solar PV installation with capacity over 750 kW, FiTs for Solar PV installation with small or middle capacity would be introduced in the following text
[40] BWMi(2017b): EEG-Umlage 2017: Fakten und Hintergründe.

With regards to the distributed generation, the EEG has regulated higher FiTs for solar PV installation with capacity equal or smaller than 100kW, which is not effected by the FiTs reform of the EEG 2017 mentioned earlier. Table 6 explains the FiTs with data and it is estimated that annually small-scale solar PV with a total capacity of 1,900 MW would be installed thanks to such FiTs.[41]

Table 6: Stationary FiTs for solar PV Installation smaller than 100kW according to EEG 2017 [42]

	Residential Buildings, Noise-insulating wall and Buildings refered to in EEG Article 48, Paragraph 3[43]			Other Installations
Capacity of the Solar PV Installation (kWp)	Up to 10 (incl.)	10 – 40 (incl.)	40 – 100(incl.)	Up to 100(incl.)
FiTs in EUR ct/kWh	12.20	11.87	10.61	8.44

CHP Act (KWKG)

Similar to the Renewable Energy Sources Act for the promotion of renewable energy, the Combined Heat and Power Cogeneration Act (KWKG) has served as a tool to promote the heat and power generation through CHP units regardless of the fuel used (coal, lignite, waste, biomass, gas and liquid fuels). KWKG was first implemented in 2002 with the latest amendment coming into effect on January 1st 2017. KWKG aims to achieve 110 TWh of generated electricity through CHP units by 2020 and 120 TWh by 2025.[44]

CHP generators are remunerated through Feed-in-Tariffs (FiTs), depending on the size of CHP units and the type of electricity feed-in (i.e. feed into grid or self-consumption). The FiTs paid to generators from the highest for units smaller than 50 kW reducing with increasing unit size.[45] Hence, the KWKG promotes the installation of small, distributed, CHP units.

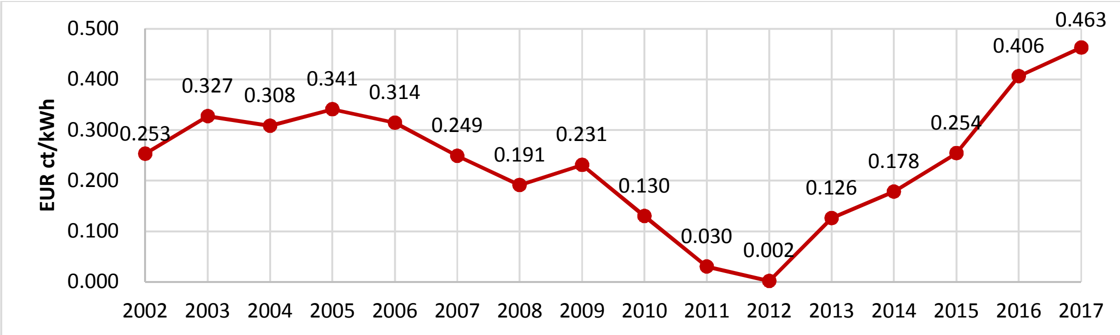
Table 7: Feed-in Tariffs for CHP plants connected to the public electricity grid in 2017 [46]

CHP Plant Size	Feed-in Tariffs in EUR ct/kWh
Smaller 50 kW	8
50 kW to 100 kW	6
100 kW to 250 kW	5
250 kW to 1 MW	4.4
1 MW to 50 MW	Determined through tendering
Bigger 50 MW	3.1

Costs for the promotion of CHP are covered through a levy on the electricity price (CHP surcharge or KWK surcharge). However, compared to the EEG surcharge the CHP surcharge is relatively low and amounts to 0.463 EUR ct/kWh in 2017 (see Figure 10).[47]

41 BMWi(2017a): Photovoltaik Dach
42 Bundesagentur(2017): Photovoltaikanlagen - Datenmeldungen und EEG-Vergütungssätze; https://www.bundesnetzagentur.de/DE/Sachgebiete/ElektrizitaetundGas/Unternehmen_Institutionen/ErneuerbareEnergien/Photovoltaik/DatenMeldgn_EEG-VergSaetze/DatenMeldgn_EEG-VergSaetze_node.html
43 For detail please refer to https://www.gesetze-im-internet.de/eeg_2014/__48.html
44 BMJV (2017a)
45 DIHK (2017)
46 DIHK (2017)
47 BNetzA (2016b)

Figure 10: Historical development of KWK surcharge since its introduction in 2002[48]



Opportunities and Challenges of Distributed Power Generation in Germany

Efficiency Improvements and Emission Reductions

The push for renewable energy is in large part driven by concerns of emissions of gasses that contribute to climate change, as well as to degradation of local air quality. PV, like most renewables, does not combust any fuel, and therefore emits no flue gasses into the atmosphere during the process of electricity generation, whilst different forms of biomass power generation do. A fair comparison, however, should also include emissions during processes of construction of the power plant, manufacturing of its equipment, the mining or collecting of the fuel (if any), and the transport associated with each of these steps. Such a scope for emission data is referred to as life-cycle emissions.

The life-cycle emissions to air for PV and a number of different biomass based power generation processes in Germany in 2016 are listed in Table 8. Other fossil and renewable power generation methods are included for comparison. The results in Table 8 show that renewables, even when regarding the full life-cycle, have close to zero greenhouse gas emissions. The exceptions are bio-power produced with rapeseed oil or with biogas produced from maize, which are due to fertilization and use of machinery during cultivation of the crops. For similar reasons, the emissions of acidifying substances, ozone precursors, and particulate matter are actually higher for these production methods than for the fossil fuel based electricity that they displace (Table 8). With regards to distributed versus centralized power generation, there are a number of factors to consider.

First, a benefit from distributed methods is that these can prevent some of the grid losses incurred when transmitting electricity over long distances. Such grid losses were as much as 8 to 9% (of net electricity generation) in Germany in 2016[49]. Where electricity from distributed generation is used on-site, as is most usually the case with rooftop PV panels or small-scale (bio) gas generators, such grid-losses can be prevented altogether[50]. In other cases, grid losses depend on distance between generation unit and end-user, as well as the voltage level in the grid, with stronger losses per km in lower voltage grids. Electricity from centralized forms of power generation still will always have to be transported over the low-

48 50 Hertz et al. (2017), BNetzA (2016b)
49 Statistische Bundesamt (2017b)
50 Kok et al (2010)

voltage grid to reach household and other small end-users. However, it is likely that the distance that electricity from centralized sources is transported over the low-voltage grid exceeds the distance of transport from local, distributed generators. Overall, transmission losses from distributed forms of generation will therefore be substantially lower.

Second, a downside from distributed generation is that smaller generators are less energy efficient and have higher emissions per unit of fuel consumption. As an indication, efficiencies and emissions for a range of different sizes of gas-fired generators is listed in Table 9. The same logic does not apply to PV panels, which will have comparable efficiency and emissions in either distributed or centralized configurations. Roof-top installations, however, may be limited in efficiency due to the alignment of the roof.

Third, and one of the strongest arguments for distributed electricity generation, is the possibility for the combined generation of heat and power. The utilization of 'waste' heat for useful energy purposes drastically improves energy efficiency (see Table 9). When such small-scale generators are used for cogeneration of electricity and heat, conversion efficiency is substantially increased, to the point where it is comparable to the efficiency of a large, modern, combined cycle gas fired power plant. Distributed cogeneration units have conversion efficiencies of 52.4~59.0%, versus approximately 58.1% for electricity from a modern combined cycle gas turbine, operating in pure electric mode; see Table 9). Emissions per kWh of useful energy, too, are comparable with those from such a large power plant operating in pure electric mode.

It is not straightforward to calculate avoided emissions from distributed CHP plants, as it is not clear what the baseline emissions would be. More importantly, the use of distributed generation is what enables the use of highly energy efficient CHP in many locations. Densely populated urban districts or industrial parks may be connected to heat/steam supply grids fed by large centralized power plants or district heating plants. The transport of heat from a centralized plant to a number of remote villages or smaller industrial users is entirely inefficient as heat losses are substantial, and infrastructure would be prohibitively expensive. In such cases, local heat networks with more distributed generation are a more sensible option. The presence or absence of a heat network is also an important factor in the sizing of the CHP generator, with highest efficiencies enabled when the generator is sized to on-site or local heat demand.

Table 8: Life-cycle emission factors for emissions to air and total avoided emissions from main processes for electricity generation in Germany (2016)

Process/fuel	Emission factors (g/kWh)				Generation (TWh)	Total avoided emissions (kt)[d]			
	CO_2-eq	SO_2-eq	TOPP	PM		CO_2-eq	SO_2-eq	TOPP	PM
Coal	973.2	1.354	1.165	0.088	111.5				
Lignite	1,056	0.899	0.729	0.032	150.0				
Gas	556.8	0.532	0.909	0.010	80.5				
Nuclear[a]	55.40	0.145	0.169	0.015	84.6	82,527	75.34	58.43	2.84
Hydro	2.790	0.007	0.011	0.002	21.0	18,490	24.20	22.79	1.43
Wind	10.22	0.029	0.040	0.009	77.4	67,574	87.51	81.75	4.66
PV	55.95	0.122	0.404	0.027	38.2	31,604	39.61	26.46	1.63
Incineration of solid	17.87	0.487	0.966	0.023	12.24	10,589	8.22	1.59	0.57

biomass waste[b]									
Biogas from manure[b]	98.68	0.785	0.959	0.023	7.93	6,222	2.97	1.09	0.37
Biogas from maize[b]	284.6	6.423	1.506	0.077	21.6	12,925	-113.64	-8.85	-0.16
Rapeseed oil[b]	286.3	7.147	5.685	0.092	0.40	237	-2.38	-1.82	-0.01
Avg. avoided fossil fuel mix (renewables, excl. nuclear)[c]	883.3	1.159	1.096	0.070		147,641	46.51	123.00	8.49
Total power generation mix	552.4	0.848	0.698	0.034	*648.4*	*358,187*[e]	*549.54*[e]	*452.35*[e]	*22.24*[e]

Notes: Calculations done with GEMIS 4.9, with German electricity mix for 2015 (scenario "Energie: Strom in DE 2015 - mit RE und KWK [kWh]" and underlying processes)[51]*; 2016 update for electricity generation from Statistische Bundesamt*[52]*; a) total avoided emissions for nuclear calculated assuming it replaces 70% lignite and 30% coal, a mix closer to baseload power output, which more closely resembles nuclear power output*[53]*; b) 2016 data values are based on values for separate biomass energy processes for 2015, multiplied by the growth in total biomass energy production from 2015 to 2016. No separate data for 2016 was available; c) avoided emissions calculated assuming that renewables replace a mix of roughly 2.8% lignite, 75.1% coal, 22.1% gas, following Fraunhofer ISE*[54]*; d) negative numbers here mean the source of renewable power generation increases emissions; e) emissions are remaining total emissions, not avoided emissions. CO_2-eq.: Carbon dioxide equivalents, a measure of the global warming potential of all greenhouse gasses combined; SO_2-eq.: Sulfuredioxide equivalents, a measure of the acidification potential of all acidifying gasses combined; TOPP: tropospheric ozone precursor potential, a measure of the potential to form tropospheric ozone, causing smog; PM: particulate matter, fine dust particles that cause respiratory health effects, amongst others.*

Table 9: Life-cycle emission factors for emissions to air from different types of natural gas-fired electricity generators

Type	Size	Efficiency		Emission factors (g/kWh)[a]			
		electric	total	CO_2-eq	SO_2-eq	TOPP	PM
ICE, cogeneration	5 kW	27	52.4	467.7	0.449	0.907	0.021
ICE, cogeneration	15 kW	28.5	53.8	454.5	0.435	0.879	0.019
ICE, cogeneration	50 kW	33.5	55.6	439.9	0.421	0.869	0.019
ICE, cogeneration	110 kW	35.5	58.9	415.8	0.398	0.820	0.018
ICE, cogeneration	250 kW	37.5	59.6	411.6	0.394	0.811	0.018
ICE, cogeneration	500 kW	41	59.0	414.5	0.397	0.819	0.018
ICE, pure electric	500 kW	41	41.0	596.9	0.571	1.180	0.025
Gas turbine, single cycle, pure electric	450 MW	42.5	42.5	569.2	0.387	0.724	0.015
Gas turbine, combined cycle, pure electric	450 MW	58.1	58.1	409.0	0.402	0.777	0.011

Notes: a) emissions for cogeneration allocate total emissions equally, on a per-energy basis, to electricity and heat; ICE: Internal combustion engine; CO_2-eq.: Carbon dioxide equivalents, a measure of the global warming potential of all greenhouse gasses combined; SO_2-eq.: Sulfuredioxide equivalents, a measure of the acidification potential of all acidifying gasses combined; TOPP: tropospheric ozone precursor potential, a measure of the potential to form tropospheric ozone, causing smog; PM: particulate matter, fine dust particles that cause respiratory health effects, amongst others. Calculations done with GEMIS 4.9, selected Germany-specific processes[55]*.*

Land Use of PV and Biomass Power Generation

A further important environmental impact of the distributed generation technologies discussed here is land use. Below, the land use of PV and biomass in general are discussed; data on land use that distinguishes between distributed and centralized generation is not available.

[51] IINAS (2017) & IINAS (2016)
[52] Statistische Bundesamt (2017a)
[53] Fraunhofer ISE (2017)
[54] Fraunhofer ISE (2017)
[55] IINAS (2017)

Solar PV

The average land utilization area of ground-mounted PV in Germany has decreased steadily in the last years due to efficiency improvements, a trend towards more cost- and area efficient modules, and limitations on the use of arable land for large-scale ground-mounted PV farms. Hence, the average land utilization was reduced from more than 4 ha/MW in 2006 to 1.6 ha/MW for the plants installed in 2016.[56] [57]

Still, ground-mounted PV remained to be one of the most land-intensive sources of power generation in Germany by 2016, although far behind on the land use intensity for crop based biomass energy (see Table 10). The German International Institute for Sustainability Analysis and Strategy (IINAS) assumes a land use of 0.87 hectare per GWh of electricity generated from PV, which would put total land use of solar PV in 2016 at 33,144 ha. The land use of PV, in ha per GWh, is roughly 20 times the land use for coal or lignite fired power generation, and about 10 times as much as for wind power generation.

Slightly older (2014) data from the Federal Agency for Nature Conservation (BfN) estimated total land use for all ground-mounted PV plants in Germany to be 23,800 ha, and provided estimates for different types of land occupied by ground-mounted PV. 62% was installed on former military areas[58] (14.863 ha), 27% was installed on arable land (6,402 ha) and the remaining 11% was installed in traffic areas (2,567 ha) (see Figure 11).[59] More recent data on different types of land used for PV installations was not readily available.

The biggest concern, the use of arable land for large-scale ground-mounted PV farms, has essentially stopped since support from the EEG for such applications was halted in 2010.[60] Combined land use for PV and agricultural purposes that do not compete or exclude each other are under investigation, and may possibly be supported by the EEG in the future.[61]

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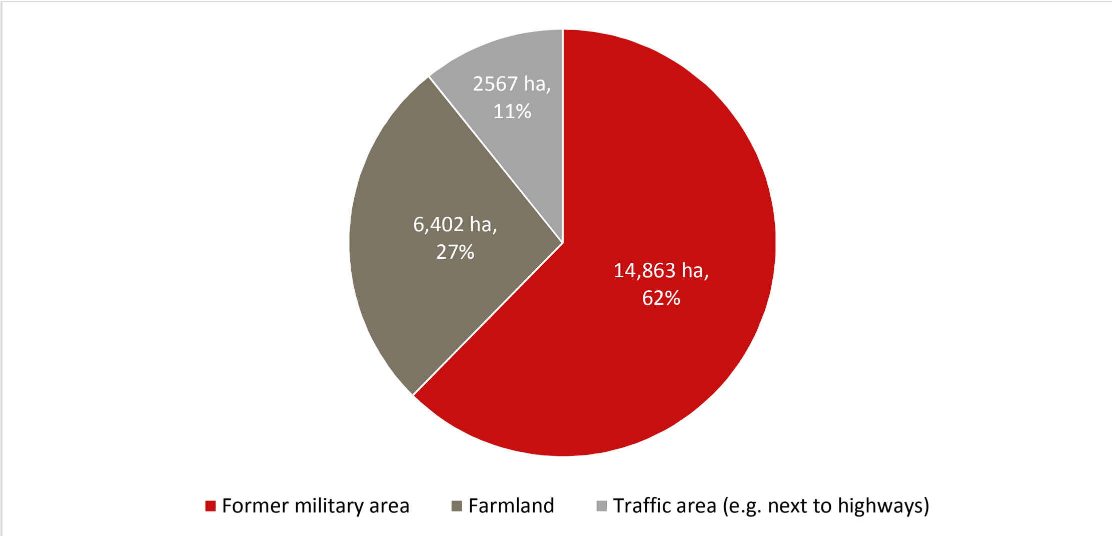
[56] ZSW (2014)
[57] BNetzA (2016a)
[58] After the Iron Curtain was lifted and Allied and German Forces gradually reduced their numbers of barracks in Germany, many former military areas are now converted and used for e.g. public housing or the installation of renewable energies.
[59] ZSW (2014), BfN (2016)
[60] Fraunhofer ISE (2017)
[61] Fraunhofer ISE (2017)

Figure 11: Land utilized by ground-mounted solar PV in 2014 by type of land[62]



Regarding rooftop solar PV installations, most plants smaller than 10 kW (representing 30% of the total installed capacity) were installed on single- and two-family-homes. Plants bigger than 10 kW but smaller than 100 kW were mainly installed on houses with a bigger rooftop area such as apartment buildings, barns, or schools. Plants bigger than 100 kW were mainly installed on large agricultural companies, supermarkets, factories and warehouses (see Table 11).[63] Because the smaller, distributed systems are typically installed on rooftops, these have less effect on land use, since these properties can still serve for other purposes while the PV panels installed on their roofs are generating electricity.

Biomass

The use of biomass for power generation, and in particular its land use and the competition between food and fuel, is discussed extensively in Germany. Electricity generation using biogas from maize uses almost 1,000 times as much land per GWh of electricity than coal or lignite fired power generation, and 50 times as much as PV power generation (see Table 10). In 2016, total land use for crop based biomass power generation is estimated at circa 1,000,000 hectare, dwarfing the land use for all other forms of power generation (see Table 10). On top of this, a similar amount of land is used for liquid biofuels for transport, estimated at 760,000 ha for biodiesel and 184,000 for bio-ethanol in 2016. In comparison: crops used by industry (e.g. for pharma industry, engineering) occupied only 269,500 ha in 2016.[64]

[62] BfN (2016)
[63] BMWi (2015)
[64] FNR (2016)

Table 10: Life-cycle land use of different processes for the production of electricity in Germany (2016)

Process/fuel	ha/GWh	ha, total	Share of electricity production (%)	Share of land use (%)
Coal/lignite	0.0464	12,123	40.3	1.16
Gas	0.0064	516	12.4	0.05
Nuclear	0.1005	8,502	13.1	0.81
Hydro	0.0101	211	3.2	0.02
Wind	0.0831	6,429	11.9	0.62
PV	0.8677	33,144	5.9	3.17
Incineration of solid biomass wastea	0.1299	1,589	1.9	0.15
Biogas from manurea	0.2508	1,989	1.2	0.19
Biogas from maizea	44.96	970,713	3.3	92.89
Rapeseed oila	76.06	30,182	0.06	2.89

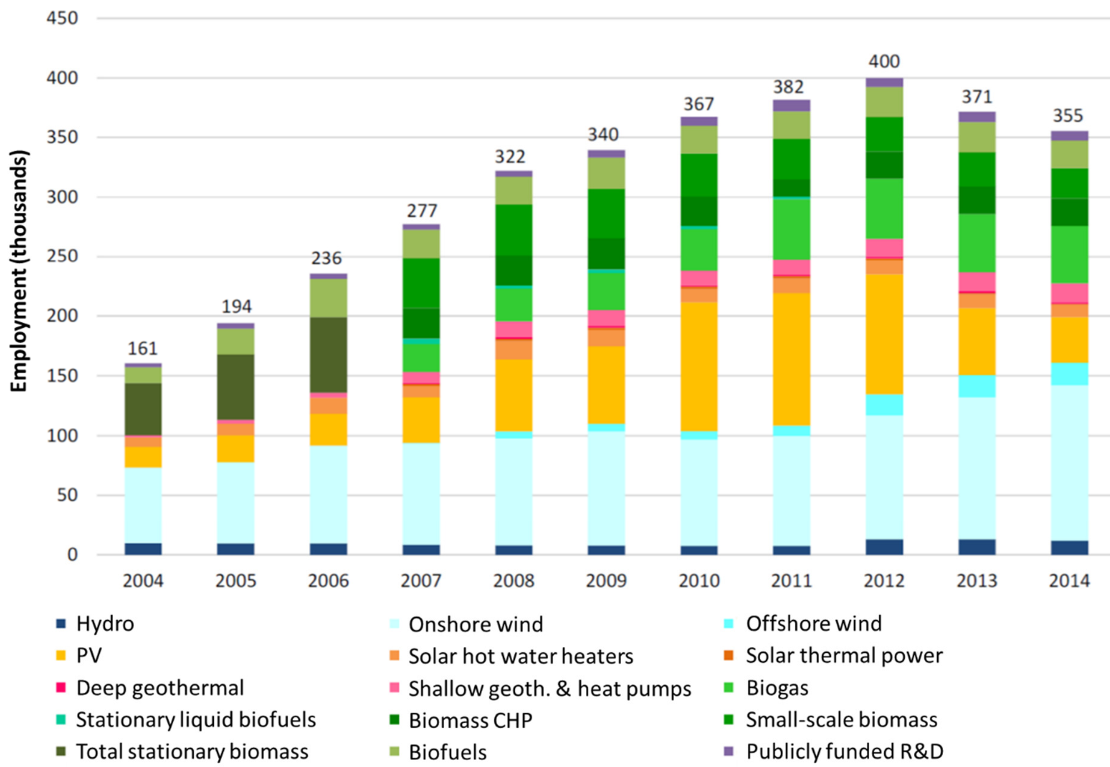
Notes: Calculations done with GEMIS 4.9, scenario "Energie: Strom in DE 2015 - mit RE und KWK [kWh]" and underlying processes[65]*; a) 2016 data values are based on values for separate biomass energy processes for 2015, multiplied by the growth in total biomass energy production from 2015 to 2016. No separate data for 2016 was available.*

Employment effects

An argument used for promoting PV, biomass and other renewables is the beneficial effects on employment and the rural economy. The economic effects of PV in particular have been the subject of much debate, as the German PV panel manufacturing industry has suffered strongly from international, predominantly Chinese, competition. Employment in this industry is currently indeed much lower than at its peak of more than 100,000 jobs in 2011, but circa 30,000 jobs remain. These jobs are in production of e.g., silicon, components, manufacturing equipment and installation and maintenance of the panels[66]. The latter jobs in particular are jobs that exclusively provide local employment opportunities, as do many jobs in different agriculture based biomass energy, estimated to provide employment to circa 125,000 people (see Figure 12). When considering all aspects including construction, mining or collection of fuel, operation and maintenance, employment per GWh of these types of renewable electricity is roughly two to three times as high as from traditional centralized fossil or nuclear power generation[67].

[65] IINAS (2017) & IINAS (2016)
[66] Fraunhofer ISE (2017)
[67] IINAS (2017)

Figure 12: Employment in different renewable energy sectors in Germany[68]



Changing Forms of Ownership

Not only the form of energy generation is changing in Germany, the ownership of energy generation units is going through a transition. Traditionally, electricity generation in Germany was in the hands of the four major utility companies ("Big 4": RWE, EnBW, E.On and Vattenfall). By 2012, 50% of installed generation capacity of renewable energy was in the hands of electricity consumers, including private individuals, industry and farmers, whilst the Big 4 owned only 4.9%.[69]

The share of consumer owned power generation capacities might be even higher regarding distributed generation, i.e. the smallest units of renewable generation and the consumer owned CHP units. A study conducted for BMWi in 2014 shows that of all rooftop PV plants, the majority of PV plants smaller 10 kW were owned by home-owners, plants in a range between 10 kW and 100 kW were owned by private investors, farmers, small companies and municipalities.[70] Table 11 shows the ownership structure of solar PV rooftop installations in 2013.

68 Fraunhofer ISE (2017)
69 Trendresearch (2014)
70 BMWi (2015)

Table 11: Investor and ownership structure of rooftop, and type of building of solar PV installations in Germany by size (in 2013)[71]

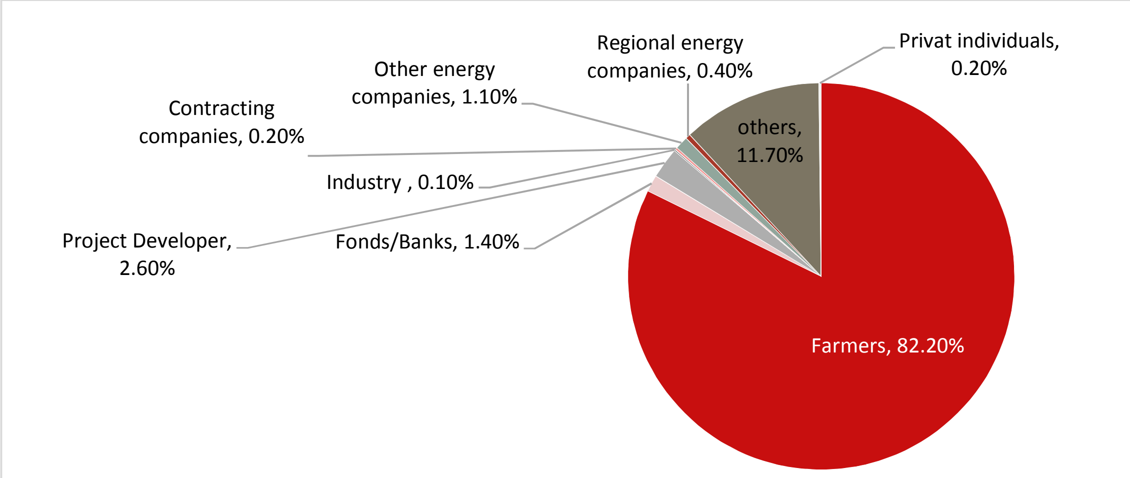
	Market share 2013		Building type	Ownership	Homoge neity
	Capacity	Number of plants			
< 10 kW	30%	70%	Single-/Two-Familiy House	Private individuals (home owner)	++
10 to 40 kW	30%	25%	Apartment buildings, barns, small companies, schools, small administrative buildings	Private individuals, farmers, small companies, public	--
40 to 100 kW	13%	3%	Big apartment buildings, barns, schools, administrative buildings, trade buildings	Private individuals, farmers, trade sector, companies, public	--
100 to 1,000 kW	23%	1.5%	Large agricultural companies, large supermarkets, factories	Farmers, companies, public, fonds, project corporations	--
> 1 MW	4%	< 0,5%	Large companies, factories and warehouses	Fonds, Project corporations, Companies	+

By 2010, 82% of biogas units smaller than 500 kW were owned by farmers; other owner groups only played a minor role (see Figure 13).[72] More recent ownership data was not readily available. However, seen the strong dependency on agricultural feedstock (mostly maize and manure), it is likely that farmers remain the largest groups of owners today. Note also that there was considerable overlap between biomass generation and CHP: the smaller scale biogas units (see also Figure 13) were predominantly CHP plants. [73]

Specific data on investor and operator structures were not available for distributed CHP. However, regarding the size of such units, it should be safe to assume that such plants are predominantly owned by individuals, cooperatives, public and private sector (excl. Big 4). Larger-scale distributed CHP plants, fired with solid biomass, biogas, or natural gas, are often organized by private or semi-private cooperatives in Germany, including in so-called 'bio-energy villages'.[74] [75]

[71] BMWi (2015)
[72] Trendresearch (2011)
[73] Karschin (2015)
[74] Jenssen (2014)
[75] von Bock und Polach (2015)

Figure 13: Share of biogas power generation installed capacity for plants smaller 500 kW by owner (2010)[76]



Challenges for the Electricity Grid

Distributed forms of power generation are more likely to be connected to the low voltage grid, which may pose an additional challenge to the German grid infrastructure and grid operators. For example, approximately 57% of the total solar PV capacity is connected to low voltage level grids (s. above).

Whether or not this results in additional stress on the grid depends crucially on the balance between generation and consumption in local grids. A large share of electricity generated by rooftop PV installations, for example, is consumed on-site or in the near vicinity of the installation. This reduces the load on the surrounding grid, rather than adding stress[77] [78].

There may still be a few days a year where solar irradiance is so high that PV output exceeds the capacity of the local, leading to failures and or damage to connected electrical equipment. Because such effects are likely to occur only a few times a year, in such areas a general grid expansion and improvement is not cost-efficient.[79] Therefore, in fact such reinforcement of the grid is called for in particular in areas where renewable power generation is not well distributed. Examples are rural areas with poorly interconnected grids and more strongly concentrated generation potential in larger ground-mounted PV farms, or in larger-scale wind farms[80]. A 2012 amendment to the EEG stipulated that PV plants must enable remote output control by the grid operator, or (more common in small-scale installations) have an automatic cut-off when output exceeds 70% of its maximum capacity, mitigating the risks of overloading the grid[81].

Intermittency remains a problem, although mostly for PV and not so much for biomass or CHP generators. Improved weather forecasts allow for better scheduling of other sources of power generation, but short-term fluctuations remain a problem. The bulk of the available

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76 Trendresearch (2011)
77 Fraunhofer ISE (2017)
78 Kok et al (2010)
79 ISEA (2016)
80 Fraunhofer ISE (2017)
81 Fraunhofer ISE (2017)

alternative power sources in the German fleet of power plants is not capable of rapid ramp-up or ramp-down. Solutions lie either in 1) expanded storage capacity, with pumped hydro, utility scale or domestic battery storage, possibly including electric vehicle batteries, or 2) by retrofitting existing fossil power plants to become more flexible in their output and/or increasing installations of flexible generation capacity[82].

CHP units (using biomass or other fuels), too, can potentially be particularly useful in balancing intermittent sources. A key question remains, however, about how the output from a pool of units with a large and diverse set of owners can be controlled e.g., by a central grid operator, for the purpose of grid wide balancing[83].

Whether or not large additional investments in grid infrastructure are required for the inclusion of substantial amounts of distributed generation, a more pressing question is who will pay for such investment. Currently, costs for operating and investing in the grid are recuperated with charges levied on each kWh of electricity consumed. If consumption is increasingly from electricity generated by the consumer itself, or acquired through peer-to-peer trading, grid operators will see diminished revenue. Potential solutions include the introduction of fixed charges to anyone with a grid connection, for example based on the type of user and/or capacity of the connection. Few experiments with such grid operator business models currently exist, however[84] [85].

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82 DIW (2013)
83 Wolsink (2012)
84 Kok et al (2010)
85 Pérez-Arriaga (2011)

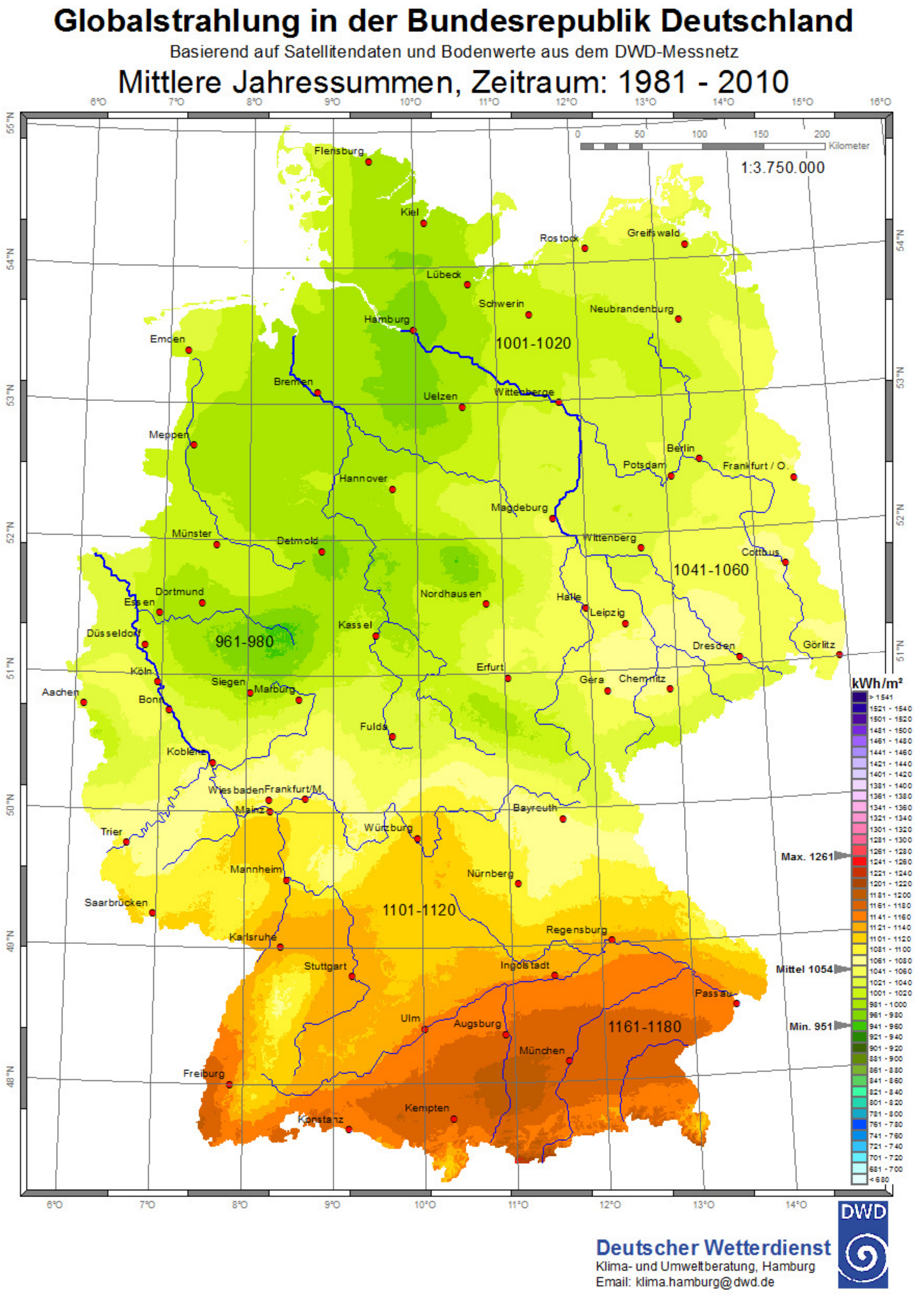
List of Appendixes

Appendix 1: Key data on the EEG 2015 [86]

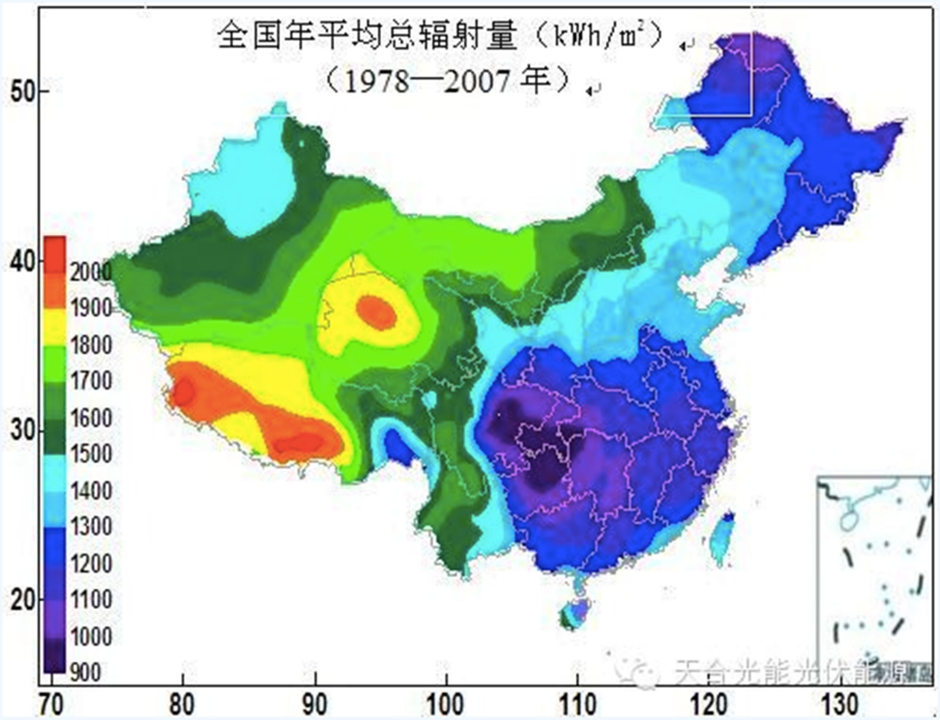
Total 2015	Energy Sources							Sum
	Hydro	Sewage, landfill, mining gas	Biomass	Geothermal	Wind (onshore)	Wind (offshore)	Solar PV	
Installed Capacity, total (in MW)	1,550	510	6,900	33	41,242	3,428	39,332	**92,995**
Net New Installations 2015 (in MW)	8	-5	101	0	3,621	2,435	1,433	**7,593**
Installed Plants, total (Number)	6,986	629	14,140	8	24,865	811	1,561,694	**1,609,133**
Produced Electricity (in GWh)	5,347	1,438	40,628	133	70,922	8,162	35,212	**161,842**
Financial Support trough EEG (Mio.€)	407	73	6,754	28	5,083	1,262	10,640	**24,248**

86 BNetzA (2017a)

Appendix 2: Annual Average Solar Irradiance in Germany from 1981 – 2010



Appendix 3: Annual Average Solar Irradiance in China from 1978 – 2007



Appendix 4: Licensed installations of CHP according to CHP Act (KWKG) from 2009 to 2016

	2009		2010		2011		2012		2013		2014		2015	
Electric Power	Amount	Capacity (MW)	Amount	Capacity (MW)	Amount	Capacity (MW)	Amount	Capacity (MW)	Amount	Capacity (MW)	Amount	Capacity (MW)	Amount	Capacity (MW)
<= 2 kW	83	0.12	239	0.27	708	0.7	1,505	1.5	2,026	2.0	1,469	1.5	1,051	1.0
> 2 <= 10 kW	3,222	17.4	1,695	9.0	1,929	10.1	2,193	11.4	2,517	13.4	2,649	14.5	2,072	11.7
> 10 <= 20 kW	932	14	649	10	786	13	950	17	1,120	20	1,458	27	922	18
> 20 <= 50 kW	545	23	475	20	598	25	520	22	686	30	886	38	554	26
> 50 <= 250 kW	170	25	239	36	253	37	262	37	409	60	600	93	400	61
> 250 <= 500 kW	52	19	55	19	71	26	89	34	97	37	167	63	100	38
> 500 kw <= 1 MW	18	12	19	13	36	27	51	39	47	34	110	78	63	46
> 1 <= 2 MW	40	62	42	67	53	87	52	86	82	135	85	140	55	91
> 2 <= 10 MW	18	97	14	52	17	94	19	90	47	209	32	135	15	58
> 10 <= 50 MW	5	132	5	113	3	70	9	174	12	275	14	331	5	96
> 50 <= 100 MW	0	0	6	442	0	0	1	98	6	391	1	62	0	0
> 100 MW	1	140	0	0	1	184	1	106	1	191	5	779	3	793
Total	5,086	542	3,438	781	4,455	574	5,652	716	7,050	1,397	7,476	1,762	5,240	1,240

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