Evaluation of greenhouse gas emissions avoided in 2023 attributable to the portfolio of wind energy, photovoltaic and biogas installations financed by Landwirtschaftliche Rentenbank

Study commissioned by Landwirtschaftliche Rentenbank

March 2024

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Stuttgart, 22 March 2024

Contents

Contents III
List of Tables III
List of Figures III
Abbreviations and explanations IV
1 Introduction 1
2 Emission savings 1
References 7
Annex: Calculation Approach 8

List of Tables

Table 1: Loans for photovoltaic installations as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state. 4
Table 2: Loans for wind energy installations as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state. 4
Table 3: Loans for biogas plants as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state. 5
Table 4: GHG emissions avoided per kWh. 5
Table 5: GHG emissions avoided per €. 6
Table 6: Emission reduction factors for the year 2022. 10

List of Figures

Figure 1: Installed power attributable to the residual debt of loans by year of investment (as of 31st December 2023). 1
Figure 2: Greenhouse gas emission savings 2023 attributable to photovoltaic installations supported by Rentenbank loans (kt = 1,000 tonnes). 2
Figure 3: Greenhouse gas emission savings 2023 attributable to wind energy installations supported by Rentenbank loans (kt = 1,000 tonnes). 2
Figure 4: Greenhouse gas emission savings 2023 attributable to biogas installations supported by Rentenbank loans (kt = 1,000 tonnes). 3
Figure 5: Overview of the calculation approach (light green arrows indicate input values, dark green arrows show calculation results). 8

Abbreviations and explanations

CO_2	Carbon dioxide
CO_{2eq}	see CO_2-equivalent
CO_2-equivalent	Unit used for measuring the global warming potential (i.e. the potential contribution to the warming of near-surface layers of the atmosphere) of a greenhouse gas in relation to the effect of CO_2. It states the quantity of CO_2 that would have the same greenhouse effect as the gas in question over a period of 100 years. For instance, one kg of methane (CH_4) has the same effect as 28 kg of CO_2.
GHG	Greenhouse gas
GWh	Gigawatt hour(s); 1 GWh = 1 million kWh
kW	Kilowatt(s)
kW_p	Kilowatts peak: peak power of PV facilities
kWh	Kilowatt hour(s)
kt	Kilo tonne (1,000 tonnes)
MW	Megawatt(s); 1 MW = 1,000 kW
PV	Photovoltaic energy
RE	Renewable energy
RES	Renewable energy sources
t	(metric) Tonne

1 Introduction

The main focus of the promotional activities of Landwirtschaftliche Rentenbank (hereinafter referred to as "Rentenbank") lies on loans for agriculture-related projects of all kinds, as well as for providing finance in rural areas. Within its loan programmes, Rentenbank supports investment in installations for using renewable energy, notably in bioenergy, wind energy and photovoltaic energy (PV). On behalf of Rentenbank ZSW developed an approach to estimate the amount of greenhouse gas (GHG) emissions avoided by photovoltaic and wind energy installations supported by the low-interest loans (see Bickel 2020). From the 2022 reporting year, the assessment was extended to biogas installations co-financed by the Rentenbank.

The present report describes the GHG emission savings attributable to the operation of the installations in 2023, based on the portfolio as of 31st December 2023. Figure 1 shows the installed power that can be attributed to the residual debt of loans by year of investment. An overview of the calculation approach is given in the annex.

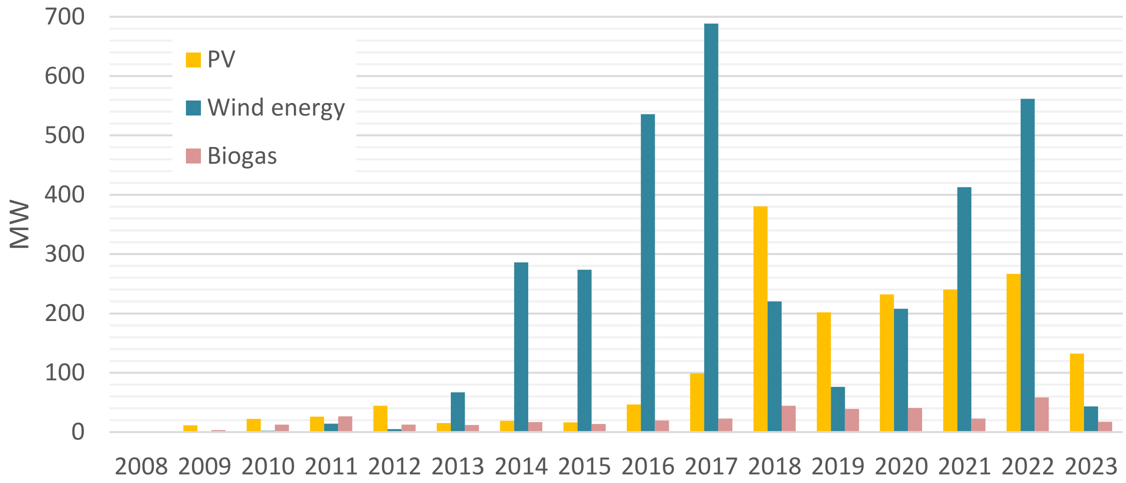

Figure 1: Installed power attributable to the residual debt of loans by year of investment (as of 31st December 2023).

2 Emission savings

The year 2023 saw different meteorological trends for solar and wind energy in Germany: whereas global solar radiation returned to normal levels after the exceptional year 2022, 2023 was the windiest year in over 20 years. For this reason, GHG emission savings attributable to the Rentenbank portfolio of PV installations slightly decreased by 1 percent year-on-year, in spite of an increase in capacity installed. In total, 1,126,500 tonnes of CO_2-equivalent (CO_{2eq}) were avoided, as illustrated in Figure 2. For the Rentenbank wind energy installations portfolio GHG emission savings increased by 11 percent year-on-year to 5,978,900 tonnes of CO_{2eq} (see Figure 3), even though the installed capacity slightly decreased.

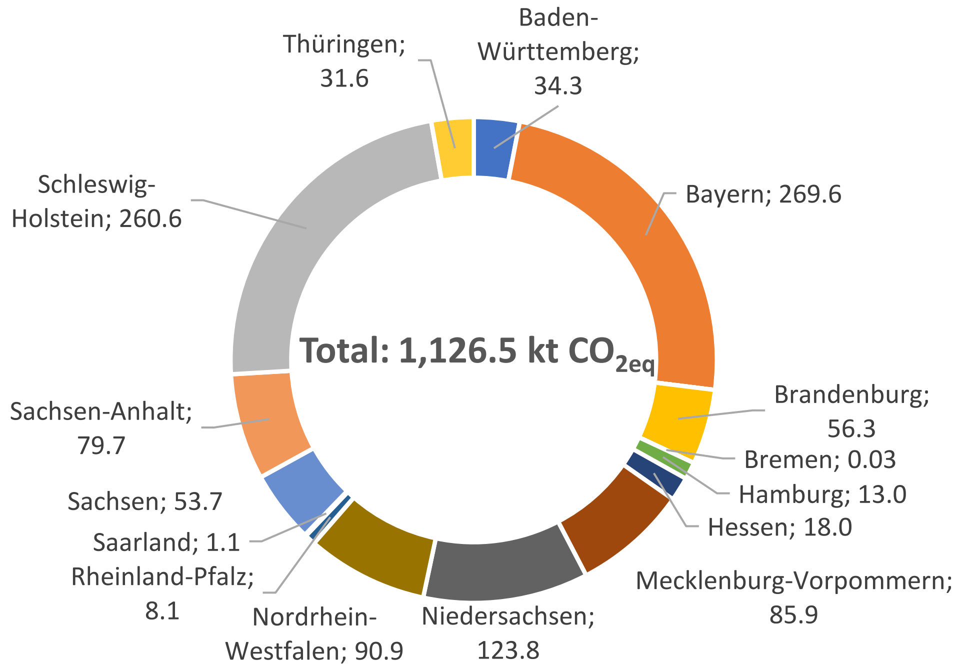

Figure 2: Greenhouse gas emission savings 2023 attributable to photovoltaic installations supported by Rentenbank loans (kt = 1,000 tonnes).

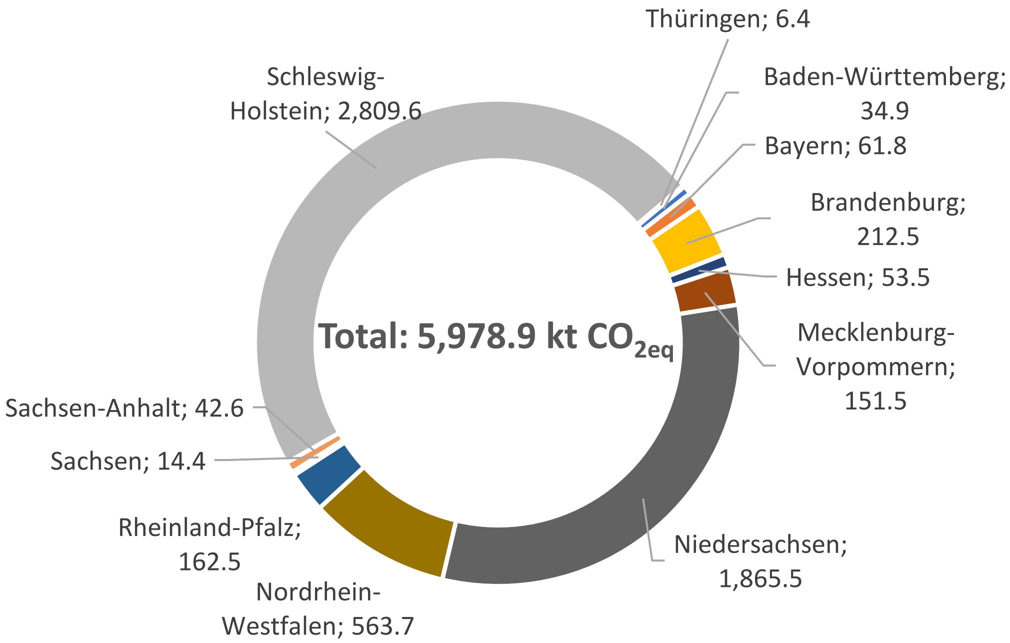

Figure 3: Greenhouse gas emission savings 2023 attributable to wind energy installations supported by Rentenbank loans (kt = 1,000 tonnes).

Electricity generation in biogas cogeneration plants is independent of meteorological conditions, which is one great advantage of this technology compared to PV and wind energy. Figure 4 illustrates the GHG emission savings attributable to the Rentenbank portfolio of biogas installations, amounting to 794,700 tonnes of CO_{2eq}. This corresponds to a decrease of 11 percent compared to the year 2022, reflecting the decline in installed capacity.

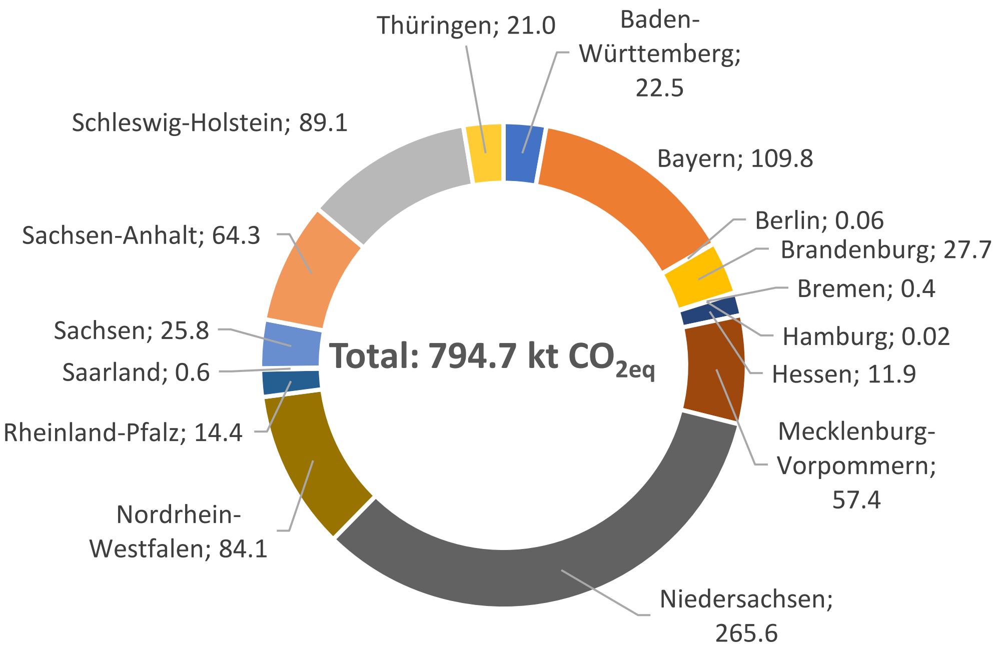

Figure 4: Greenhouse gas emission savings 2023 attributable to biogas installations supported by Rentenbank loans (kt = 1,000 tonnes).

Table 1, Table 2 and Table 3 present the results by federal state. It has to be noted that the values are aggregated across all years of investment. The average specific investment costs reflect the underlying time structure of investments in the portfolio. PV installations saw a substantial decline in specific investment cost between 2008 and 2020, followed by a cost increase until 2023. As a consequence, considerable variation can be observed between federal states according to different financing volumes over time. High values result from early investments with higher specific costs. For wind energy installations the variation is comparably small as there was relatively little variation in specific costs between investment years (see Table 2). For biogas plants, the differences in average specific investment costs are mainly due to a high variability of specific costs by plant concepts and plant size. Specific costs tend to decrease with increasing plant size (see annex for more information).

Table 1: Loans for photovoltaic installations as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW$_p$	MW$_p$	GWh	t CO_2	t CO_{2eq}
Total	**12,656**	**-1,683.8**	**960**	**1,755.3**	**1,632.0**	**1,052,400**	**1,126,500**
Baden-Württemberg	413	-48.2	950	50.6	49.6	32,000	34,300
Bayern	2,853	-366.0	930	392.8	390.5	251,800	269,600
Brandenburg	138	-67.7	890	76.5	81.6	52,600	56,300
Bremen	5	-0.2	2,670	0.06	0.05	31	34
Hamburg	36	-25.4	900	28.1	18.8	12,100	13,000
Hessen	229	-25.9	940	27.6	26.1	16,800	18,000
Mecklenburg-Vorpommern	291	-111.8	870	127.8	124.4	80,200	85,900
Niedersachsen	3,555	-221.5	1,040	213.1	179.3	115,600	123,800
Nordrhein-Westfalen	2,261	-149.9	1,000	150.4	131.6	84,900	90,900
Rheinland-Pfalz	293	-14.3	1,150	12.5	11.7	7,600	8,100
Saarland	5	-1.9	930	2.1	1.6	1,000	1,070
Sachsen	193	-71.4	920	77.3	77.9	50,200	53,700
Sachsen-Anhalt	287	-96.0	890	107.6	115.5	74,500	79,700
Schleswig-Holstein	1,922	-440.0	1,000	441.5	377.5	243,500	260,600
Thüringen	175	-43.7	920	47.4	45.8	29,500	31,600

Totals may differ due to rounding.

Table 2: Loans for wind energy installations as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW	MW	GWh	t CO_2	t CO_{2eq}
Total	**2,954**	**-4,918.2**	**1,450**	**3,396.1**	**7,888.4**	**5,596,400**	**5,978,900**
Baden-Württemberg	13	-37.6	1,530	24.6	46.0	32,700	34,900
Bayern	105	-50.8	1,470	34.6	81.5	57,800	61,800
Brandenburg	33	-202.1	1,430	141.1	280.4	198,900	212,500
Hessen	18	-39.8	1,440	27.7	70.6	50,100	53,500
Mecklenburg-Vorpommern	69	-133.7	1,440	93.2	199.9	141,800	151,500
Niedersachsen	944	-1,547.9	1,430	1,084.0	2,461.3	1,746,200	1,865,500
Nordrhein-Westfalen	655	-463.3	1,430	323.2	743.7	527,600	563,700
Rheinland-Pfalz	32	-127.1	1,390	91.6	214.4	152,100	162,500
Sachsen	10	-13.3	1,370	9.7	19.0	13,500	14,400
Sachsen-Anhalt	29	-40.1	1,440	27.9	56.3	39,900	42,600
Schleswig-Holstein	1,041	-2,257.1	1,470	1,534.8	3,706.9	2,629,800	2,809,600
Thüringen	5	-5.5	1,500	3.7	8.4	6,000	6,400

Totals may differ due to rounding.

Table 3: Loans for biogas plants as of 31st Dec. 2023 and attributable effects in the year 2023, by German federal state.

	Loans		Average specific inv. cost	Attributable to loans			
	Count	Residual debt		Installed power	Electricity production	GHG emissions avoided	
		Million €	€/kW$_p$	MW$_p$	GWh	t CO_2	t CO_{2eq}
Total	**6,524**	**-1,472.5**	**4,070**	**362.0**	**1,651.6**	**1,143,900**	**794,700**
Baden-Württemberg	159	-44.0	4,230	10.4	46.7	32,400	22,500
Bayern	1,484	-228.8	4,330	52.9	228.1	158,000	109,800
Berlin	1	-0.1	7,210	0.02	0.12	85	59
Brandenburg	98	-42.3	3,860	10.9	57.6	39,900	27,700
Bremen	6	-0.6	4,360	0.1	0.8	540	370
Hamburg	1	-0.1	2,880	0.02	0.03	24	17
Hessen	125	-27.6	4,430	6.2	24.7	17,100	11,900
Mecklenburg-Vorpommern	213	-81.9	3,730	22.0	119.3	82,600	57,400
Niedersachsen	2,312	-500.8	4,080	122.8	552.1	382,400	265,600
Nordrhein-Westfalen	626	-171.4	3,990	42.9	174.8	121,000	84,100
Rheinland-Pfalz	71	-28.1	4,290	6.5	29.9	20,700	14,400
Saarland	8	-1.6	5,600	0.3	1.3	900	600
Sachsen	128	-42.2	4,150	10.2	53.6	37,100	25,800
Sachsen-Anhalt	256	-105.3	3,770	27.9	133.7	92,600	64,300
Schleswig-Holstein	902	-163.0	4,090	39.8	185.1	128,200	89,100
Thüringen	134	-34.7	3,910	8.9	43.7	30,300	21,000

Totals may differ due to rounding.

Table 4 shows the comparison of the GHG emissions avoided per kWh of electricity produced with the corresponding values calculated for the total 2023 electricity production from PV, onshore wind installations and biogas plants in Germany reported in BMWK (2024). The specific GHG-avoidance factors show very good agreement for all three plant types.

Table 4: GHG emissions avoided per kWh.

g CO_{2eq} / kWh	Rentenbank	BMWK (2024)	Relative Difference
Photovoltaic energy	690	690	0.01 %
Wind energy onshore	758	758	0.01 %
Biogas cogeneration	481	486	0.9 %

A further comparison, based on the amount of CO_{2eq} avoided per Euro invested (see Table 5) is made, to check the plausibility for the parts of the calculation with the highest uncertainty. The values of the Rentenbank portfolio are compared with the latest published figures (year 2020) for the RE loan programmes assessed in Bickel and Kelm (2021). The Rentenbank portfolio 2023 avoided less GHG emissions per invested Euro than the loan programmes 2020 for PV and biogas, for wind energy the avoidance was higher. Besides differences in meteorology between the years considered, the composition of the portfolio is an important reason for the different specific avoidance of GHG emissions: The Rentenbank PV portfolio includes installations from 2008 to 2022 with high specific investment costs for the earlier years, resulting in comparably high average specific cost of investment (see Table 1) and thus finally to lower values regarding GHG emissions avoided per invested Euro. The corresponding value for the year 2018 (based on Bickel and Kelm 2019) with underlying similar specific cost of investment, is 18.8 percent lower than the current value of the Rentenbank PV portfolio. This is mainly due to a lower GHG avoidance factor in 2018. Thus, the emissions avoided per Euro of investment of the Rentenbank PV portfolio lie within the range of the comparative values. For wind energy installations, the Rentenbank portfolio 2023 shows a higher avoidance than the comparative values of 2020 and 2018, which is due to a combination of lower specific investment costs and a lower GHG avoidance factor in 2018. For biogas plants the comparison shows good agreement, considering the high uncertainties involved in determining average specific investment costs and estimating installed power as well as generated electricity attributable to the Rentenbank portfolio.

Table 5: GHG emissions avoided per €.

g CO_{2eq} / €	Rentenbank	Bickel and Kelm (2021, 2019)		Relative Difference	
year	2023	2020	2018	2020	2018
Photovoltaic energy	669	831	563	19.3 %	-18.8 %
Wind energy onshore	1,216	1,130	1,060	-7.6 %	-14.6 %
Biogas cogeneration	540	561	542	3.8 %	0.5 %

Concluding remark

The calculations presented are estimates based on limited information and to the best of our knowledge. They do not represent exact calculations. However, according to the current state of knowledge and under the assumptions made, the estimates provide a realistic indication of the actual savings in GHG emissions resulting from the operation of the PV, wind power and biogas installations supported by Rentenbank loans. This is confirmed by the plausibility checks performed.

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Annex: Calculation Approach

The following sections describe the calculation approach in general as well as the data used and the assumptions made. A more detailed description of the approach can be found in Bickel (2020) for photovoltaic (PV) and wind energy plants. For biogas plants the approach is described in more detail in Bickel (2023).

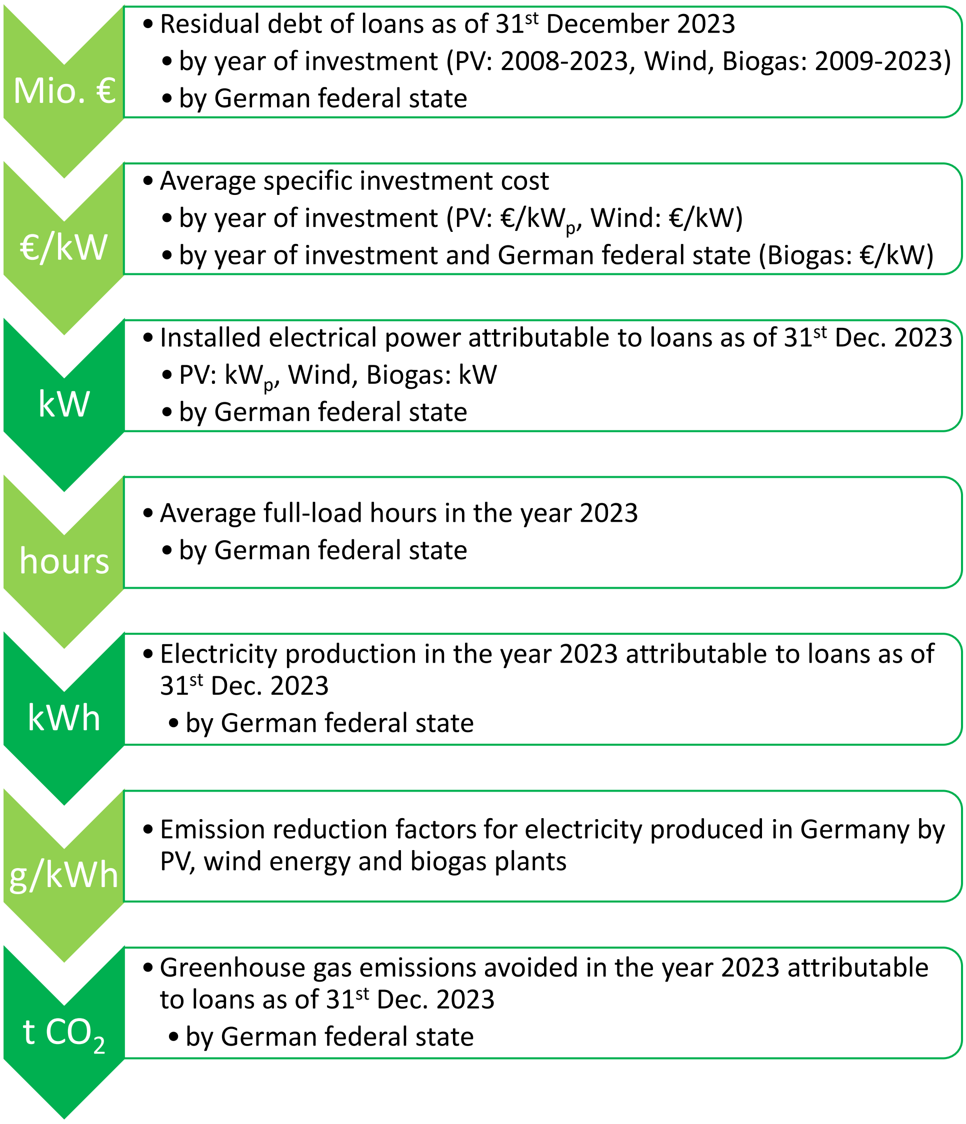

Figure 5: Overview of the calculation approach (light green arrows indicate input values, dark green arrows show calculation results).

The only information available on the PV, wind energy and biogas plants built with the support of Rentenbank loan programmes is the residual debt of loans as of 31st December 2023, categorised by year of investment and German federal state. This can be interpreted as share of the installations and their operation that is attributable to the loan programmes and is the starting point of the calculation. Figure 5 illustrates the calculation approach with light green arrows indicating input values and dark green arrows displaying calculation results.

One central assumption underlying the calculations is that the investment in wind energy, photovoltaic and biogas plants, is fully covered by the Rentenbank loans and that the investment is exempt of value-added tax. If the investment volume were higher than the loan, the GHG emission savings of the installations co-financed might be underestimated.

In lack of specific information on the plants supported, it was assumed that the year of investment corresponds to the year in which the facilities were put into operation. In case of a time gap of more than one year between investment and start of electricity production, the amount of GHG emissions avoided would be overestimated.

In the first calculation step, the installed electrical capacity can be estimated from the residual debt of loans using specific investment cost values. As the cost per kW of electrical power installed has changed over the last years, average values differentiated by year of investment are used for PV and wind installations. As for the previous years, average specific investment costs for the plants installed in Germany in the year 2023 were provided by ZSW.

In the next step, the electricity production is calculated from the installed electrical power and average full-load hours in the year 2023. Full-load hours and thus the electricity produced by a PV or wind energy plant vary with geographical location within Germany. This is taken into account by using full-load hours differentiated by German federal state, which were derived based on data from DWD (2024) for wind energy and Anemos (2024) for photovoltaics. For biogas average full-load hours were derived by federal state based on Netztransparenz (2023). In lack of more recent data, values for the year 2022 had to be used for the operation of biogas plants in 2023.

The initial commissioning dates of new plants are distributed over the months of the calendar year, i.e. they produce electricity only for a part of the first year of operation. This is reflected in the common assumption that only half of the full-load hours are taken into consideration for the first year of operation. In other words: the plants that were built in 2023 were assumed to generate half of the electricity which they would have produced with a start of operation on January 1st 2023.

The final step is the multiplication of the electricity production by emission reduction factors for electricity produced in German PV, wind energy and biogas plants. These factors describe net emission savings, setting off the volume of emissions caused by the use of renewables (final energy supply) against the volume of gross emissions that are no longer being released due to fossil sources having been replaced with renewables. All upstream process chains involved in the production and supply of the various energy sources and in installation construction and operation (but not dismantling) are considered. The factors are provided for emissions of CO_2 and CO_2-equivalents for PV, wind energy and biogas plants (as well as other renewable energy sources), by the German federal environmental agency ("Umweltbundesamt" - UBA). Table 6 shows the values for 2022, which is the most recent year available.

Table 6: Emission reduction factors for the year 2022.

g/kWh	CO_2	CO_{2eq}
Photovoltaic energy	645	690
Wind energy onshore	709	758
Biogas cogeneration	693	481

Source: UBA (2023), values rounded.

With respect to the uncertainties involved in the assessment it should be noted that the missing technical information on the installations supported by the loans imply considerable uncertainties. This is even more true for biogas plants than for PV and wind energy, because the specific investment costs strongly depend on plant concept and plant capacity. Therefore, the main and most important factor for improving the reliability of the estimates would be the provision of technical information on the facilities supported. In particular, data on the electrical capacity installed would be essential to eliminate the uncertainty involved in the estimation of the electrical capacity based on specific investment costs.