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# Application of the Oeko-Institut/WWF-US/ EDF methodology for assessing the quality of carbon credits

This document presents results from the application of version 3.0 of a methodology, developed by Oeko-Institut, World Wildlife Fund (WWF-US) and Environmental Defense Fund (EDF), for assessing the quality of carbon credits. The methodology is applied by Oeko-Institut with support by Carbon Limits, Greenhouse Gas Management Institute (GHGMI), INFRAS, Stockholm Environment Institute, and individual carbon market experts. This document evaluates one specific criterion or sub-criterion with respect to a specific carbon crediting program, project type, quantification methodology and/or host country, as specified in the below table. Please note that the CCQI website Site terms and Privacy Policy apply with respect to any use of the information provided in this document. Further information on the project and the methodology can be found here: www.carboncreditquality.org

| | |
|---|---|
| Sub-criterion: | 1.3.2 Robustness of the quantification methodologies applied to determine emission reductions or removals |
| Project types: | Solar photovoltaic power<br>Wind power (onshore) |
| Quantification methodology: | Clean Development Mechanism (CDM) ACM0002, Versions 20.0, and relevant tools |
| Assessment based on carbon crediting program documents valid as of: | 15 May 2022 |
| Date of final assessment: | 31 January 2023 |
| Score: | 2 |

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# Assessment

## Relevant scoring methodology provisions

The methodology assesses the robustness of the quantification methodologies applied by the carbon crediting program to determine emission reductions or removals. The assessment of the quantification methodologies considers the degree of conservativeness in the light of the uncertainty of the emission reductions or removals. The assessment is based on the likelihood that the emission reductions or removals are under-estimated, estimated accurately, or over-estimated, as follows (see further details in the methodology):

| Assessment outcome | Score |
|---|---|
| It is very likely (i.e., a probability of more than 90%) that the emission reductions or removals are underestimated, taking into account the uncertainty in quantifying the emission reductions or removals | 5 |
| It is likely (i.e., a probability of more than 66%) that the emission reductions or removals are underestimated, taking into account the uncertainty in quantifying the emission reductions or removals<br>OR<br>The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) and uncertainty in the estimates of the emission reductions or removals is low (i.e., up to ±10%) | 4 |
| The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) but there is medium to high uncertainty (i.e., ±10-50%) in the estimates of the emission reductions or removals<br>OR<br>It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, but the degree of overestimation is likely to be low (i.e., up to ±10%) | 3 |
| The emission reductions or removals are likely to be estimated accurately (i.e., there is about the same probability that they are underestimated or overestimated) but there is very high uncertainty (i.e., larger than ±50%) in the estimates of the emission reductions or removals<br>OR<br>It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, and the degree of overestimation is likely to be medium (±10-30%) | 2 |
| It is likely (i.e., a probability of more than 66%) or very likely (i.e., a probability of more than 90%) that the emission reductions or removals are overestimated, taking into account the uncertainty in quantifying the emission reductions or removals, and the degree of overestimation is likely to be large (i.e., larger than ±30%) | 1 |

## Information sources considered

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5 "TOOL03: Tool to calculate project or leakage CO2 emissions from fossil fuel combustion", version 3.

6 "TOOL05: Baseline, project and/or leakage emissions from electricity consumption and monitoring of electricity generation", version 3.0.

7 "TOOL07: Tool to calculate the emission factor for an electricity system", version 7.0.

8 "TOOL09: Determining the baseline efficiency of thermal or electric energy generation systems", version 3.0

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## Assessment outcome

The quantification methodology in combination with version 3 of TOOL03, version 3.0 of TOOL05 version 7.0 of TOOL07 and version 3.0 of TOOL09, is assigned a score of 3.

## Justification of assessment

### Project type

This assessment refers to the following two project types:

- **Solar photovoltaic power:** Installation of a new solar photovoltaic power plant. The electricity is fed into a national or regional electricity grid, replacing more greenhouse gas intensive electricity generation.
- **Wind power (onshore):** Installation of a new onshore wind power plant. The electricity is fed into a national or regional electricity grid, replacing more greenhouse gas intensive electricity generation.

### Applicability conditions

The methodology is applicable to grid-connected renewable energy power generation project activities, including projects using the following technologies: hydro power plant/unit with or without reservoir, wind power plant/unit, geothermal power plant/unit, solar power plant/unit[1], wave power

[1] Both solar photovoltaic (PV) and solar thermal

plant/unit or tidal power plant/unit. The methodology is thus applicable to the two project types described above.

**Selection of emission sources for calculating emission reductions or removals**

The methodology specifies that the following emission source shall be considered:

- $CO_2$ emissions from electricity generation in fossil fuel fired power plants that are displaced due to the project activity

None of the sources of emissions from the project activity that are listed in section 5.1 of the methodology are applicable to either wind power projects or solar PV projects.

Furthermore, the emission sources for calculating emission reductions for the assessed project types are also specified in "TOOL07: Tool to calculate the emission factor for an electricity system" and include:

- All existing power plants/units that are physically connected through transmission and distribution lines to the project activity (the project electricity system).
- All existing power plants/units that are physically connected to any connected electricity system. A "connected electricity system" is an electricity system that is connected by transmission lines to the project electricity system, but where transmission constraints exist between the two systems.
- Off-grid power plants in the project electricity system (optional).

The above sources are considered to be a more detailed list/subsets of the emission sources specified in the methodology.

No leakage emissions are considered in the methodology[2]. The emissions potentially arising due to activities such as power plant construction and upstream emissions from fossil fuel use (e.g., extraction, processing, transport etc.) are neglected.

**Determination of baseline emissions**

The baseline scenario in the case of a greenfield wind or solar PV power plant is that electricity delivered to the grid by the project activity would have otherwise been generated by the operation of existing grid-connected power plants and by the addition of new generation sources, as reflected in the combined margin (CM) calculations described in "TOOL07: Tool to calculate the emission factor for an electricity system". Baseline emissions are therefore calculated by multiplying the net electricity generation that is generated and fed into the grid because of the implementation of the CDM project activity (in MWh/yr) by the combined margin $CO_2$ emission factor for grid connected power generation (in t $CO_2$/MWh) calculated using the latest version of "TOOL07". This generic approach is generally appropriate. Key assumptions in the calculation of baseline emissions are discussed below.

2 The term "leakage" is also used in this methodology to describe project emissions from the operation of binary geothermal power plants (physical leakage of working fluid contained in heat exchangers), which is not relevant in this assessment.

*Quantity of net electricity generation that is produced and fed into the grid*

The methodology specifies that electricity meters are used to quantify the net electricity generation that is produced and fed into the grid because of the implementation of the CDM project activity. Meters used for this purpose are usually fiscal meters with a low level of uncertainty, and usually two sets of meters (one owned by the project developer, one by the purchasing grid) are available. Estimation of this parameter is therefore not considered to lead to any significant over- or underestimation of emission reductions or to introduce significant levels of uncertainty.

*Combined margin emission factor*

With respect to the combined margin emission factor, as calculated by using “TOOL07: Tool to calculate the emission factor for an electricity system”. The tool determines the emission factor as a combination of the “build margin (BM)” and the “operating margin (OM)”. The build margin aims to reflect that the construction of new renewable power plants may lead to fewer other power plants being constructed. The BM emission factor intends to reflect which mix of power plants would not be constructed due to the registered CDM project. The operating margin aims to reflect that a new renewable power plant may displace electricity generation in existing power plants, in particular those plants that operate at the margin of the dispatch order. The tool uses different weightings for the BM and OM emission factors are used to arrive at a “combined margin (CM)” emission factors.

The following issues are identified to potentially lead to over- or underestimation of emission reductions or to introduce uncertainty:

*OE1: Exclusion of registered CDM projects in the calculation of the BM*

The tool requires that power plants registered as CDM project activities be excluded when determining the sample group for calculation of the build margin (BM). CDM projects are only included in the BM calculation if other power plants make up a small proportion of electricity generation. By excluding renewable energy projects registered under the CDM, the cohort of power plants used in the BM calculation will probably be biased towards fossil fuel fired power plants. An example of this would be Zambia, where the 120 MW capacity Itezhi-Tezhi power station, which is the only grid connected CDM project in the country, would have to be excluded in the BM calculation. The resulting BM would therefore be biased towards recently built coal fired power plants. In conclusion, the exclusion of CDM plants may lead to an overestimation of emission reductions where the project electricity system relies on CDM projects for a significant proportion of most recently installed generation capacity. This may, however, only apply to a small fraction of projects (Source 14). Moreover, CDM projects are included in the sample group if there are too few non-CDM plants that were constructed in the past 10 years. For these reasons, the risk of over-estimation is relatively small.

*U1 / OE2: Weighting of OM and BM in determining the CM*

The tool specifies the following default values for weighting of the operating margin (OM) and BM ($w_{OM}$ and $w_{BM}$):

- Wind and solar power generation project activities: $w_{OM}$ = 0.75 and $w_{BM}$ = 0.25 (owing to their intermittent and non-dispatchable nature) for the first crediting period and for subsequent crediting periods;

- All other projects: $w_{OM}$ = 0.5 and $w_{BM}$ = 0.5 for the first crediting period, and $w_{OM}$ = 0.25 and $w_{BM}$ = 0.75 for the second and third crediting period, unless otherwise specified in the approved methodology which refers to this tool.

The above default values aim to specifically reflect the intermittent and non-dispatchable nature of wind and solar power generation project activities, and that this will result in these projects primarily replacing existing power generation plants. This is a simplified approach to addressing this issue. Ideally, the weighting of the BM should reflect what is termed the capacity value (also called capacity credit) of the specific generation technology. Capacity value gives an indication of the probability that a particular type of generation will reliably contribute to meeting demand, which generally means that it will be available to generate electricity during the peak hours (Source 2). This is an important metric in the planning of future electricity systems, and thus also determines the extent to which the installation of wind or solar power plants only displaces power generation in existing plants (reflected by the OM) or reduces the need to build or maintain other (back-up) power capacity (the BM). The extent to what new solar and wind power plants need for back-up capacity to address peak demand in times of low solar or wind power supply depends on the location of the project activity. In addition, the capacity factor/intermittency of solar projects may differ significantly to that of wind projects. The capacity value of wind power projects is considered to range from 5 to 40 % whereas that of solar PV is considered to range from <25 to 75% (Sources 2, 11 and 23). This would suggest that a weighting of 0.25 for the $w_{BM}$ might be more or less adequate for wind power as it represents a value reasonably within the range of given capacity values; however, this is associated with considerable uncertainty, given that the actual factor in an electricity grid could be lower or higher (U1). For solar PV, the weighting of 0.25 for the $w_{BM}$ is at the lower end of the indicated range for capacity values. If the weighting should reflect the typical capacity value, then a higher figure would be more appropriate. Given that the BM is lower than the OM in the majority of electricity systems (Source 12), the weighting of 0.25 for the BM is likely to lead to an overestimation of emission reductions (OE2). Noting the values indicated for the BM and OM for different electricity systems in source 12 and assuming that 0.5 represents a value reasonably within the range of given capacity values, the grid emission factor would be overestimated in the range of 20-30% on average, although it could be overestimated by up to 50% in some countries, as well as underestimated in a limited number of countries.

*OE3: Use of historical data to determine the grid emission factor*

The tool allows project participants to either fix the grid emission factor (GEF) at the start of the crediting period or to update the GEF annually. Fixing the GEF at the start of the crediting period means that the GEF is highly backward looking. Whether this leads to over- or underestimation of emission reductions depends on the energy strategy and trends of the country. Given that most country's energy policies are aimed at increasing the share of renewables and reducing a country's grid emission factor, a backward looking GEF is **likely to lead to an overestimation of emission reductions**.

This issue also arises if the GEF is updated on an annual basis (i.e., due to the need to collect BM data from the previous X years), though to a lesser extent than if the GEF is fixed for the crediting period. Most projects use the option of fixing the GEF for the crediting period. The degree of overestimation depends on how strongly the GEF of the grid decreases over time.

Moreover, the tool does not include any provisions to consider the country's NDC and relevant climate or energy policies. If a country's NDC has a renewable electricity generation target, for example, this will not be reflected in the BM which is calculated based on historical data. In this case, the "real" BM and therefore the combined margin may be lower than what it would be estimated to be based on historical data. This would therefore also lead to an overestimation of emission reductions.

*U2: Treatment of electricity transfers*

Electricity transfers from a connected electricity systems (CES) to the project electricity system (PES) are defined as electricity imports while electricity transfers from the project electricity system to connected electricity systems are defined as electricity exports. For electricity imports, one of the following options to determine the $CO_2$ emission factor(s):

(a) 0 t $CO_2$/MWh; or

(b) The simple operating margin emission rate of the exporting grid, determined as described in Step 4 section 6.4.1, if the conditions for this method, as described in Step 3 below, apply to the exporting grid; or

(c) The simple adjusted operating margin emission rate of the exporting grid, determined as described in Step 4 section 6.4.2 below; or

(d) The weighted average operating margin (OM) emission rate of the exporting grid, determined as described in Step 4 section 6.4.4 below.

Choosing option (a) above leads to underestimation of emission reductions and is therefore considered conservative. Only using the OM as the emission factor for the exporting grid (options (b) to (d)), and no BM component, could instead lead to overestimation of emission reductions, because (1) the implementation of the project could also impact the construction of power plants in a connected electricity and (2) the BM emission factor is typically lower than the OM emission factor. The impact of this issue will depend on the volume of imports of electricity from the CES, which in the majority of cases are not expected to be large. Moreover, the overall effect will depend on how frequently option (a) is chosen and how frequently options (b) to (d) are chosen. Overall, this issue is therefore assessed to contribute to uncertainty, though the overall effect may be limited due to the relatively small size of imports and exports of electricity globally.

Electricity exports from the project electricity system (electricity transfers from the project electricity system to connected electricity systems) are not subtracted from electricity generation data used for calculating and monitoring the electricity emission factors. This is not considered to lead to either over- or underestimation of emission reductions.

*OE4: Consideration of off-grid power plants*

Project participants may choose to (i) only include grid power plants to calculate the operating margin and build margin emission factor, or (ii) to include both grid power plants and off-grid power plants in the calculation. Option (ii) can only be used when the total capacity or the total electricity generation by off-grid sources amounts to at least 10% in each case. The rationale for choosing (ii) is to reflect that in some countries off-grid power generation is linked to an unreliable and unstable electricity grid (e.g., back-up diesel generation), and that these off-grid sources can partially be displaced by grid-connected CDM project activities, where these project activities improve the reliability of the grid and therefore lead to a reduction in the use of off-grid sources. Given that off-grid power generation is usually supplied by diesel generators, using this option will usually lead to an increase in the calculated grid emission factor. This could lead to **an overestimation of emission reductions** if the project activity does not in fact lead to an improvement in the reliability of the grid and therefore a reduction in the use of off-grid sources. The significance of this issue will depend on a number of factors, including the total installed capacity of off-grid power plants and the extent to which solar and wind power actually improves the reliability of the grid (i.e., for how many hours of the year black-outs are actually reduced). Given limited capacity value of solar and wind power, as identified above, it may not be reasonable to assume that off-grid power plants are displaced to the same extent as grid-connected power plants.

A report from the International Finance Corporation published in 2019 estimates the global back-up generator fleet at 450 gigawatts, with about 25 percent in sub-Saharan Africa (Source 13). In Africa the regional back-up generator fleet is about twice the installed grid capacity excluding South Africa. Countries outside Africa where use of backup generators is high (based on fuel consumption) include India, Pakistan and Iran. This report would therefore indicate that the fraction of projects affected by this element could be significant, at least in Africa and parts of South Asia.

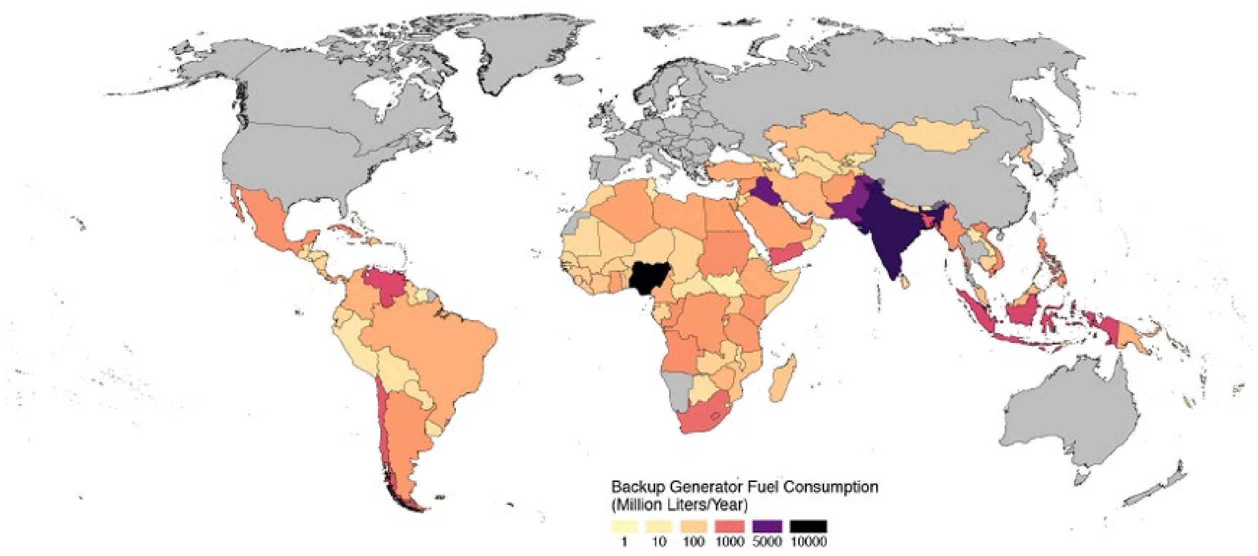


**Figure 1: Total diesel and gasoline consumed in 2016 across all modelled countries (Source: IFC)**

The average degree of overestimation could also be significant as the EF for diesel generation could be double of the GEF. Although it would be reasonable to assume that providing some additional power supply could reduce the number of power cuts, the impact of this issue is still considered potentially significant.

*OE5: Determination of the OM emission factor*

The calculation of the operating margin (OM) emission factor is based on one of the following four methods: (a) Simple OM, (b) Simple adjusted OM, (c) Dispatch data analysis OM, or (d) Average OM. The choice of method to be used depends on data availability and the share of and production from low-cost/must-run resources. The method with highest accuracy is method (c) – the dispatch data analysis OM – and the methodology requires that this method be chosen if the data is available. All other methods are expected to have a lower accuracy than dispatch data analysis OM (Source 15).

Methods (b) and (d) may potentially lead to an **underestimation of emission reductions**. This is because in most electricity grids fossil fuels will be at the margin at most times, but these methods consider a significant share of renewable sources in determining the OM. An increasing share of wind or solar PV in the system may indeed lead to a situation in which renewable power generation is at the margin in some hours. In many instances, however, the power plants at the margin during these times are hydropower dams or storage systems which have the ability to store energy and dispatch electricity based on the demand in the grid. In this case, the total renewable power generation from the grid would hardly be affected, as the non-dispatch hydro power electricity generation due to a high supply from wind or solar PV systems could be dispatched at a later point in time, when fossil fuels are at the margin of the grid. Only in few electricity systems and during a limited set of hours, other non-dispatchable renewable power generation plants are shut down due to oversupply in the grid. During these hours, it is reasonable to assume that any wind or solar PV generation would not displace any fossil fuels emissions.

Method (a) allows to exclude low-cost/must-run power plants from the calculation of the OM. However, 'low-cost' power plants are not clearly defined. The methodology identifies that low-cost/must-run plants include "hydro, geothermal, wind, low-cost biomass, nuclear and solar generation". The methodology further specifies that "if a fossil fuel plant is dispatched independently of the daily or seasonal load of the grid and if this can be demonstrated based on the publicly available data, it should be considered as a low-cost/must-run". It is indeed important to consider fossil fuel power plants that run steadily as low-cost/must-run plants, given that in many countries coal power plants are operated as base load power plants. The methodology, however, specifies that such plants should only be included as low-cost/must-run if "this can be demonstrated based on publicly available data". This opens the door for project developers to not include such plants, as the detailed data may not always be publicly available. Not including such plants could lead to an overestimation of emission reductions, as it would include plants with a particularly high emission factor (coal power plants) in the simple OM, while in reality their operation may not be affected by solar or wind power generation. In addition, the methodology identifies low-cost biomass as a plant type that should be considered as low-cost/must-run; in practice, however, some of these plants may be dispatchable and do not operate in the base load. Overall, the provision of excluding low-cost/must-run power plants may thus lead to an overestimation of baseline emissions and therefore **an overestimation of emission reductions**.

It should be noted that method (a) is by far the most adopted method, being used many more times than all other methods combined (Source 12). Overall, we therefore assess that the OM emission factor is more likely to be overestimated than underestimated, through the degree of overestimation is uncertain.

*UE1: Use of default values*

The tool allows using several default values for parameters such as the electric efficiency of power plants, and refers to Table 2, Appendix of "TOOL09: Determining the baseline efficiency of thermal or electric energy generation systems". The values provided can be considered to be conservative, i.e., they assume rather high electric efficiencies. Where these default values are used, this may lead to an underestimation of baseline emissions and therefore an **underestimation of emission reductions**.

**Determination of project emissions**

The methodology specifies that for most renewable energy power generation project activities, project emissions are equal to zero, but that some project activities may involve project emissions that can be significant. In these instances, the methodology requires estimating project emissions from three possible sources:

- Project emissions from fossil fuel consumption in year *y* (specifically for geothermal and solar thermal projects)
- Project emissions from the operation of dry, flash steam or binary geothermal power plants in year *y*
- Project emissions from water reservoirs of hydro power plants in year *y*

As this assessment relates only to wind power and solar PV projects, the determination of these project emissions is not relevant. Given that wind power and solar PV projects do not cause any major emissions during their operation, not considering any project emissions is appropriate.

**Determination of leakage emissions**

The methodology does not include any leakage emissions.

*U3 / UE2: Neglection of leakage emissions*

Leakage emissions can arise from the construction and decommissioning of the solar and wind power plants as well as from emission sources associated with power plants operated in the baseline scenario that are not considered as part of baseline emissions. This includes emissions from (see Figure 2):

- upstream processes such as the construction of the plants;
- operational processes, such as the extraction, processing, and transportation of fossil fuels; and
- downstream processes, such as the decommissioning of the power plants.

Emissions from raw material extraction and fossil fuel use for the manufacturing of components and construction of solar and wind and power plants can be significant. Likewise, upstream emissions from fossil fuel extraction in the baseline scenario can also be significant. To assess whether neglecting these emissions results in any significant under- or overestimation of emission reductions a review was carried out of published research which aims to assess the upstream emissions of GHGs of various renewable technologies compared to the emissions from upstream processes for fossil fuels. This review was not comprehensive, but some findings are presented below:

- The National Renewable Energy Laboratory (NREL) concluded that upstream processes for solar PV may be as high as 30 $gCO_2eq/kWh$, whereas for coal this figure would be <10 $gCO_2eq/kWh$ (Figure 2) (Source 12). It should be noted, however, that this publication includes emissions from coal mining, preparation and transport in operational processes and not other processes. A direct comparison between emissions from upstream processes for PV and coal as reported in this publication would not be valid, however, the reference is useful for the purposes of providing emissions estimates from upstream processes for solar PV.

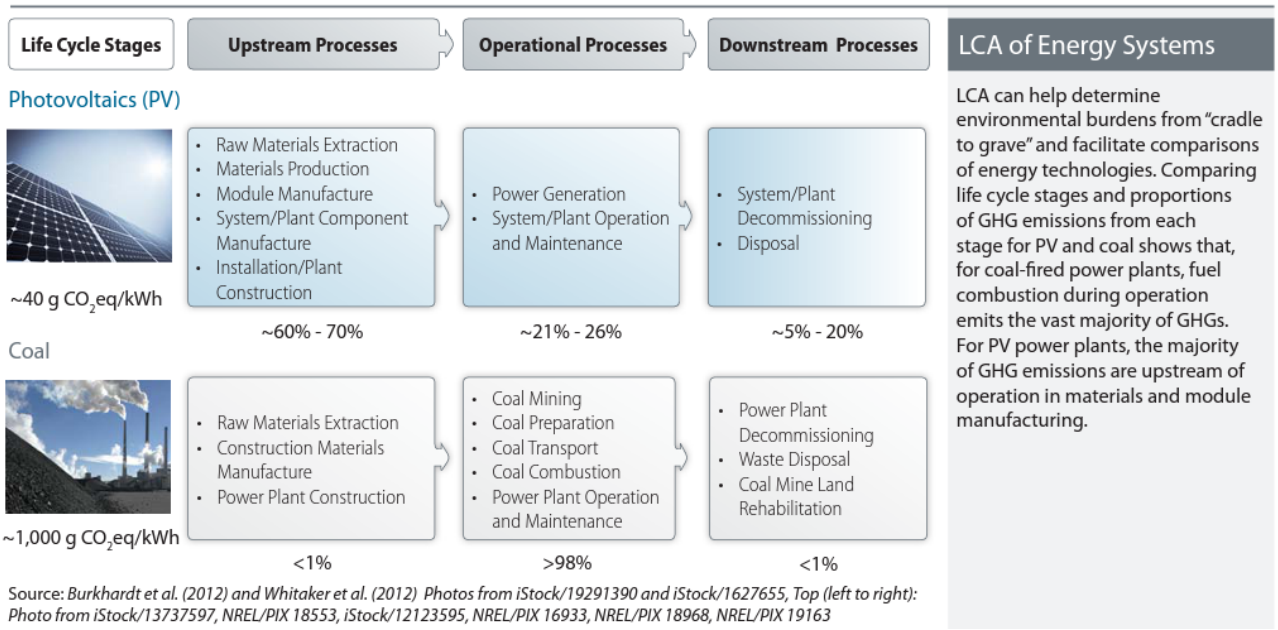


**Figure 2: Comparison of life cycle processes and greenhouse gas emissions for solar PV and coal power by life cycle stage.**

- NREL also concluded that upstream processes for wind may be as high as 10 $gCO_2eq/kWh$ (Source 14) (Figure 3). As for the previous reference a direct comparison between emissions from upstream processes for wind and coal as reported in this publication would not be valid.

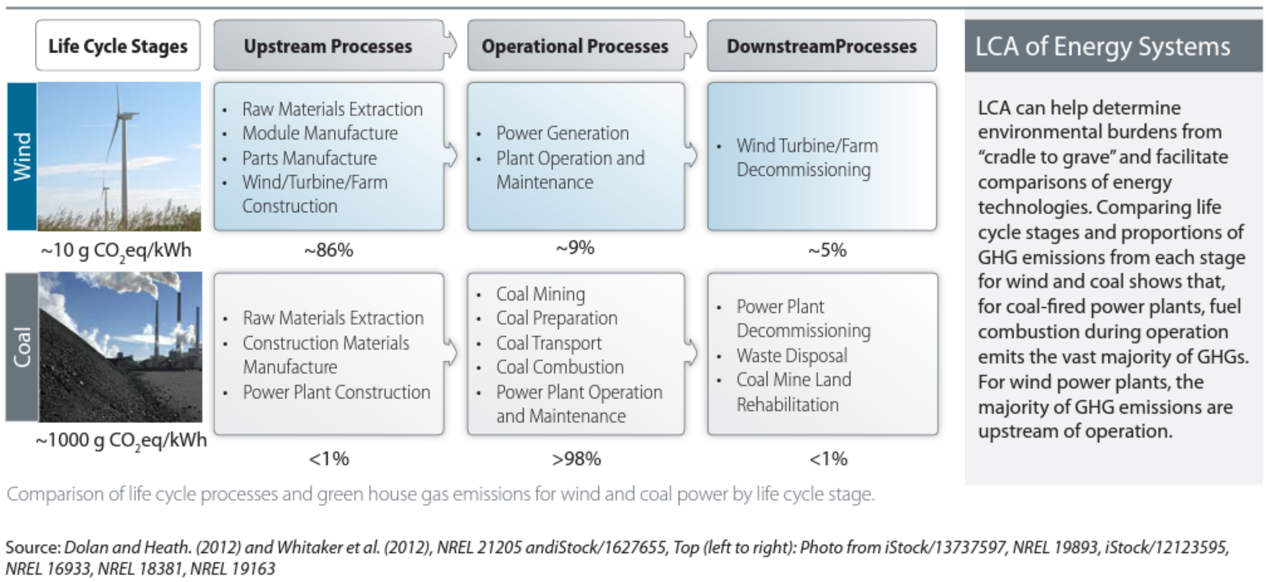


**Figure 3: Comparison of life cycle processes and greenhouse gas emissions for wind and coal power by life cycle stage.**

- A study funded by the Norwegian Research Council concluded that the LCA GHG emissions for onshore wind power farms are 11.0 and 15.1 $gCO_2eq/kWh$, and vary between 18.0 and 31.4 g $gCO_2eq/kWh$ for offshore wind power farms (Source 10).

- A paper published in 2020 showed a correlation between capacity of wind power projects and emissions, which varied between 10.0 and 40 $gCO_2eq/kWh$ (Source 1) (Figure 4).

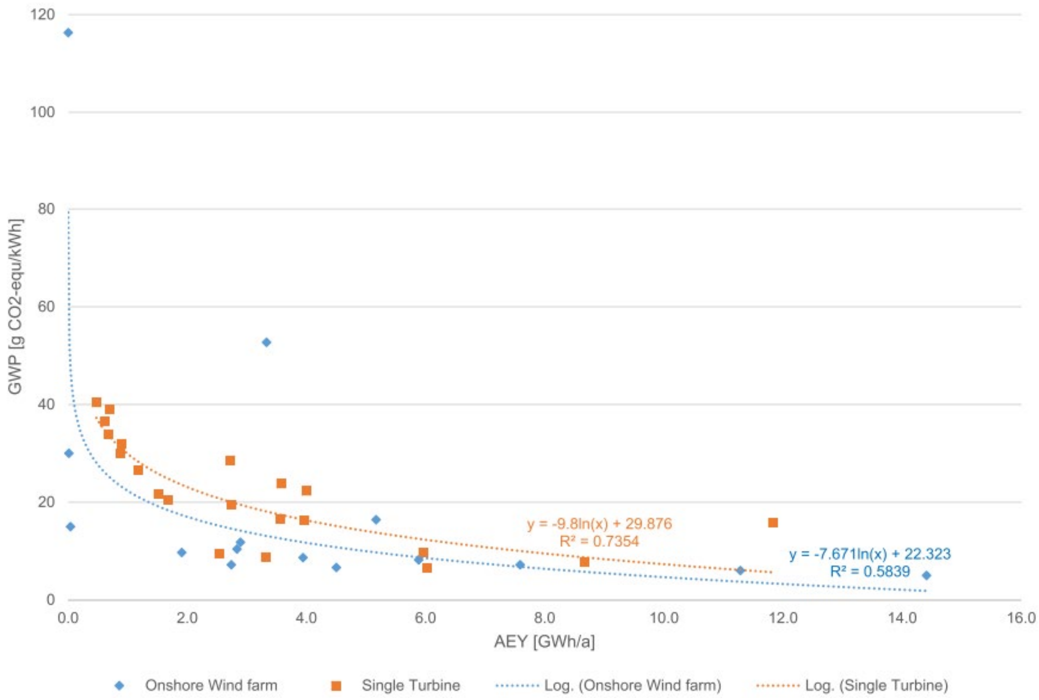


**Figure 4:** **Relationship between the Annual Energy Yield (AEY) and the GWP for single turbines and onshore wind farms**

- A meta-survey assessing the lifecycle greenhouse gas emissions from solar PV and wind energy showed a mean of 43 $gCO_2eq/kWh$ for solar PV and a mean of 57 $gCO_2eq/kWh$ for wind projects (incl. onshore and offshore) (Source 16)

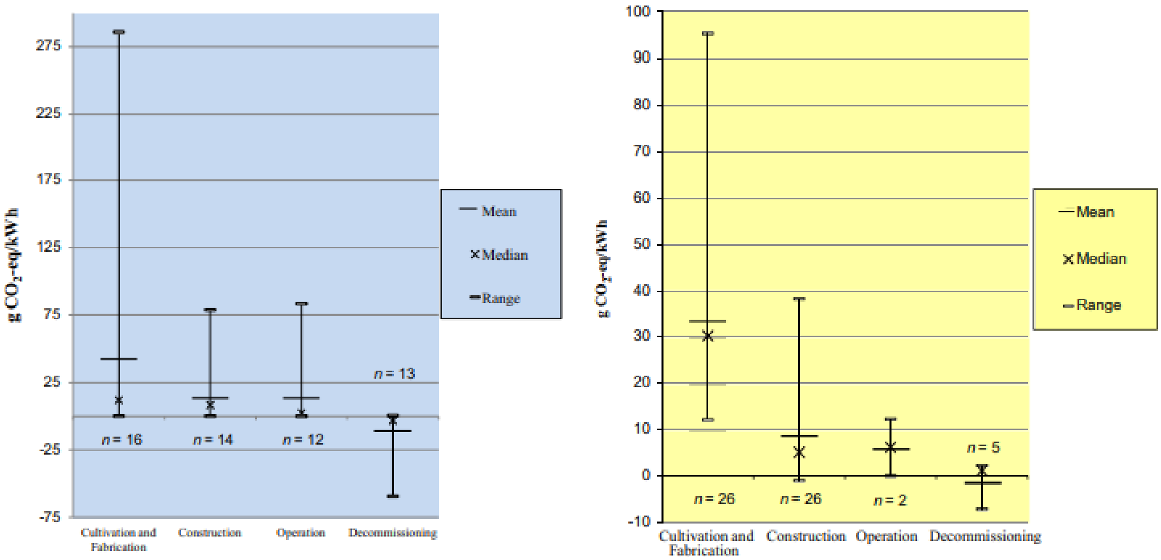


**Figure 5:** **Lifecycle greenhouse gas emissions for wind (blue) and solar PV (yellow) energy by lifecycle stage**

- NREL have also published Median Life Cycle Emissions Factors for Electricity Generation Technologies, by Life Cycle Phase (Source 16). This includes figures for solar PV, wind, hydropower and fossil fuels such as coal and natural gas (Figure 5).

| | Generation Technology | One-Time Upstream | Ongoing Combustion | Ongoing Non Combustion | One-Time Downstream | Total Life Cycle | Sources |
|---|---|---|---|---|---|---|---|
| Renewable | Biomass | NR | — | NR | NR | 52 | EPRI 2013<br>Renewable Electricity Futures Study 2012 |
| Renewable | Photovoltaic[a] | ~28 | — | ~10 | ~5 | 43 | Kim et al. 2012<br>Hsu et al. 2012<br>NREL 2012 |
| Renewable | Concentrating Solar Power[b] | 20 | — | 10 | 0.53 | 28 | Burkhardt et al. 2012 |
| Renewable | Geothermal | 15 | — | 6.9 | 0.12 | 37 | Eberle et al. 2017 |
| Renewable | Hydropower | 6.2 | — | 1.9 | 0.004 | 21 | DOE 2016 |
| Renewable | Ocean | NR | — | NR | NR | 8 | IPCC 2011 |
| Renewable | Wind[c] | 12 | — | 0.74 | 0.34 | 13 | DOE 2015 |
| Storage | Pumped-storage hydropower | 3.0 | — | 1.8 | 0.07 | 7.4 | DOE 2016 |
| Storage | Lithium-ion battery | 32 | — | NR | 3.4 | 33 | Nicholson et al. 2021 |
| Storage | Hydrogen fuel cell | 27 | — | 2.5 | 1.9 | 38 | Khan et al. 2005 |
| Nonrenewable | Nuclear[d] | 2.0 | — | 12 | 0.7 | 13 | Warner and Heath 2012 |
| Nonrenewable | Natural gas | 0.8 | 389 | 71 | 0.02 | 486 | O'Donoughue et al. 2013 |
| Nonrenewable | Oil | NR | NR | NR | NR | 840 | IPCC 2011 |
| Nonrenewable | Coal | <5 | 1010 | 10 | <5 | 1001 | Whitaker et al. 2012 |

**Figure 6: Median Published Life Cycle Emissions Factors for Electricity Generation Technologies, by Life Cycle Phase (g $CO_2e$/kWh)**

Emissions of GHGs from flaring of associated gas and fugitive emissions of methane during extraction and transport of fossil fuels can be significant. The World Resources Institute presents a more comprehensive review of upstream emissions (production and processing) as a percentage of overall emissions (including combustion). This is a significant issue, as there are inconsistencies in how the emission factors for upstream processes for fossil fuels presented in the above-mentioned studies are estimated and how different sources of emissions are allocated to different life cycle phases. For example, for natural gas the fugitive emissions of methane during extraction and transport of the fuel are included in the phase entitled "on-going non-combustions" in some studies whereas in others emissions of methane from coal mining are included in the "on-going combustion" phase. This makes direct comparison between different generation technologies and different life cycle phases challenging.

With respect to coal, a study undertaken within Germany concluded that coal-based electric power generation resulted in mean methane emissions of 0.6 g $CH_4$/kWh, (15 g $CO_2e$/kWh)[3], based on the country-specific methane content of hard coals imported to Germany, the coal mix and power plant efficiencies (Source 15). The same study highlighted, however, that emission factors varied significantly depending on the source country of the coal, as summarized in Table 1. The same study

[3] Using a 100-year GWP of 25 to align the studies.

concluded that upstream $CO_2$ emissions from mining, preparation and transport of coal to power plant sites in Germany were ~ 8 g/kWh for domestic and of ~ 12 g/kWh for imported hard coal. Combining emission factors upstream $CO_2$ and $CH_4$ suggests a combined emission factor of ~ 23 g $CO_2$e/kWh for domestic and of ~ 27 g $CO_2$e/kWh for imported hard coal for Germany. Table 1 therefore also presents this range of upstream $CO_2$ emissions from mining, preparation and transport of coal, and total upstream $CO_2$e/kWh (upstream emissions of $CH_4$, as $CO_2$e, and $CO_2$).

### Table 1: Country specific mean $CH_4$ emissions for power generation

| Origin country | $gCH_4$/kWh | $gCO_2$e/kWh | $gCO_2$/kWh | $gCO_2$e/kWh |
|---|---|---|---|---|
| Russia Federation | 2.0 | 50 | 8 - 12 | 58-62 |
| USA | 0.8 | 20 | 8 - 12 | 28-32 |
| South Africa | 0.6 | 15 | 8 - 12 | 23-27 |
| Colombia | 1.7 | 42.5 | 8 - 12 | 50.5-54.5 |
| Poland | 2.5 | 62.5 | 8 - 12 | 70.5-74.5 |
| Germany | 1.4 | 35 | 8 - 12 | 43-47 |
| Others | 1.5 | 37.5 | 8 - 12 | 45.5-49.5 |

The above quoted studies show a large degree of variation in the given estimates for upstream emission factors for GHGs of both renewable energy and fossil fuel technologies. Table 2 summarizes the higher and a lower upstream emission factor for solar PV and wind, plus the emission factors for natural gas and coal fired electricity generation, as presented in the referenced studies.

### Table 2: Lifecycle emissions for renewable energy and thermal projects (not including ongoing combustion)

| Technology | Lifecycle EF |
|---|---|
| | gCO2eq/kWh |
| Solar | ~ 35 to ~48 |
| Wind | ~ 13 to ~ 58 |
| Natural gas | 75 |
| Coal | ~ 25 to ~ 80 |

In conclusion, neglecting emissions from power plant construction and decommissioning, and upstream emissions from fossil fuel use, may for renewable power generation projects may in some cases lead to underestimation of emission reductions, specifically in the case of wind power generation where the baseline is grid has a significant share of natural gas in the fuel mix, and in other cases to overestimation of emission reductions (e.g. a solar PV project where the baseline is a grid with mainly coal with a relatively emissions intensity). On average, wind power generation is expected to have lower emissions from power plant construction and decommissioning than solar

PV power. Therefore, neglecting these leakage emissions is likely to lead to an underestimation of emission reductions (UE3), whereas the impact for solar PV power is uncertain (U3).

**Summary and conclusion**

Table 3 summarizes the results of the assessment and, where possible, presents the potential impact on the quantification of emission reductions for each of the previously discussed elements.

**Table 3 Relevant elements of assessment and qualitative ratings**

| Element | Fraction of projects affected by this element[4] | Average degree of under- or overestimation where element materializes[5] | Variability among projects where element materializes[6] |
|---|---|---|---|
| **Elements likely to contribute to overestimating emission reductions or removals** | | | |
| OE1: Exclusion of registered CDM projects in the calculation of the BM | Low | Low | Medium |
| OE2: Weighting of OM and BM in determining the CM (for solar PV power only) | High | Medium | High |
| OE3: Use of historical data to determine the GEF | High | Medium | Medium |
| OE4: Including off-grid power plants in the calculation of GEF | Low to Medium | Low to Medium | High |
| OE5: Choice of method for calculation of the operating margin (specifically for method (a)) | High | Low | Low |
| **Elements likely to contribute to underestimating emission reductions or removals** | | | |
| UE1 Use of default values provided in Tool 09 | Low | Low | Low |
| UE2: Neglection of leakage emissions (for wind power only) | High | Low | Low to Medium |
| **Elements with unknown impact** | | | |
| U1: Weighting of OM and BM in determining the CM (for solar PV power only) | High | Low | High |
| U2: Treatment of electricity transfers | Low | Low | Low to Medium |

The table shows that the potential sources of overestimation outweigh the potential sources of underestimation. The use of historical data to determine the grid emission factor (OE3) is the most important factor contributing to overestimation. Other factors could, however, also have significant

[4] This parameter refers to the likely fraction of individual projects (applying the same methodology) that are affected by this element, considering the potential portfolio of projects. “Low” indicates that the element is estimated to be relevant for less than one third of the projects, “Medium” for one to two thirds of the projects, “High” for more than two third of the projects, and “All” for all of the projects. “Unknown” indicates that no information on the likely fraction of projects affected is available.

[6] This refers to the variability with respect to the element among those projects for which the element materializes. “Low” means that the variability of the relevant element among the projects is at most ±10% based on a 95% confidence interval. For example, an emission factor may be estimated to vary between values from 18 and 22 among projects, with 20 being the mean value. “Medium” refers to a variability of at most ±30%, and “High” of more than ±30%.

impact. In aggregate, we estimate that emission reductions are likely to be overestimated within the range of 10-30%. Although wind power performs somewhat better than solar photovoltaic power, we estimate that this degree of overestimation is still applicable to both project types. Therefore, a score of 2 is assigned to this methodology.

[6] This refers to the variability with respect to the element among those projects for which the element materializes. “Low” means that the variability of the relevant element among the projects is at most ±10% based on a 95% confidence interval. For example, an emission factor may be estimated to vary between values from 18 and 22 among projects, with 20 being the mean value. “Medium” refers to a variability of at most ±30%, and “High” of more than ±30%.