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Bringing climate policy up to date – decreasing cost projections for renewable energy and batteries and their implications

Discussion paper

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Bringing climate policy up to date – decreasing cost projections for renewable energy and batteries and their implications

Discussion paper
within the project „Implikationen des Pariser Klimaschutzabkommens auf nationale Klimaschutzanstrengungen“

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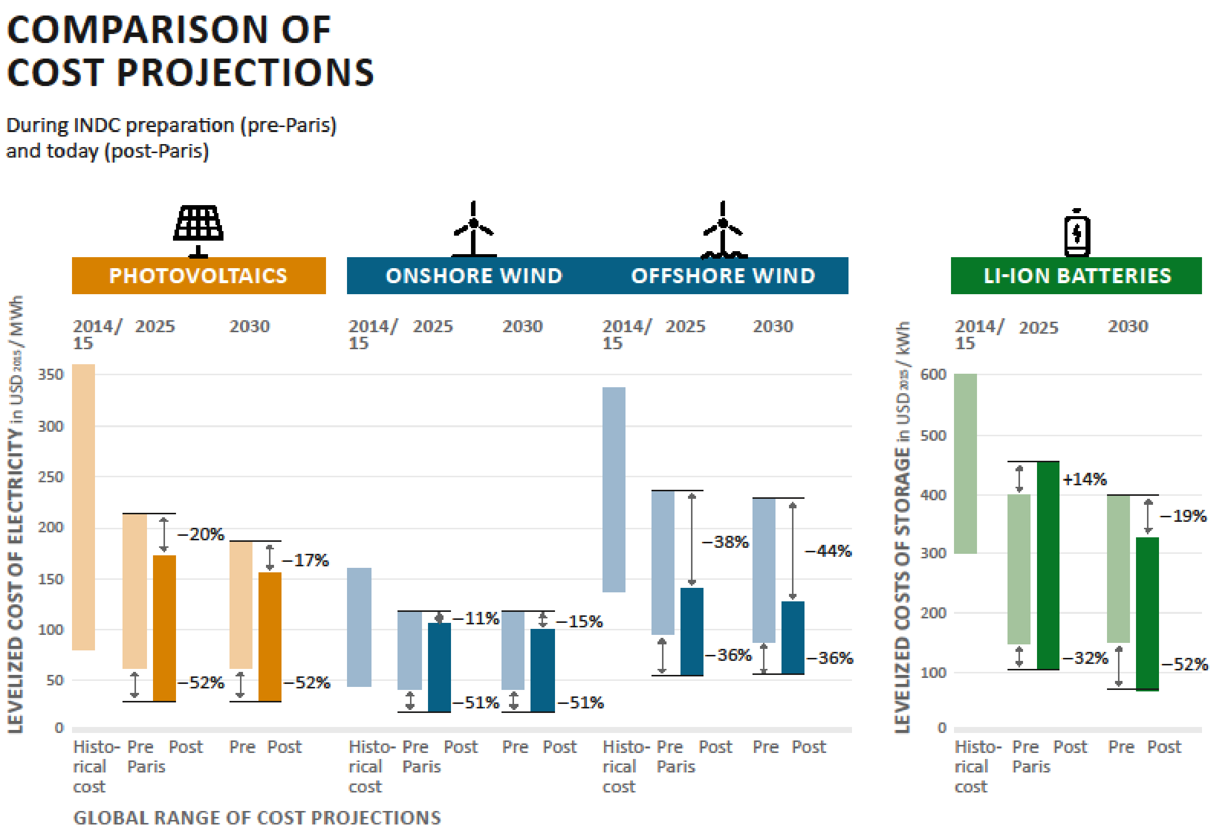
CAPEX	Capital expenditures
CAT	Climate Action Tracker
CCS	Carbon capture and sequestration
EV	Electric vehicle
GHG	Greenhouse gases
GW	One billion Watt
IPCC	Intergovernmental Panel on Climate Change
LCOE	Levelized costs of energy
LCOS	Levelized costs of storage
MWh	One million Watt hours
NDC	Nationally determined contributions
PA	Paris Agreement
PV	Photovoltaics
RES	Renewable energy sources
RES-E	Electricity from renewable energy sources
TWh	One trillion Watt hours
UNFCCC	United Nations Framework Convention on Climate Change
USD	US-Dollar

1 Executive Summary

The current commitments of the parties to the Paris Agreement in their nationally determined contributions (NDC) were defined in the run-up to the Paris Climate Summit 2015, COP21. Jointly, they are not yet sufficient to achieve the objectives of the Paris Agreement, and would lead to warming of at least 3°C (CAT 2018). However, since then better and more up-to-date information has become available. As part of their Paris commitments, parties will review and strengthen their NDCs by 2020. In this context, they have the opportunity to take into consideration that the **cost projections for certain key mitiga-tion technologies have decreased substantially since the preparation of NDCs** in the run-up to COP21 in Paris. In particular, this applies to cost projections for electricity from renewable energy sources (RES) and battery storage (see Figure 1).

In this discussion paper, we compare global cost projections for key mitigation technologies in recent reports with those that were available in the run-up to COP21. The results of the evaluation show that the latest **projections for levelized costs of energy in 2025 and 2030 are substantially lower, namely up to 51 – 52% for photovoltaics and onshore wind** (ranges 17 – 52% for photovoltaics, 11 – 51% for onshore wind) as well as **more than 36 % for offshore wind** (range 36 – 44%). For Lithium-Ion batteries used in electric vehicles, there is higher uncertainty about the reduction of costs (with an increase of the upper range in 2025), but **the reductions of battery cost projections range up to 38% in 2025 and 52% in 2030** (ranges +14% – -32% in 2025 and -19% – -52%; details in Section 3).

Figure 1: Projections for the levelized costs of energy/storage in 2025 and 2030 for renewable electricity and Lithium-Ion batteries before and after COP 21 in Paris



Source: own representation

Latest cost projections for RES electricity are mainly based on the recent outcomes of RES auctions around the globe. Although there are caveats when interpreting auction results as being equivalent to future generation costs, **worldwide auction outcomes serve as a strong indicator that the levelized costs of energy for RES technologies are decreasing faster than expected**. Photovoltaics and onshore wind power are even undercutting fossil power prices in some world regions. For batteries, the recent announcements of car manufacturers also suggest that recent cost projections are more in line with current expectations.

One consequence of the recent decrease in projected costs for key mitigation technologies is that an increase of ambition of NDCs is enabled. In this new situation, the same investments that were foreseen for the NDCs, now lead to higher outcomes and allow for higher targets. **For each GW of RES expansion in an NDC, the same level of investment now could lead to an additional capacity expansion of up to 0.9 GW** (range 0.2 – 0.9 GW both in 2025 and 2030)**. For each further million of electric vehicles in an NDC, the reduced cost projections can result in an additional market uptake of up to another 0.93 million of electric vehicles** (range 0 – 0.7 million electric vehicles in 2025; 0.08 – 0.93 million electric vehicles in 2030).

In summary, this discussion paper shows that current NDCs may be based on outdated assumptions and provides the global order of magnitude of the **potentials to increase the ambition of NDCs based on the reduction of cost projections for key mitigation technologies.** This **can be a starting point for the revision of the NDCs**, which nevertheless would require a detailed analysis of a specific country's techno-economic potentials and socio-economic needs.

2 Introduction

In December 2015, the Parties to the United Nations Framework Convention on Climate Change (UNFCCC) adopted the Paris Agreement (PA) with one central goal being to limit global warming to "well below 2°C above pre-industrial levels" and to make efforts to "limit the temperature rise to 1.5°C above pre-industrial levels". However, the current emissions reduction commitments of the parties in their nationally determined contributions (NDC) are far from being sufficient to achieve the objectives of the PA but would lead to warming in the order of 3.2°C (CAT 2017). The parties will have a chance to reduce or even eliminate this gap, when they review and adapt their NDCs by 2020 after the consultations of the Talanoa Dialogue taking place in 2018.

The NDCs (back then referred to as INDCs) were designed in the run-up to the Paris climate conference in December 2015, as agreed in December 2013 at COP19 in Warsaw. They were therefore based at least in part on projections for the development of technologies and estimated cost developments available in 2014/15. There is, however, strong evidence that between 2014 and today, the costs of certain key mitigation technologies have decreased substantially faster than in those projections, in particular renewable power generation and batteries for electric vehicles (EVs) and grid storage (Climate Analytics 2018, Fraunhofer ISI et al. 2017). This raises hopes that parties could update their goals based on the latest cost projections and, henceforth, increase the ambition of their NDCs.

2.1 Objectives of the study

Given the developments described above, the goal of this short study is to provide scientific arguments for increasing the 2030 ambition of the NDCs due to faster-than-expected decrease of technology costs. In particular, answers to the following questions will be provided:

- How do the current cost estimates for key mitigation technologies in 2025 and 2030 compare to those available when the NDCs were prepared (2014/15)?
- What is the relative magnitude of the additional uptake of key mitigation technologies that arise from the cost reductions achieved under the assumption that cost savings are reinvested in the same mitigation technology?
- How large are the additional emissions reduction potentials and fossil fuel cost savings associated with the additional expansion of key mitigation technologies?

2.2 Technology choice and structure of the report

In the preliminary step, the key mitigation technologies to be considered are chosen based on three criteria:

(1) The technologies should be able to provide substantial contributions to global climate change mitigation by 2030.
(2) The techno-economic development of the technologies after 2014 has been faster than expected in 2014/15.
(3) Sufficient data on assumptions about future costs in 2014/15 and today are available for the technologies.

Based on the first criterion, we focus our attention on electricity supply and the electrification of end-use sectors (in particular transport and heating), which provide the largest contributions to technology-based mitigation before 2030. For electricity supply, technologies with high mitigation potentials are renewable energy sources (RES), nuclear power and carbon capture and sequestration (CCS). Neither nuclear power nor CCS has experienced unexpected cost reductions in the recent past (WEO 2017). Out of the RES, the cost reductions particularly of photovoltaics (PV) and concentrated solar power (CSP) but also of onshore and offshore wind have been unexpectedly high (IRENA Power Costs 2017), mainly because of the high amount of new installations. Moreover, recent RES auctions for PV, onshore and offshore wind have all yielded unexpectedly low outcomes (see details in Section 3.1). Therefore, we will consider these technologies in detail in this study. The absolute costs of CSP, on the contrary, are still relatively high. Moreover, CSP plays only in a minor role in the majority of the NDCs and is therefore not considered in the detailed analysis based on criterion (1). Nevertheless, the cost reductions in combinations with its storage capabilities make CSP a valuable option to be addressed in the future NDCs.

Key technologies for the electrification of the heating sector and the transport sector are heat pumps and EVs respectively. While the cost development of heat pumps has not shown unexpected dynamics, the costs of Li-ion batteries, which are the main cost driver of EVs, have strongly decreased between 2014 and 2017 (IEA ETP 2017). Hence, we will also consider Li-ion batteries and EVs in detail in this study. With regard to criterion (3), there is significant data on historic cost development and future projections for all chosen technologies. However, the cost projections do not cover the time horizon until 2030 for all the technologies. We will therefore have to make assumptions to close the gaps in some cases below.

The body of this short study consists of two parts: the comparison of cost developments of key mitigation technologies and estimates of the resulting potential to increase ambition of the NDCs. We start by explaining the approach and assumptions of both steps and then present the results in separate subsections. In a final section, we discuss limitations of the results, in particular with regard to regional peculiarities, specific assumptions in NDCs, costs for system integration of RES and future cost developments in general, and draw conclusions on possible increases of the ambition of the NDCs.

3 Comparison of cost projections of key mitigation technologies and estimate of potential impacts

The first step to estimate the potentials to increase ambition of NDCs is an evaluation and comparison of the cost projections of the chosen key mitigation technologies. We focus here on the most relevant literature on costs of RES and batteries (IEA's Energy Technology Perspective and World Energy Outlook, IRENA reports), but also take into account peer reviewed articles as well as the results of recent RES auctions. The result is a description of the ratio between the LCOE of RES electricity in studies published in 2014/15 and those published between 2016 and June 2018 for the latest available historical year as well as projections for 2025 and 2030 as well as the analogous ratio for the levelized costs of storage (LCOS) of batteries. The results are summarized in the form of infographics for 2025 and 2030.

The second step is to estimate the potentials to increase ambition of NDCs. To this end, the following sub-steps are carried out:

- *Estimation of additional uptake of key mitigation technologies*: Under the assumption that the total available remaining funds for investment, due to lower-then-expected costs are reinvested in the same key technology, the difference of the additional capacity expansion based on the post-Paris cost projections and based on the pre-Paris cost projections can be estimated based on the ratio of the former expectations and the current expectations about the LCOE of the technology under study. To this end, we consider the mean increase over the three time periods 2015 – 2020, 2020 – 2025, 2025 – 2030, and aggregate the increase over time. This is a conservative estimate, as the avoided costs for the replaced technologies including their fossil fuel demand are not taken into account. Under the assumption that capacity factors do not change, this also yields the additional RES generation. To derive the ratio of the number of EVs, the additional market uptake due to higher cost competitiveness will be included as well.
- *Specification of reference emissions*: The estimation of the potential to increase ambition has to be based on the avoided emissions with regard to one reference technology (or a mix of several) that is meant to be replaced by the mitigation technology, e.g. fossil-fired power plants and fossil-fueled cars for EVs. To this end, suitable reference technologies have to be identified for each key mitigation technology and specified with regard to its GHG emissions. For the use of RES electricity, we select also the new installation of fossil plants as a reference as well as suitable reference technologies when used for heating purposes and in the transport sector respectively.

We do not carry out an aggregation/optimization of the different options, as this is highly dependent on the regional circumstances, but only sketch an application in an instructive example. Future analyses can use the results to estimate the additional potentials for countries and regions.

3.1 Comparison of cost development

In the following, we present and compare the ranges from the most important global energy technology studies published in 2014/15 with those published between 2016 and June 2018. For PV as well as onshore and offshore wind, key reports that contain cost projections are on the one hand the IEA Energy Technology Perspectives (IEA ETP 2014/15/17), the associated Tracking Clean Energy Progress reports (IEA TCEP 2014/15/17) as well as the World Energy Outlook 2016 (IEA WEO 2016) and, on the other hand, the IRENA Power Costs reports (IRENA Power Costs 2014/17) as well the Power to Change report (IRENA PTC 2016). It is important to note that the latest IEA projections for 2030 are significantly higher than the IRENA projections for 2025, while no recent IRENA projections for 2030 are available.

Therefore, we apply the IRENA projections for 2025 also to 2030. This is a conservative estimate, as we do not extrapolate the trend of the projections. Projections from the individual reports, including also some regional estimates can be found in the annex.

For Li-ion batteries, a review report by Nykvist and Nilsson (2015) was published in Nature Climate Change, which covered all relevant cost projections up to that point in time. Currently, the most relevant cost projections can be found in the IRENA Electricity Storage 2017 report. The IEA Energy Technology Perspectives and World Energy Outlooks do not contain explicit cost projections for batteries. Due to low availability of cost projections for 2025 in the pre-Paris reports, the upper range for 2030 has been applied to 2025. Moreover, we again take into account the lower range for 2025 for 2030. Individual projections from the evaluated reports can also be found in the annex.

3.1.1 Photovoltaics

The aggregated results of the evaluation of cost projections for PV plants in the studies named above are shown in Table 1. For reasons of comparability, we focus here on utility-scale PV plants.

Table 1: Comparison of cost projections for utility-scale PV plants before and after COP 21 in Paris

LCOE in USD_{2015}/MWh	Latest historical year*		2025		2030	
	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Global range 2014/15	80	360	62	214	62	187
Global range 2016/17	68	311	30	172	30	155
Reduction of cost estimate	**-15%**	**-14%**	**-52%**	**-20%**	**-52%**	**-17%**

The aggregation to "Global range" uses the lowest projection for the corresponding year or an earlier year. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data.
Sources: IEA ETP 2014/15/17, IEA TCEP 2014/15/17, IEA WEO 2016, IRENA Power Costs 2014/17, IRENA PTC 2016 and own calculations. N/A = not available.

The central findings for the aggregated ranges are:

- For the post-Paris reports, the lower and the upper estimates for the latest historical year available (2016/17) are 14 – 15% lower than the latest historical year available (2014/15) in the pre-Paris reports.
- For 2025 and 2030, there is an enormous difference between the pre-Paris and the post-Paris cost projections. In particular, the best-case estimate has decreased by 52%. The worst-case estimate has decreased by 20% in 2025 and 17% in 2030.

Moreover, PV power will be cost-competitive with fossil power generation in 2025/30 in those regions, where the LCOEs for PV are close to the lower range of 30 USD/MWh. The decreasing costs for PV plants in the global Post-Paris studies are in line with the results obtained in several RES electricity auctions worldwide (own research based on press releases):

- Globally, the highest price reductions have been achieved in the post-Paris period: Mexico awarded PV in 2016 with 40.2 USD/MWh in 2015, decreasing to 32.5 USD/MWh in 2016 and finally reaching 21.3 USD/MWh in 2017. Saudi Arabia also awarded one of the lowest prices worldwide for a PV project, in this case for 23.4 USD/MWh, all of them being significantly lower than the lower range of projected costs of 64 USD/MWh in 2030 assumed in the pre-Paris period – and even lower than the 30 USD/MWh in 2030 based on the post-Paris studies.

- In Germany, the average awarded prices in the utility-scale PV auctions decreased from 82.3 USD/MWh in April 2016 to 53.7 USD/MWh in June 2018, while the average between 2016 and 2018 amounted to 65.4 USD/MWh.
- In the US, PV auction resulted in 2015 resulted in a price level of around 40 USD/MWh, which is significantly lower than the assumed LCOEs of the US in 2016, as well as the most optimistic projected costs of 59 USD/MWh in the US in 2030.
- India awarded contracts for PV projects for 87.5 USD/MWh in 2015 and 70.6 USD/MWh in 2016, respectively, falling sharply to around 40 USD/MWh in 2017. These results are significantly lower than the proposed LCOE proposed in 2016, as well as the lowest assumed, global 2030 LOCE of 64 USD/MWh of the pre-Paris study, and concerning the 2017 results, significantly lower than the projected 2030 LCOE for India of 56 USD/MWh.
- In Brazil, prices fell from 85.9 USD/MWh in 2015, which were already lower than both the lower range in the pre-Paris studies, as well as significantly lower than the 132 USD/MWh proposed for Brazil in 2016. The latest auctions results for Brazil fell to 45.7 USD/MWh in 2017, a value already significantly lower than the 64 USD/MWh assumed for 2030.

As we can see based on the above examples, costs for PV plants are decreasing sharply in the post-Paris period, already being awarded prices significantly lower than the projected values for 2030. This suggests that the more recent cost projections for PV are more reliable than those available in the pre-Paris period.

3.1.2 Offshore/Onshore wind

The results of the evaluation of cost projections for onshore and offshore wind power plants in the studies named above are shown in Table 2 and Table 3. For 2030, again only the more conservative IEA estimates are available.

Table 2: Comparison of cost projections for onshore wind before and after COP 21 in Paris

LCOE in USD2015/MWh	Latest historical year*		2025		2030	
	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Global range 2014/15	45	160	41	118	41	118
Global range 2016/17	20	121	20	106	20	101
Reduction of cost estimate	**-56%**	**-25%**	**-51%**	**-11%**	**-51%**	**-15%**

The aggregation to “Global range” uses the lowest projection for the corresponding year or an earlier year. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. The regional LCOEs shown were derived from WEO 2016 based on the discount rates and lifetimes used in the IRENA reports.
Sources: IEA ETP 2014/15/17, IEA TCEP 2014/15/17, IEA WEO 2016, IRENA Power Costs 2014/17, IRENA PTC 2016 and own calculations. N/A = not available.

Table 3: Comparison of cost projections for offshore wind before and after COP 21 in Paris

LCOE in USD_2015/MWh	Latest historical year*		2025		2030	
	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Global range 2014/15	140	340	92	233	92	233
Global range 2016/17	128	237	59	145	59	130
Reduction of cost estimate	**-9%**	**-30%**	**-36%**	**-38%**	**-36%**	**-44%**

The aggregation to "Global range" uses the lowest projection for the corresponding year or an earlier year. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. The regional LCOEs shown were derived from WEO 2016 based on the discount rates and lifetimes used in the IRENA reports.
Sources: IEA ETP 2014/15/17, IEA TCEP 2014/15/17, IEA WEO 2016, IRENA Power Costs 2014/17, IRENA PTC 2016 and own calculations. N/A = not available.

The key findings for the aggregated ranges are:

- Both in the pre-Paris and in the post-Paris reports, the lower cost range for onshore wind plants is roughly constant from the latest historical year to 2030. However, the lower range in the post-Paris reports is less than half as high throughout the whole period. The upper range slightly decreases. In the post-Paris reports, it is 11% lower in 2025 and 15% lower in 2030.
- In the post-Paris reports, the lower and the upper range for offshore wind plants in the latest historical year available (2016/17) are 9% and 30% respectively lower than the latest historical year available (2014/15) in the pre-Paris. For the lower range, the reduction of the cost projection increases to 36% in 2025 and 2030, while the reduction of the upper range reaches 38% in 2025 and 44% in 2030.

In those regions, where the LCOEs for onshore wind are close to the lower range of 20 USD/MWh, onshore wind power is even cost-competitive with fossil power generation already today. The decreasing costs for both onshore and offshore wind plants in the global Post-Paris studies is in line with the results obtained in several RES electricity auctions worldwide (own research based on press releases):

- European Union: In Germany, the average awarded prices in the wind onshore auctions decreased from 65.3 USD/MWh in May 2017 to 43.2 USD/MWh in November 2017 and slightly increased again in May 2018, with an average price of 73.5 USD/MWh. The average between 2017 and 2018 amounted to 56.4 USD/MWh, which is slightly higher than the most optimistic scenario identified in the Pre-Paris analyses for 2025/30. France, another major European country awarded wind onshore with 76.5 USD/MWh in 2018, whereas Spain was able to have subsidy-free auction outcomes from 2016 on, showing already lower prices compared to the projected costs for Europe in 2030.
- Latin American countries: Brazil awarded onshore wind between 2015 and 2017 with an average of 41.7 USD/MWh, while in Mexico, the price of wind onshore decreased from 49.4 USD/MWh in the 2015 auction to 19.2 USD/MWh in 2017. Although the 2015 result is almost in line with the projected costs for Brazil (both for 2016 and 2030), the results in 2017 show significantly lower remuneration levels compared to the lower range of 41 USD/MWh for 2030 projected in the Pre-Paris studies, as well as the 45 USD/MWh proposed for Brazil.

- In India's auctions in 2017, the average awarding prices amounted to 41.7 USD/MWh, which decreased to 37 USD/MWh in 2018, both being significantly lower than the ranges proposed for India, as well as the most optimistic scenario of 41 USD/MWh in the Pre-Paris studies.

Regarding offshore wind plants, auctions in the recent years have experienced sharp price drops:

- European Union: Germany awarded offshore wind in 2017 with an average of 50 USD/MWh (mostly subsidy-free), while the 2018 auction resulted in an average price of 55 USD/MWh. The Netherlands tendered an offshore wind project in the first subsidy-free auction worldwide in 2017. Belgium realized an average price of 153 USD/MWh in 2016, while the price decreased to 89 USD/MWh in 2017. Denmark on the other hand awarded offshore wind in 2016 with an average price of 58.6 USD/MWh.
- In Massachusetts, USA, an offshore wind farm has signed a PPA in 2018 for 65 USD/MWh, significantly lower than the lower range of the 2030 figures, as well as the 109 USD/MWh projected for the US in 2030. In Australia, an offshore wind farm signed a PPA in 2018 selling the output for around 44 USD/MWh.

Consequently, even in the offshore wind sector, the trend of decreasing prices is clear, since most of the results after 2015 are significantly lower than the assumed lower range of 92 USD/MWh for 2030 in the Pre-Paris studies. These results should be interpreted with caution (see section 3.1), but they provide clear evidence the sharply decreasing price trend of onshore wind technologies and the difference to the projected costs of the Pre-Paris studies.

3.1.3 Lithium-Ion batteries for electric vehicles

The results of the evaluation of cost projections for Lithium-Ion batteries in the studies named above are shown in Table 4. The main findings are:

- For the post-Paris report, the lower range for the latest historical year available (2016/17) is one third lower than the lower range for latest historical year available (2014/15) in the pre-Paris reports.
- For 2025, the lower range of the cost projections has decreased by 32%. On the contrary, the upper range has increased by 14% in 2030.
- For 2030, the lower range of the cost projections in Post-Paris reports is less than half as high as in pre-Paris reports, and the upper range has decreased by 19%.

Table 4: Comparison of cost projections for Li-ion batteries before and after COP 21 in Paris

LCOE in USD2015/kWh	Latest historical year*		2025		2030	
	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Global range 2014/15	300	600	160	400	160	400
Global range 2016/17	200	840	109	457	77	326
Reduction of cost estimates	**-33%**	**+40%**	**-32%**	**+14%**	**-52%**	**-19%**

* The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. Projections that were published before 2008 have not been included in the range.
Sources: Nykvist and Nilsson (2015), IRENA Electricity Storage 2017 and own calculations

In summary, we find substantial reductions of the cost projections in the Post-Paris reports when compared to the Pre-Paris reports, in particular for the lower cost range, but in the longer term also for the upper cost range. The target costs of car manufacturers are even more optimistic than the lower ranges of Post-Paris reports (IEA 2017):

- In 2015, General Motors announced cost targets for cells of 145 USD/kWh for 2017, 120 USD/kWh for 2020 and 100 USD/kWh for 2022.
- Tesla Motors aims at cell costs of 100 USD/kWh for 2020 already.

Though the target announcements of car manufacturers may overestimate the cost reduction potentials, they provide some evidence that the lower cost projections in the Post-Paris reports are not over-optimistic. Nevertheless, it is important to note that the upper range of the LCOS for the latest historical year have not decreased but increased, while the future cost projections have decreased. Hence, there is still uncertainty about how fast the targeted cost reductions can be achieved.

3.2 Estimate of the potential to increase ambition and its impacts

We now turn to the two sub-steps that enable interested parties to estimate the potential to increase NDC ambition and its impacts:

1. Estimation of additional expansion / market uptake of key technologies
2. Estimation of specific emission reductions and fossil fuel cost savings

3.2.1 Estimation of additional expansion / market uptake of key technologies

This section focuses on the additional expansion of technologies compared to expectations when NDCs were prepared. Nevertheless, countries with low RES targets can also consider an upscaling of RES and EVs based on the lower cost projections and the increasing competitiveness with fossil fuel power and fossil-fuelled cars.

For a country with certain RES technologies in its NDC, we expect that there is substantial additional technical potential of those RES technologies.[1] Furthermore, it is commonly assumed in the literature that Lithium-Ion battery LCOS in an order of magnitude of 150 USD/kWh will make EVs cost-competitive to fossil-fuelled cars (see e.g. Nykvist and Nilsson 2015). To derive the impact of the reduced cost projections for key mitigation technologies, we thus analyse the effect of increasing the ambition of the NDCs based on the following assumptions:

- the reductions of LCOEs for RES electricity from PV, onshore and offshore wind are reinvested into the same technology;
- the lower battery costs lead to a faster market uptake of EVs.

We estimate the latter based on Gnann (2015), who finds that 25% lower battery costs lead to 38% higher market shares of EVs in 2025 and 55% higher market shares in 2030. For the worst-case of an increase of battery cost projections until 2025 and a decrease only afterwards, we assume that there is

[1] It is important to note that a realization of the potential may be limited by grid constraints. As these are country-dependent, we do not consider this here, but a detailed country analysis should include the necessary grid extensions.

an additional market uptake only between 2025 and 2030, while NDC targets for 2025 are assumed to remain the same.

We take into account the evolution of the cost reductions over time to account for the time delay of expanding the RES capacities and of the market uptake of EVs. Since the reductions of cost projections have a similar magnitude, as is 2025/2030 already in 2020, the additional uptake of RES and EVs is still approximately proportional to the inverse of the cost reductions. The possible increase of ambition for the various technologies is listed in Table 5. We note that the increase in 2025 can be larger than in 2030 because the increases are specified relative to NDC levels.

Table 5: Additional expansion / market uptake of key technologies relative to the assumptions of the NDCs

Additional uptake of key technologies	Unit	2025		2030	
		Best case	Worst case	Best case	Worst case
Photovoltaics	GW / GW_{NDC}	+77%	+23%	+78%	+21%
Onshore wind	GW / GW_{NDC}	+89%	+24%	+85%	+20%
Offshore wind	GW / GW_{NDC}	+83%	+32%	+69%	+40%
Electric vehicles (EV)	million EV / million EV_{NDC}	+70%	+0%	+93%	+8%

Based on those assumptions, the additional capacity expansion can be up to 77%/78% of the capacity expansion in an NDC for PV and up to 89%/85% for onshore wind in 2025/30, respectively. In the worst-case scenario, the additional expansion is still 23% – 24% in 2025 and between 20% – 21% in 2030. The large range reflects the large range of the reduction of cost projections, which is mainly related to regional differences. For offshore wind, the maximal possible increase of ambition is a bit lower than for PV and onshore wind in 2030 (+83/69% in 2025/30), but due to the lower regional differences it is also more robust with lower increases of 32% in 2025 and 40% in 2030.

For EVs, the market uptake in addition to that in NDCs based on the pre-Paris reports can be only 8% in 2030 with no growth in 2025, but in the best case, the uptake amounts to 70% in 2025 and 93% in 2030. This reflects the uncertainty about the time period for realizing the expected cost reductions.

3.2.2 Estimation of specific emission reductions and fossil fuel cost savings

Next, we consider the specific emission reductions and fossil fuel cost savings of the fossil technology substitution by RES electricity and EVs in the power, the heating and the transport sector. In the power sector, we consider the substitution of the range of globally dominating fossil reference technologies of steam coal plants and combined cycle gas turbines by RES electricity (RES-E). In the heating sector, we consider the use of RES-E in air heat pumps, which can be used independent of geographical conditions, replacing fossil-fueled boilers. For the latter, we consider a range given by the globally most relevant heating technologies: oil boilers with low efficiencies and highly efficient gas boilers. In the transport sector, we consider the substitution of the range of gasoline- and Diesel-fueled cars with battery EVs. The savings by replacing a fossil-fueled car with an EV is split up between the use of RES electricity in EVs and the EV itself by considering the use of the global power mix from the New Policies Scenario in EVs as an intermediate step.

We specify the mitigation and fossil technologies based on the latest IPCC emission factors as well as various sources for the efficiencies of the mitigation and reference technologies (Oeko-Institut et al.

2016, Tractebel et al. 2018, IEA WEO 2016). Furthermore, we use the fossil fuel prices in the New Policies Scenario from IEA WEO 2017 (steam coal: USD 61 – 89 per ton, oil: USD 83 – 94 per barrel in 2025/30). We express all specific values with regard to gross electricity consumption by assuming grid losses of 10%. The results from the comparison of mitigation and fossil technologies are listed in Table 6.

Table 6: GHG emission reductions and fossil fuel cost savings of substitutions of fossil technologies per gross electricity consumption

Impact of substituting technologies	Unit	2025		2030	
		Best case	Worst case	Best case	Worst case
Substitution of fossil power by RES-E	t CO_2 / MWh_{elec}	-1.0	-0.3	-1.0	-0.3
	USD / MWh_{elec}	-63	-16	-63	-16
Substitution of fossil heating by RES-E air heat pump	t CO_2 / MWh_{elec}	-1.0	-0.45	-1.1	-0.4
	USD / MWh_{elec}	-194	-102	-235	-115
Substitution of power mix EV by RES-E EV	t CO_2 / MWh_{elec}	-0.4	-0.4	-0.3	-0.3
	USD / MWh_{elec}	-16	-16	-16	-16
Substitution of fossil-fueled car by power-mix EV	t CO_2 / MWh_{elec}	-0.4	-0.3	-0.4	-0.3
	USD / MWh_{elec}	-132	-120	-135	-132

While the emission reduction is high, when RES electricity is used to replace coal power, the fossil fuel cost savings are relatively low because of the comparably low coal price. However, there can be large additional savings, if the building of new coal plants can be avoided. This is highly dependent on the current energy system of the specific country and is thus not considered here but should be included in country-specific assessments. The specific emission reductions and fossil fuel cost savings are particularly large, when RES electricity is used in air heat pumps to replace oil boilers of low efficiency. The splitting of emission reductions and cost savings for the replacement of fossil-fueled cars between EVs and the change of the power mix results in almost the same emission reduction for both substitutions, while the cost savings are mainly attributed to the EV itself due to comparably high oil price.

The specific emission reductions and fossil fuel cost savings can be combined with the additional expansion of RES and the additional market uptake of EVs from Section 3.2.1 respectively to obtain the corresponding additional emission reductions and fossil fuel cost savings. As this is highly country-specific, we leave this for future research and instead sketch an instructive example here. For a fictive country, we assume that in 2030

- the NDC includes an expansion of PV capacity by 15 GW and a market uptake by 3 million EVs;
- the mean value of the ranges of cost projections is applicable to the country;
- 80% of the additional RES electricity replaces fossil power production and 20% is used in EVs;
- the national fossil power mix contains 80% steam coal and 20% natural gas;
- EVs only replace gasoline-fueled cars.

Then the additional emission reductions are 10.3 Mt CO_2 per year (3.7 – 17.0 Mt CO2/a for the full range of cost projections), with 7.7 Mt CO2 attributed to the additional PV expansions and 2.6 Mt CO2 attributed to the additional market uptake of EVs. The additional fossil fuel cost savings amount to more than USD 700 million per year (range USD 175 – 1'226 million/a), with USD 236 million attributed to the additional PV expansions and USD 465 million attributed to the additional market uptake of EVs. This suggests that the lower cost projections can provide substantial potential to increase the ambition of NDCs. However, the large ranges clearly show that our global analysis cannot replace an assessment on the country-level.

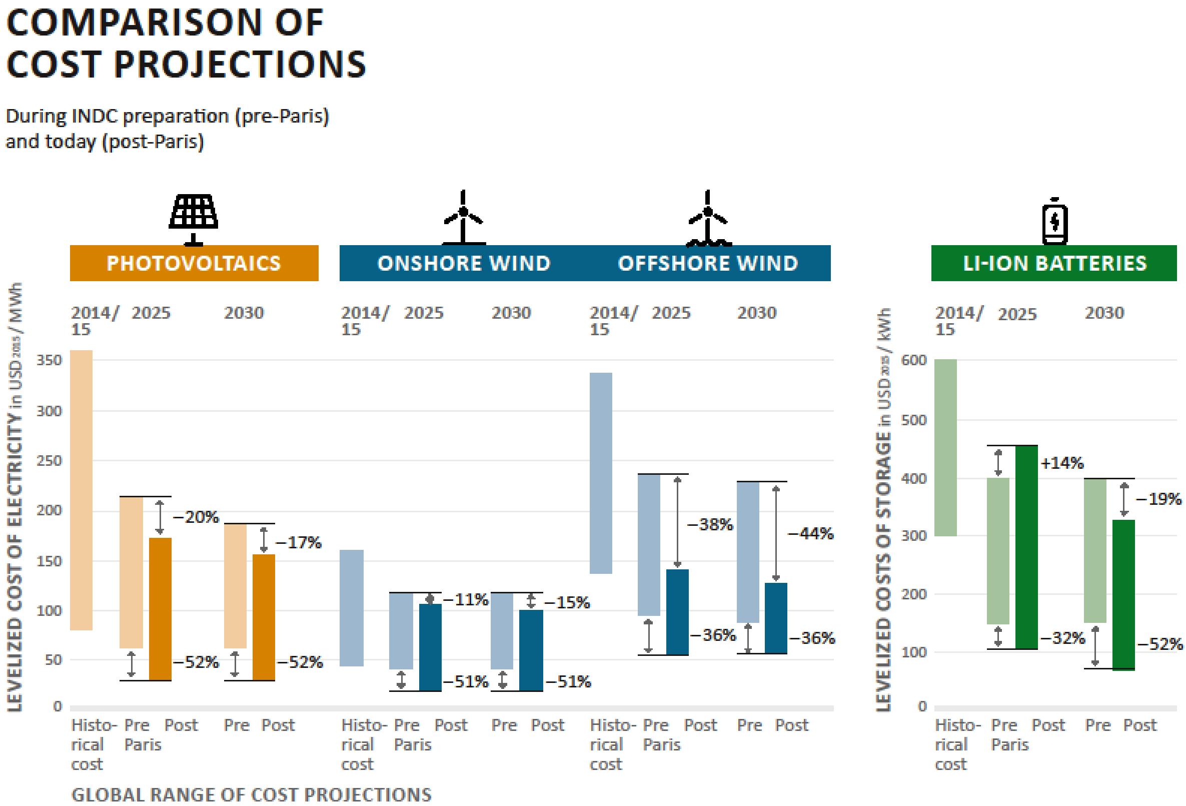
4 Discussion and conclusion

In the first part of this discussion paper, we have compared the global cost projections for key mitigation technologies in the most recent reports with those that were available when countries prepared their NDCs in the run-up to COP 21 in Paris. The results of the evaluation strongly suggest that it is worthwhile to update the cost assumptions underlying the preparation of the NDCs for both the commonly used target years 2025 and 2030 (see Figure 1).

The latest LCOE projections are substantially lower, namely up to 51-52% for PV and onshore wind in 2025 and 2030 (ranges 17 – 52% for PV, 11 – 51% for onshore wind) as well as more than 36% for offshore wind (range 36 – 44%). For Lithium-Ion batteries used in EVs, there is higher uncertainty about the reduction of cost projections, but in the best-case the additional reductions of LCOS in relation to the assumptions in 2014/15 amount up to 38% in 2025 and 52% in 2030 (ranges +14% – -38% in 2025 and -19% – -52% in 2030).

As CSP does not play an important role in the existing NDCs, we have not considered it in detail in the paper. However, the cost projections for CSP have also displayed substantial cost reductions recently. E.g. IRENA now finds LCOEs of 6 – 14 USD/MWh in 2020 (IRENA Power Cost 2017), while in 2014 the LCOEs were projected to lie in the range of 11 – 19 USD/MWh for 2025 (IRENA Power Cost 2014). Given the benefits of CSP in terms of short-term energy storage, an increase of ambition for CSP is a valuable option for countries with relevant CSP potentials.

Figure 1: Projections for the levelized costs of energy/storage in 2025 and 2030 for renewable electricity and Li-ion batteries before and after COP 21 in Paris



Source: own representation, reprinted from this report's executive summary

The recent reduction of cost projections for RES electricity are mainly based on the recent results of RES auctions around the globe. Theoretically, price bids in auctions should correspond to LCOEs, as the defined support levels are to cover the costs of the auction participants. However, there are certain caveats when auction results are assumed to be equivalent to future generation costs (cf. Fraunhofer ISI et al. 2017):

- "First, auction participants need to estimate future market prices and technology costs when calculating their bids. While they might have better information regarding the development of costs than a central entity, this information is not perfect. They might, therefore, underestimate the necessary revenue levels.
- Secondly, winning an auction does not necessarily mean that plants are built. While recent auctions try to reach high realization rates by penalties and prequalification criteria, in certain cases, less favorable market price and technology cost developments (and thus higher LCOE) might prohibit the realization of plants if penalties are lower than expected losses.
- Thirdly, auction results also reflect the current market competition and firm strategies. For some companies (and given a high competition in the auction) bidding below costs in an auction is a market-entry strategy."

Nevertheless, the worldwide decreasing auction outcomes serve as a strong indicator that costs for RES technologies are steadily decreasing thus providing an important window of opportunity for increasing the level of ambition in the respective NDCs. Photovoltaics and onshore wind power are even undercutting fossil power prices in some world regions. For batteries, the recent announcements of car manufacturers also suggest that recent cost projections are more in line with current expectations.

In the second part of this paper, we have analysed the potential impacts of an increase of ambition of NDCs based on the recent decrease of cost projections for key mitigation technologies, in particular PV, onshore and offshore wind as well as EVs. The analyses have shown that for each GW of RES expansion in an NDC, the same level of investment now can lead to an additional capacity expansion of up to 0.9 GW (range 0.2 – 0.9 GW both in 2025 and 2030). For each million of EVs in an NDC, the reduction of cost projections can result in an additional market uptake of up to 0.93 million of EVs (range 0 – 0.7 million EV in 2025/30 and 0.08 – 0.93 million EV in 2030). For Li-ion batteries, the ranges reflect the various reports evaluated and the existing uncertainty about the time required for cost reductions. While the ranges for RES electricity also partially originate from the differences between the various reports evaluated, they mainly reflect regional differences with regard to RES potentials. In addition, the additional potentials can be limited by regional grid constraints, which have to be dealt with by grid extensions. A more precise picture can be obtained by focussing on specific countries in future research.

With this discussion paper, we have taken a first dive into the potentials to increase the ambition of NDCs based on the reduction of cost projections for key mitigation technologies. To this end, the paper has taken a relatively simple approach to estimate the additional expansion of key mitigation technologies as well as the corresponding emission reductions and fossil fuel cost savings. The results, therefore, can be taken as a first estimate of the resulting order of magnitude, which provide insights about the most promising options. Nevertheless, the revision of NDCs should be based on a more detailed analysis of a specific country's techno-economic potentials and socio-economic needs.

5 Literature

CAT (2018): Climate Action Tracker. Retrieved from https://climateactiontracker.org/

Climate Analytics (2018): “Keeping up with the renewable revolution - updating the NDCs”. Retrieved from http://climate-analytics.org/briefings/keeping-up-with-the-renewable-revolution-updating-the-ndcs.html

Fraunhofer ISI et al. (2017): “Renewable Energy Directive Target”, report funded by the European Parliament, ITRE committee. Retrieved from www.europarl.europa.eu/RegData/etudes/STUD/2018/614201/IPOL_STU(2018)614201_EN.pdf

Gnann, T. (2015): “Market Diffusion of Plug-in Electric Vehicles and their Charging Infrastructure”, Fraunhofer Institute for Systems and Innovation Research ISI, Book Series »Innovation Potentials«. Retrieved from http://publica.fraunhofer.de/documents/N-364342.html

IEA (2017): Global EV outlook 2017. Beyond one million electric cars, International Energy Agency. Retrieved from https://www.iea.org/publications/freepublications/publication/GlobalEVOutlook2017.pdf

IEA ETP (2014): "Energy Technology Perspectives 2014". Retrieved from http://www.iea.org/etp/etp2014/

IEA ETP (2015): "Energy Technology Perspectives 2015". Retrieved from http://www.iea.org/etp/etp2015/

IEA ETP (2017): “Energy Technology Perspectives 2017”. Retrieved from http://www.iea.org/etp2017/summary/

IEA TCEP (2014): "Tracking Clean Energy Progress 2014". Retrieved from http://www.iea.org/etp/tracking2014/

IEA TCEP (2015): "Tracking Clean Energy Progress 2015". Retrieved from http://www.iea.org/etp/tracking2015/

IEA TCEP (2017): "Tracking Clean Energy Progress 2017". Retrieved from http://www.iea.org/etp/tracking2017/

IEA WEO (2016): “World Energy Outlook 2016”. Retrieved from https://webstore.iea.org/world-energy-outlook-2016

IEA WEO (2017): “World Energy Outlook 2017”. Retrieved from https://webstore.iea.org/world-energy-outlook-2017

IRENA Electricity Storage (2017): "Electricity storage and renewables: Costs and markets to 2030". Retrieved from http://www.irena.org/publications/2017/Oct/Electricity-storage-and-renewables-costs-and-markets

IRENA Power Costs (2014): "Renewable Power Generation Costs in 2014". Retrieved from http://www.irena.org/publications/2015/Jan/Renewable-Power-Generation-Costs-in-2014

IRENA Power Costs (2017): "Renewable Power Generation Costs in 2017". Retrieved from http://www.irena.org/publications/2018/Jan/Renewable-power-generation-costs-in-2017

IRENA PTC (2016): "The Power to Change: Solar and Wind Cost Reduction Potential to 2025". Retrieved from http://www.irena.org/publications/2016/Jun/The-Power-to-Change-Solar-and-Wind-Cost-Reduction-Potential-to-2025

Nykvist and Nilsson (2015): "Rapidly falling costs of battery packs for electric vehicles". Nature Climate Change 5, 329–332.

Oeko-Institut et al. (2016): „Erarbeitung einer fachlichen Strategie zur Energieversorgung des Verkehrs bis zum Jahr 2050“, report funded by the German Federal Agency for the Environment. Retrieved from: https://www.umweltbundesamt.de/publikationen/erarbeitung-einer-fachlichen-strategie-zur

Tractebel et al. (2018): “Technology pathways in decarbonisation scenarios”, report from ASSET project funded by the European Commission. Retrieved from https://ec.europa.eu/energy/en/studies/review-technology-assumptions-decarbonisation-scenarios

6 Annex

The LCOEs for utility-scale PV plants from all evaluated studies are shown in Table 7. For the modified range, the lowest projections among the years 2020, 2025 and 2030 were applied to all later years. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. In particular, latest historical years are usually more recent for reports that are more recent. The regional LCOEs shown for WEO 2016 were derived from the CAPEX, OPEX and capacity factors by assuming the same discount rates (7.5% for OECD countries and China, 10% otherwise) and lifetimes (25 years) as in the IRENA reports. The regional LCOEs for 2025 were derived from those in 2020 and 2030 based on linear interpolation. Among the studies evaluated, globally consistent cost projections on the regional level for PV are only available in the special report on renewable energies contained in WEO (2016). For 2030, these are roughly twice as high as the lower range of the global estimates with the exception of Japan, which the LCOEs are 30 – 40% larger than in the other regions.

Table 7: The ranges of LCOEs of PV plants in selected global projections up to 2030

LCOE in USD2015/MWh	Region	Latest historical year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IEA ETP 2014	Global	119	318	97	254	83	214	73	187
IEA TCEP 2014	Global	120	250			83	214		
IEA ETP 2015	Global								
IEA TCEP 2015	Global	97	220			64	166		
IRENA Power Costs 2014	Global	80	360			62	152		
Range 2014-2015	**Global**	**80**	**360**	**97**	**254**	**62**	**214**	**73**	**187**
Modified range 2014-2015	**Global**	**80**	**360**	**80**	**254**	**62**	**214**	**62**	**187**
IRENA PTC 2016	Global	82	311	40	190	30	120		
IRENA Power Costs 2017	Global	68	272						
IEA ETP 2017	Global								
IEA TCEP 2017	Global	107	195	67	158				
IEA WEO 2016	Global	103	267	76	189	66	172	56	155
IEA WEO 2016	Europe	108	108	84	86	74	80	64	73
IEA WEO 2016	USA	110	110	81	82	70	73	59	64
IEA WEO 2016	Japan	177	177	132	134	115	120	98	105
IEA WEO 2016	China	104	104	79	79	69	71	58	62
IEA WEO 2016	India	103	103	76	77	66	69	56	60
IEA WEO 2016	Brazil	132	132	88	89	76	79	64	69

LCOE in USD2015/MWh	Re-gion	Latest histori-cal year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Range 2016-2017	**Global**	**68**	**311**	**40**	**190**	**30**	**172**	**56**	**155**
Modified range 2016-2017	**Global**	**68**	**311**	**40**	**190**	**30**	**172**	**30**	**155**
Ratio of modi-fied ranges	**Global**	**1.2**	**1.2**	**2.0**	**1.3**	**2.1**	**1.2**	**2.1**	**1.2**
Reduction of cost projection	**Global**	**-15%**	**-14%**	**-50%**	**-25%**	**-52%**	**-20%**	**-52%**	**-17%**

The LCOEs for onshore and offshore wind plants from all evaluated studies are shown in Table 8 and Table 9. For the modified range, the lowest projections among the years 2020, 2025 and 2030 were applied to all later years. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. In particular, latest historical years are usually more recent for reports that are more recent. The regional LCOEs shown for WEO 2016 were derived from the CAPEX, OPEX and capacity factors by assuming the same discount rates (7.5% for OECD countries and China, 10% otherwise) and lifetimes (25 years) as in the IRENA reports. The regional LCOEs for 2025 were derived from those in 2020 and 2030 based on linear interpolation. Among the studies evaluated, globally consistent cost projections on the regional level are again available only in the special report on renewable energies contained in WEO (2016). For onshore wind plants, these differ strongly between the regions mainly because of the different capacity factors. However, even the lower range of the regional projections is more than twice as high as the lower range of the latest global projections. For offshore wind plants, the regional variation is lower, but also here the lowest regional projections is more than twice as high as the lower range of the global projections.

Table 8: The ranges of LCOEs and CAPEX of onshore wind plants in selected global projections up to 2030

LCOE in USD2015/MWh	Re-gion	Latest histori-cal year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IEA ETP 2014	Global								
IEA TCEP 2014	Global	45	160			41	118		
IEA ETP 2015	Global								
IEA TCEP 2015	Global	56	132			43	112		
IRENA Power Costs 2014	Global	50	130			45	102		
Range 2014-2015	**Global**	**45**	**160**			**41**	**118**		
Modified range 2014-2015	**Global**	**45**	**160**	**45**	**160**	**41**	**118**	**41**	**118**
IRENA PTC 2016	Global					30	90		

LCOE in USD2015/MWh	Region	Latest historical year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IRENA Power Costs 2017	Global	20	120	20	99				
IEA ETP 2017	Global								
IEA TCEP 2017	Global								
IEA WEO 2016	Global	48	121	46	113	46	106	45	101
IEA WEO 2016	Europe	96	96	89	89	88	88	86	87
IEA WEO 2016	USA	65	65	62	62	61	61	59	60
IEA WEO 2016	Japan	121	121	107	112	102	106	97	99
IEA WEO 2016	China	64	64	63	63	63	63	62	63
IEA WEO 2016	India	95	95	93	93	89	90	85	87
IEA WEO 2016	Brazil	48	48	46	47	46	47	45	46
Range 2016-2017	**Global**	**20**	**121**	**20**	**113**	**30**	**106**	**45**	**101**
Modified range 2016-2017	**Global**	**20**	**120**	**20**	**113**	**20**	**106**	**20**	**101**
Ratio of modified ranges	**Global**	**2.3**	**1.3**	**2.3**	**1.4**	**2.1**	**1.1**	**2.1**	**1.2**
Reduction of cost projection	**Global**	**-56%**	**-25%**	**-56%**	**-30%**	**-51%**	**-11%**	**-51%**	**-15%**

Table 9: The ranges of LCOEs and CAPEX of offshore wind plants in selected global projections up to 2030

LCOE in USD2015/MWh	Region	Latest historical year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IEA ETP 2014	Global								
IEA TCEP 2014	Global	150	340			92	180		
IEA ETP 2015	Global								
IEA TCEP 2015	Global	192	270			130	233		
IRENA Power Costs 2014	Global	140	250			110	190		
Range 2014-2015	**Global**	**140**	**340**			**92**	**233**		
Modified range 2014-2015	**Global**	**140**	**340**	**140**	**250**	**92**	**233**	**92**	**233**

LCOE in USD2015/MWh	Re-gion	Latest histori-cal year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IRENA PTC 2016	Global								
IRENA Power Costs 2017	Global	128	237	59	187				
IEA ETP 2017	Global								
IEA TCEP 2017	Global								
IEA WEO 2016	Global	136	189	115	159	103	145	90	130
IEA WEO 2016	Eu-rope	145	145	120	120	107	111	94	101
IEA WEO 2016	USA	180	180	154	156	132	138	109	120
IEA WEO 2016	Japan	183	183	151	152	131	137	111	121
IEA WEO 2016	China	136	136	115	116	103	107	90	98
IEA WEO 2016	India	189	189	159	159	140	145	120	130
IEA WEO 2016	Brazil	164	164	138	139	122	127	106	115
Range 2016-2017	**Global**	**128**	**237**	**59**	**187**	**103**	**145**	**90**	**130**
Modified range 2016-2017	**Global**	**128**	**237**	**59**	**187**	**59**	**145**	**59**	**130**
Ratio of modi-fied ranges	**Global**	**1.1**	**1.4**	**2.4**	**1.3**	**1.6**	**1.6**	**1.6**	**1.8**
Reduction of cost projection	**Global**	**-9%**	**-30%**	**-58%**	**-25%**	**-36%**	**-38%**	**-36%**	**-44%**

The LCOS' for Li-ion batteries from all evaluated studies are shown in Table 10. For the modified range, the more costly Titanate batteries were excluded, the lowest projections among the years 2020, 2025 and 2030 were applied to all later years, and the highest projection among the years 2020, 2025 and 2030 were applied to all earlier years. The latest historical year refers to the most recent cost estimate in the report that is based on historical market data. In particular, latest historical years are usually more recent for reports that are more recent. For the modified range 2014-15, the lower range in 2025 was applied to 2030 and the upper range for 2030 was applied to 2025.

Table 10: The ranges of LCOS' of Li-Ion batteries in selected global projections up to 2030

LCOS in USD2015/kWh	Type	Latest histori-cal year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
IEA ETP 2014									
IEA ETP 2015									

LCOS in USD2015/kWh	Type	Latest historical year		2020		2025		2030	
		Lower range	Upper range	Lower range	Upper range	Lower range	Upper range	Lower range	Upper range
Nykvist + Nilsson 2015*		300	600	250	500	160	258	200	400
Range 2014-2015		**300**	**600**	**250**	**500**	**160**	**258**	**200**	**400**
Modified range 2014-2015		**300**	**600**	**250**	**500**	**160**	**400**	**160**	**400**
IEA ETP 2017									
IRENA Electricity Storage 2017	LFP	200	840	152	641	109	457	77	326
	NCA	200	840	155	652	113	476	82	347
	NMC	200	840	153	646	110	465	80	335
	Titanate	473	1260	377	1006	285	760	215	574
Range 2016-2017		**200**	**1260**	**152**	**1006**	**109**	**760**	**77**	**574**
Modified range 2016-2017		**200**	**840**	**152**	**641**	**109**	**457**	**77**	**326**
Ratio of modified ranges		**1.5**	**0.7**	**1.6**	**0.8**	**1.5**	**0.9**	**2.1**	**1.2**
Reduction of cost projection		**-34%**	**40%**	**-39%**	**28%**	**-32%**	**14%**	**-52%**	**-19%**