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Future renewable energy costs: solar photovoltaics

How technology innovation is anticipated to reduce the cost of energy from European photovoltaic installations

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Renewable Energies

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How technology innovation is anticipated to reduce the cost of energy from European photovoltaic installations

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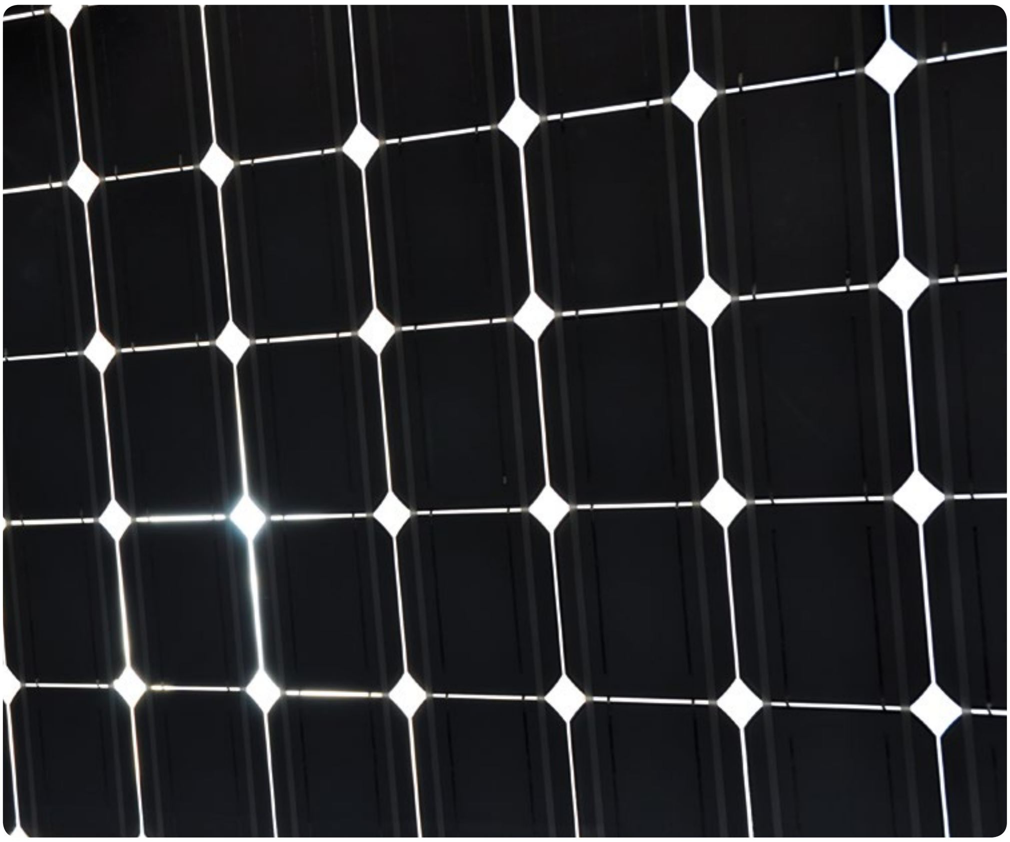

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Executive summary

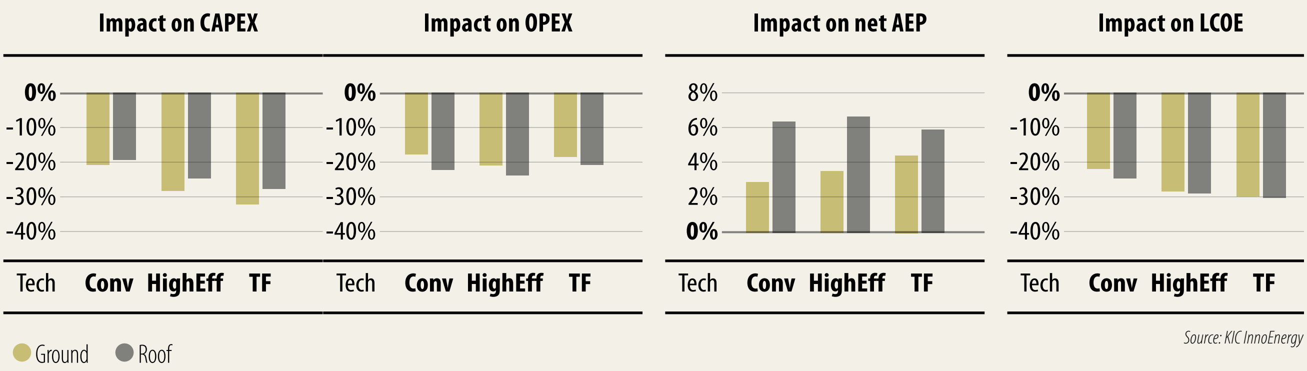
KIC InnoEnergy is developing credible future technology cost models for four renewable energy generation technologies using a consistent and robust methodology. The purpose of these cost models is to enable the impact of innovations on the levelised cost of energy (LCOE) to be explored and tracked in a consistent way across the four technologies. While the priority is to help focus on key innovations, credibility comes with a realistic overall LCOE trajectory. This report examines how technology innovation is anticipated to reduce the cost of energy from European photovoltaic installations over the next 15 years.

For this report, input data is closely based on the KIC InnoEnergy technology strategy and roadmap work stream published in July 2014. The output of that work was an exhaustive and comprehensive set of many discrete innovations and groups of innovations together with their potential impact on known reference plant, built on expert vision and knowledge. For this report, the temporal scope of KIC InnoEnergy technology strategy and roadmap, 5 years ahead, has been extended 15 years according to the methodology set up for this series of report.

At the heart of this study is a cost model in which elements of baseline PV installations are impacted on by a range of technology innovations. These PV installations are defined in terms of the Technology Type (conventional crystalline silicon, high efficiency silicon and thin film), site conditions (ground mounted, 5 MW and below 100 kW, rooftop PV installations on a mid-radiation site: 1,320 kWh/m2/yr), and three points in time at which the projects reach the final investment decision (FID) (2015 (the baseline), 2020 and 2030). In this study, the plants lifetime is set to 20 years for LCOE calculation matters.

The combined impact that technology innovations over the period are anticipated to have on projects with different combinations of Technology Type and Site Type is presented in Figure 0.1.

Figure 0.1 **Anticipated impact of all innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015[1].**



The impacts from PV innovations (excluding transmission, decommissioning, supply chain and finance effects) contribute at least an anticipated 22% reduction in the LCOE. Figure 0.2 shows that more than 80% of the total anticipated technology impact is achieved through seven innovations, mainly in the area of cell manufacturing for crystalline silicon technologies with also relevant contributions related to the improvement of inverters lifetime and frameless module concepts. In the area of thin films, the seven most important innovations account for more than 90% of the total anticipated technology impact, mainly in the area of module manufacturing as well as regarding the extension of inverters lifetime.

The study concludes that LCOE savings of at least 37% are anticipated for conventional c-Si technology, 49% for high efficiency c-Si technology and at least 44% for thin film. The obtained improvements are slightly less important for rooftop installations than for ground mounted PV plants.

More than 30 technology innovations were identified as having the potential to cause a substantial reduction in LCOE through a change in the design of hardware, software or process. Technology innovations are distinguished from supply chain innovations, which are addressed separately. Many more technical innovations are being developed, so some of those described in this report may be superseded by others. Overall, however, industry expectation is that the LCOE will reduce to values included in a range that includes the aggregate level described. In most cases, the anticipated impact of each innovation has been significantly moderated downwards in order to give overall LCOE reductions in line with industry expectations. The availability of this range of innovations with the potential to impact LCOE further gives confidence that the picture described is achievable.

To calculate a realistic LCOE for each scenario, real-world effects of supply chain dynamics, pre-FID risks, the cost of finance, transmission and decommissioning are considered in addition to technology innovations.

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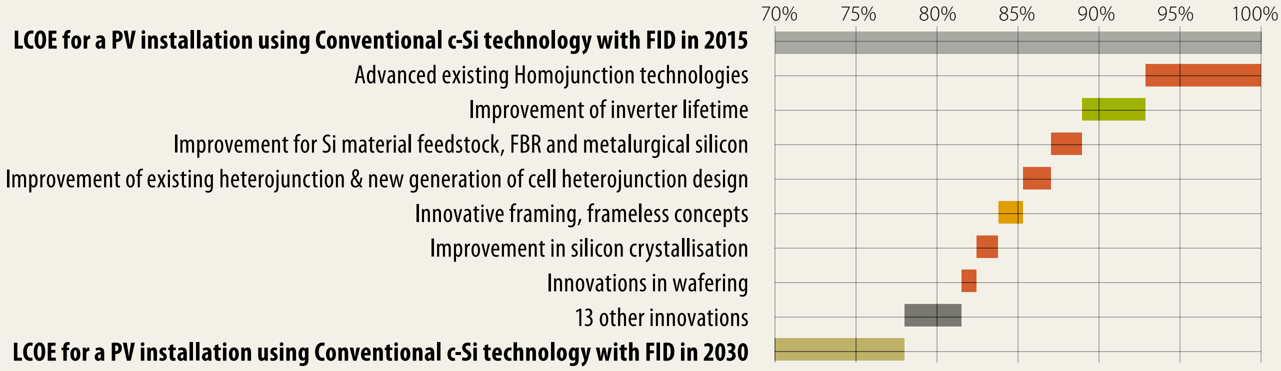
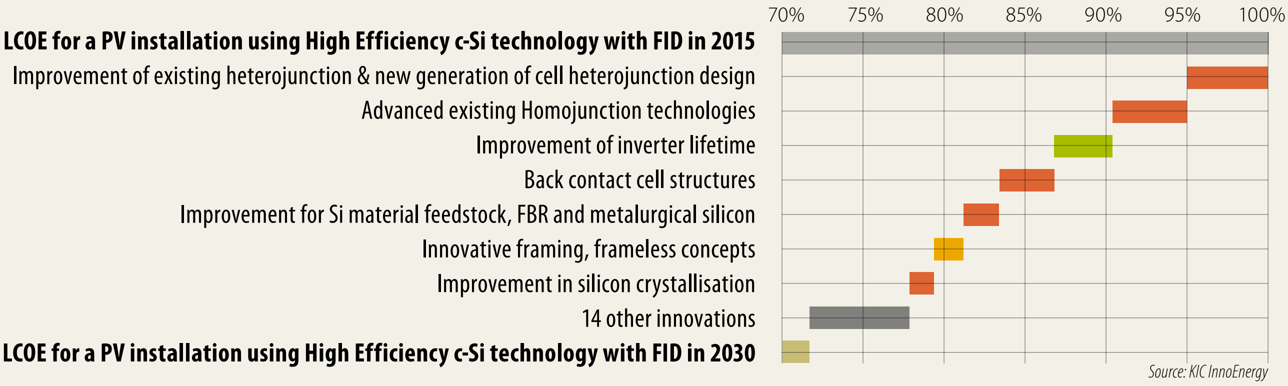
2 Negative values indicate a reduction in the item and positive values indicate an increase in the item. All OPEX figures are per year, from year six. The LCOE calculations are based on the capital expenditure (CAPEX), operational expenditure (OPEX) and annual energy production (AEP) values presented. This is in order to present accurate relative cost changes while only showing the impact of technology innovations. Appendix B provides data behind all figures in this report.

Figure 0.2a **Anticipated impact of technology innovations for a ground mounted PV Installation using Conventional c-Si technology and with FID in 2030, compared with a PV installation with FID in 2015.**



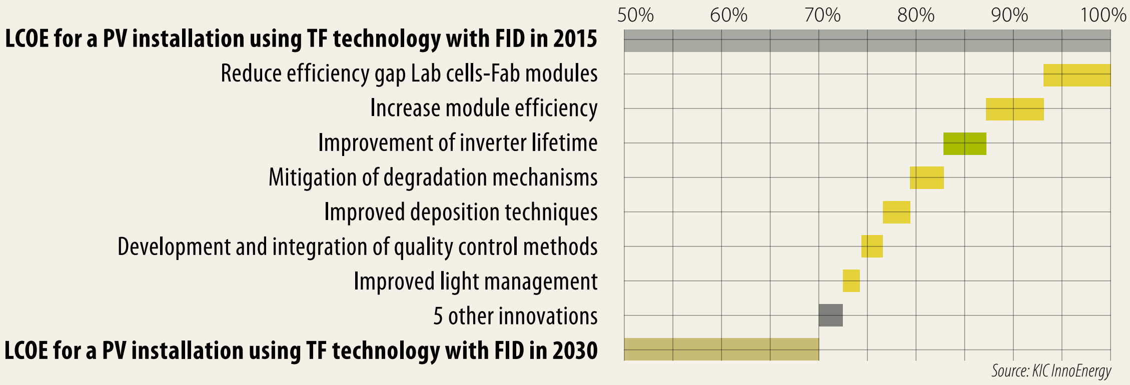
Source: KIC InnoEnergy

Figure 0.2b **Anticipated impact of technology innovations for a ground mounted PV Installation using High Efficiency c-Si technology and with FID in 2030, compared with a PV installation with FID in 2015.**



Source: KIC InnoEnergy

Figure 0.2c **Anticipated impact of technology innovations for a ground mounted PV Installation using TF technology and with FID in 2030, compared with a PV installation with FID in 2015.**



Source: KIC InnoEnergy

In c-Si cell manufacturing, the innovations address the upper part of the value chain, from silicon feedstock, the crystallisation process, wafering and the different cell architectures. The LCOE is anticipated to drop by around 16% for conventional c-Si technology and by around 22% for High Efficiency c-Si during the period.

On top of those cell manufacturing innovations, further innovations affecting module manufacturing are anticipated to reduce the LCOE by 2 to 3.5% in the period depending on the technology and site type. The major benefit here comes from CAPEX reduction with the introduction of frameless concepts as well as alternative backsheet materials and front covers. One challenge for PV module manufacturers will be to reach ever more streamlined processes meaning a step change in verification testing. Focusing on demonstrating long term module reliability to customers is also seen as critical to maintain high levels of competitiveness.

Together, all the innovations in thin film module manufacturing generate about a 25% reduction in the LCOE during the period, mainly through the optimisation of manufacturing processes. Key innovations come together to bridge the gap existing between small scale lab sample production and large volume module manufacturing facilities.

The impact of innovations in inverters is dominated by improvements in lifetime increase, through new designs and the use of new materials to reduce the stress on components. Also significant are the developments in integrated electronics and smart module concepts. Combined, innovations in inverters are anticipated to reduce the LCOE by approximately 5% over the period.

The two biggest innovations in OMS are related to the introduction of smart PV plant monitoring techniques as well as vegetation maintenance reduction techniques. Zero cleaning solutions are also under study in this report although the end impact thereof on LCOE is limited due to a relatively low market penetration. We anticipate the reduction in the LCOE due to such innovations to be approximately 1% during the period.

Overall, reductions in CAPEX per megawatt installed over the period are anticipated to be between approximately 19% and 32% during the period and depending to the technology considered. OMS costs are anticipated to drop by approximately 20% and AEP, at fixed nominal capacity, is anticipated to increase by around 3% to 6%. From a higher baseline, CAPEX reductions are greater for High Efficiency c-Si and TF technologies. This is due to the relatively lower maturity level of these technologies that making the way for more significant improvement.

There are a range of innovations not discussed in detail in this report because their anticipated impact may still be negligible on projects reaching FID in 2030. Amongst these are materials and concepts such as perovskites and concentrated PV. On a PV installation level, improved logistics and installation methods and advanced O&M strategies offer the prospect of further savings, along with changes to PV installation design life. On a system level, there is expected to be significant further progress in terms of voltage increase for generating assets. The unused potential at FID in 2030 of innovations modelled in the project, coupled with this further range of innovations not modelled, suggests there are significant further cost reduction opportunities when looking to 2030 and beyond.

Glossary

AEP. Annual energy production.
Anticipated impact. Term used in this report to quantify the anticipated market impact of a given innovation. This figure has been obtained by moderating the potential impact through the application of various real-world factors. For details on the methodology, see Section 2.
BIPV. Building Integrated Photovoltaics.
BoS. Balance of System: for the purpose of this document, the BoS refers to the support structures and electrical array, see Appendix A. More generally, in photovoltaics, BoS refers to everything other than the PV modules.
Baseline. Term used in this report to refer to "today's" technology, as would be incorporated into a project.
Capacity Factor (CF). Ratio of annual energy production to annual energy production when a plant is generating continuously at rated power.
CAPEX. Capital expenditure.
CPV. Concentrated Photovoltaics.
Conv c-Si. Conventional crystalline silicon technology.
DECEX. Decommissioning expenditure.
FEED. Front end engineering and design.
FID. Final investment decision, defined here as the point in a project's life cycle at which all consent, agreements and contracts required in order to commence construction have been signed (or are at or near the execution stage) and there is a firm commitment by equity holders and, if applicable, of debt finance or debt funders, to provide or mobilise funding to cover the majority of construction costs.
Generic WACC. Weighted average cost of capital applied to generate LCOE-based comparisons of technical innovations across certain scenarios. Different from Scenario-specific WACC.
HighEff c-Si. High Efficiency crystalline silicon technology.
HJ. Heterojunction.
LCOE. Levelised cost of energy, considered here as pre-tax and real in mid-2014 terms. For details of methodology, see Section 2.
MW. Megawatt.
MWh. Megawatt hour.
OMS. Operations, planned maintenance and unplanned (proactive or reactive) service in response to a fault.
OPEX. Operational expenditure.
Other effects. Effects beyond those of power plant innovations, such as supply chain competition and changes in financing costs.
Potential impact. Term used in this report to quantify the maximum potential technical impact of a given innovation. This impact is then moderated through the application of various real-world factors. For details of methodology, see Section 2.
RD&D. Research, development and demonstration.
Scenario. A specific combination of Technology Type and year of FID.
Scenario-specific WACC. Weighted average cost of capital associated with a specific Scenario. Used to calculate real-world LCOE incorporating other effects, ref. Section 2.4.
Technology Type. Term used in this report to describe a specific photovoltaic technological trend for which baseline costs are derived and to which innovations are applied. For details of the methodology see Section 2.
TF. Thin Film.
WACC. Weighted average cost of capital, considered here as real and pre-tax.
WCD. Works completion date.

Table of contents

1. Introduction

1.1. Framework

As a promoter of innovation, KIC InnoEnergy is interested in assessing the impact of visible innovation on the cost of energy from various renewable energy technologies. This analysis is critical to understand where the biggest opportunities and challenges are from a technological point of view.

In publishing a series of consistent analyses of various technologies, KIC InnoEnergy hopes to help in the understanding and definition of innovation pathways that industries could follow to maintain the competitiveness of the European renewable energy sector worldwide. In addition, it seeks to help solve the existing challenges on a European level: reducing energy dependency, mitigating the effects of climate change and facilitating the smooth evolution of the energy mix for the end consumer.

With a time frame extending to 2030, this work includes a range of innovations that may be further from the market than normally expected of KIC InnoEnergy. This constitutes a longer term approach, complementary to KIC InnoEnergy's technology mapping focusing on innovations reaching the market in the short to mid-term (up to five years into the future).

1.2. Purpose and background

The purpose of this report is to document the anticipated future solar photovoltaic cost of energy for projects reaching their financial investment decision (FID) in 2030, through reference to robust modelling of the impact of a range of technical innovations and other effects. This work is based on KIC InnoEnergy's technological strategy and workstream roadmap published in July 2014. This earlier work involved significant industry engagement, as detailed in the above report. This has been enhanced by continued dialogue with players across the industry, right up until publication of this report.

The study does not consider the market share of the different Photovoltaic Technology Types considered. The actual average levelised cost of energy (LCOE) in a given year will depend on the mix of such parameters for projects with FID in that year.

1.3. Structure of this report

This report is structured as follows:

Section 2 Methodology. This section describes the scope of the model, project terminology and assumptions, the process of technology innovation modelling, industry engagement and the treatment of risk and health and safety.

Section 3 Baseline PV plants. This section summarises the parameters in relation to the baseline PV plants for which results are presented. Assumptions in relation to these PV technologies are presented in Section 2.

The following four sections consider each element of PV installation in turn, exploring the impact of innovations on that element.

- **Section 4 Innovations in c-Si PV cell manufacturing.** This section incorporates the innovations impacting the PV value chain from the treatment of raw material up to manufacturing of the cells.
- **Section 5 Innovations in c-Si PV module manufacturing.** This section incorporates innovations affecting the module manufacturing and encapsulation processes.
- **Section 6 Innovations in TF module technology.** This section incorporates innovations affecting TF module manufacturing
- **Section 7 Innovations in inverters.** This section incorporates the innovative trends in inverter technology.
- **Section 8 Innovations in operations, maintenance and service.** This section incorporates all activities after the works completion date (WCD) until decommissioning.
- **Section 9 Summary of the impact of innovations.** This section presents the aggregate impact of all innovations, exploring the relative impact of innovations in different PV elements.

Section 10 Conclusions. This section includes technology-related conclusions.

Appendix A Details of methodology. This appendix discusses project assumptions and provides examples of methodology use.

Appendix B Data tables. This appendix provides tables of the data behind the figures presented in the report.

2. Methodology

2.1. Scope of model

The basis of the model is a set of baseline elements of capital expenditure (CAPEX), operational expenditure (OPEX) and annual energy production (AEP) for a range of different representative PV Technologies on given Site Types, affected by a range of technology innovations. Analyses are conducted at a number of points in time (years of FID), thus describing various potential pathways that the industry could follow, each with an associated LCOE progression.

2.2. Project terminology and assumptions

2.2.1. Definitions

A detailed set of project assumptions was established prior to the modelling. These are shown in Appendix A, covering technical and non-technical global considerations and PV plant-specific parameters.

2.2.2. Terminology

For the purpose of clarity, when referring to the impact of innovation that lowers costs or the LCOE, terms such as reduction or saving are used, and the changes are quantified as positive numbers. When these reductions are represented graphically or in tables, reductions are expressed as negative numbers as they are intuitively associated with downward trends.

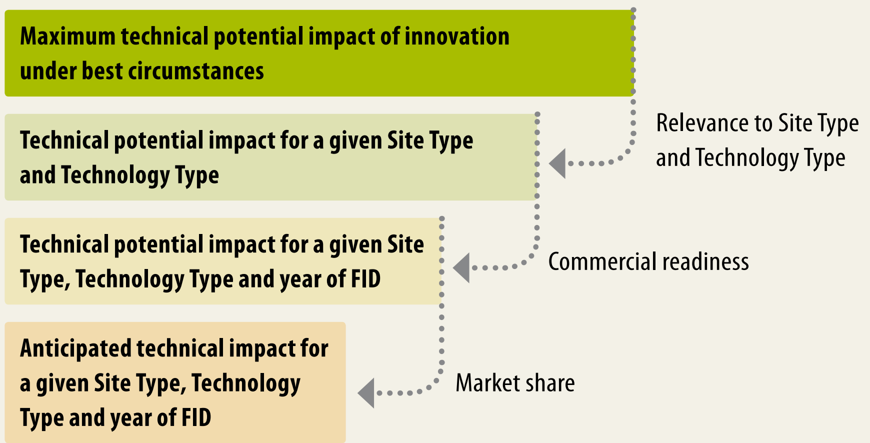
Changes in percentages (for example, losses) are expressed as relative changes. For example, if losses are decreased by 5% from a baseline of 10%, then the resultant losses are 9.5%.

2.3. Technology innovation modelling

The basis of the model is an assessment of the different impact of technology innovations on each of the PV plant elements for each of the baseline PV plants, as outlined in Figure 2.1. This section describes the methodology for the analysis of each innovation in detail. An example is given in Appendix A.

Figure 2.1 **Process to derive the impact of innovations on the LCOE.**

Figure 2.2 **Four stage moderation process applied to the maximum potential technical impact of an innovation to derive the anticipated impact on LCOE.**



2.3.1. Maximum technical potential impact

Each innovation may impact a range of different costs or operational parameters, as listed in Table 2.1. The maximum potential technical impact on each of these is recorded separately for the PV technology and Site Type most suited to the given innovation. Where relevant and where possible, this maximum technical impact considers timescales that may be well beyond the final year of FID.

Frequently, the potential impact of innovation can be achieved in a number of ways, for example through reduced CAPEX or OPEX or increased AEP. The analysis uses the implementation resulting in the largest reduction in the LCOE, which is a combination of CAPEX, OPEX and AEP.

Table 2.1 **Information recorded for each innovation.** (%)

Impact on cost of		Impact on
• PV plant modules	• Development, installation and construction	• Gross AEP
• PV plant inverters		• Performance Ratio
• BoS structures	• PV balance of plant and operation, maintenance and service	
• BoS electrical		

2.3.2. Relevance to technology Type

The maximum potential technical impact of an innovation compared with the baseline may not be achieved for every Technology Type. In some cases, an innovation may not be relevant to a given Technology Type at all. For example, seed selection reducing vegetation treatment is unlikely to have an impact on rooftop installations, so the relevance of this innovation to rooftop scenarios is established as 0%. In other cases, the maximum technical potential may only be achieved for some plant types, with a lower technical potential achieved for others. In this way, relevance indicators for a given Technology Type may be between zero and 100% with, at least one Technology Type having 100% relevance.

This relevance is modelled by applying a factor specific to each Technology Type independently for each innovation. The factor for a given Site Type and Technology Type combination is applied uniformly to each of the potential technical effects derived above.

2.3.3. Commercial readiness

In some cases, the technical potential of a given innovation will not be fully achieved even on a project reaching FID in 2030. This may be for a number of reasons:

- A long research, development and demonstration period for an innovation,
- The technical potential can only be achieved through the ongoing evolution of the design based on feedback from commercial-scale manufacturing and operations, or
- The potential technical impact of one innovation is decreased by the subsequent introduction of another innovation.

This commercial readiness is modelled by defining a factor for each innovation specific to each year of FID, defining how much of the technical potential of the innovation is available to projects reaching FID in that year. If the figure is 100%, this means that the full technical potential will be achieved by the given year of FID. The factor relates to how much of the technical potential is commercially ready for deployment in a project of the scale defined in the baseline.

2.3.4. Market share

Each innovation is assigned a market share for each Technology Type and year of FID. This is the market share of an innovation for a given Technology Type for projects reaching FID in a given year; it is not the market share of the innovation across the whole market that consists of a range of projects with different Technology Types.

The resulting anticipated impact of a given innovation, as this takes into account the anticipated market share on a given Technology Type in a given year of FID, can be combined with the anticipated impact of all other innovations to give an overall anticipated impact for a given Technology Type and year of FID. At this stage, the impact of a given innovation is still calculated in terms of its anticipated impact on each capital, operational and energy-related parameter, as listed in Table 2.1.

These impacts are then applied to the baseline costs and operational parameters to derive the impact of each innovation on LCOE for each Technology Type and year of FID, using a generic weighted average cost of capital (WACC).

The aggregated impact of all innovations on each operational and energy-related parameter in Table 2.1 is also derived, enabling a technology-only LCOE to be derived for each Technology Type and FID year combination.

2.4. Treatment of other effects

In order to derive a real-world LCOE, this technology-only LCOE is factored to account for the impact of various other effects, defined for each combination of Technology Type and year of FID as follows:

- Scenario-specific WACC, taking into account risk (or contingency)
- Transmission fees, covering transmission capital and operating costs and charges related to the infrastructure from input to substation to the transmission network for utility scale PV installations, or connection fees for rooftop and distributed applications.
- Supply chain dynamics, simplifying the impact of the supply chain levers such as competition, collaboration and scale effects.
- The risk that some projects may be terminated prior to FID, thereby inflating the equivalent cost of work carried out in this phase on a project that has been constructed. For example, if only one in three projects reach FID, then the effective contribution to the cost of work energy carried out on projects prior to FID is modelled as three times the actual cost for successful projects, and
- Decommissioning costs, as described in Appendix A.

A factor for each of these effects was obtained from the KIC InnoEnergy technology strategy and workstream roadmap published in July 2014 and the expert consultation taking place afterwards.

The factors are applied as follows:

- Scenario-specific WACC is used in place of the generic WACC to calculate a revised LCOE, and
- Each factor is applied in turn to this LCOE to derive the real-world WACC, that is, a 5% effect to account for transmission costs (the first factor in Table A.4) is applied as a factor of 1.05.

These factors are kept separate from the impact of technology innovations in order to clearly identify the impact of innovations, but they are needed in order to be able to rationally compare LCOE for different scenarios.

The effects of changes in construction time are not modelled.

2.5. Treatment of health, safety and environmental impacts

The health and safety of operational staff is of primary importance in the solar photovoltaic industry. This study incorporates any mitigation required in order to at least preserve existing levels of health and safety into the cost of innovations. Some of the innovations considered to reduce LCOE over time have an intrinsic benefit to health and safety performance, for example the increased reliability of equipment and plant monitoring/remote diagnostics, which provide a more effective and proactive service and hence reduce tasks and time spent working on the installation.

3. Baseline PV installations

The modelling process described in Section 2 serves to:

- Define a set of PV installations and derive costs and energy-related parameters for each,
- Derive the anticipated impact on these same parameters for each baseline PV installations for a given year of FID for each of a range of innovations, and
- Combine the impact of a range of innovations to derive costs and energy-related parameters for each of the baseline PV installations for each year of FID.

This section summarises the costs and other parameters for the baseline PV installations. The baselines were developed from a review of current trends in PV installations in combination with industry engagement. The technical parameters of the baseline PV installations are detailed in Appendix A.

It is recognised that there is significant variability in costs between projects due to both supply chain and technological effects, even within the portfolio of a given PV plant developer. This is particularly true for solar photovoltaics where local supply chain development, financing conditions, site topography and regional customs and practices in PV plant development and operation can vary significantly. As such, any baseline represents a wide spectrum of potential costs and it is accepted that there will be actual projects in operation with LCOEs significantly higher and lower than those associated with these baselines.

The baseline costs presented in Table 3.1, Figure 3.1 and Figure 3.2 are values obtained from cost data currently available from recent studies or reports and are for projects reaching FID in 2015. As such, they incorporate reasonable margins to all value added steps along the value chain without distortion. All the results presented in this report incorporate the impact of technology innovations only, except where the LCOEs are presented in Figure 3.3 and in Section 9, which also incorporate the other effects discussed in Section 2.4.

It is assumed that efficiencies of 15.5% for crystalline silicon, 17.5% for high efficiency crystalline silicon and 13.5% for thin films are commercially available to the market for projects with FID in 2015. "Commercially available" means that it is technically possible to use such technology in volume and that they have been sufficiently prototyped and demonstrated to have a reasonable prospect of sale into a commercial scale project. No assumptions are made in this report about the market share of one specific technology compared with the another.

Table 3.1 **Baseline parameters.**

Type	Parameter	Units	Conv c-Si Ground-15	Conv c-Si Roof-15	HighEff c-Si Ground-15	HighEff c-Si Roof-15	TF Ground-15	TF Roof-15
CAPEX	Modules	€k/MW	576	604.8	722	758.1	481	505.05
	Inverters		65	188	65	188	65	188
	BoS structures		63	130	56	115	73	130
	BoS electrical		11	300	10	266	13	300
	Dev. Constr & installation		164	95	145	95	188	95
OPEX	Operation and maintenance	€k/MW/yr	19	20	19	20	19	20
	Other OPEX		12	-	12	-	14	-
AEP	Gross AEP	MWh/yr/MW	1,656	1,718	1,618	1,678	1,637	1,1658
	Losses (1-PR)	%	20.3	23.2	18.4	21.3	19.4	20.4
	Net AEP	MWh/yr/MW	1,320	1,320	1,320	1,320	1,320	1,320
	Net Capacity Factor	%	15.1	15.1	15.1	15.1	15.1	15.1

Source: KIC InnoEnergy

Figure 3.1 **Baseline CAPEX by element.** *Source: KIC InnoEnergy*

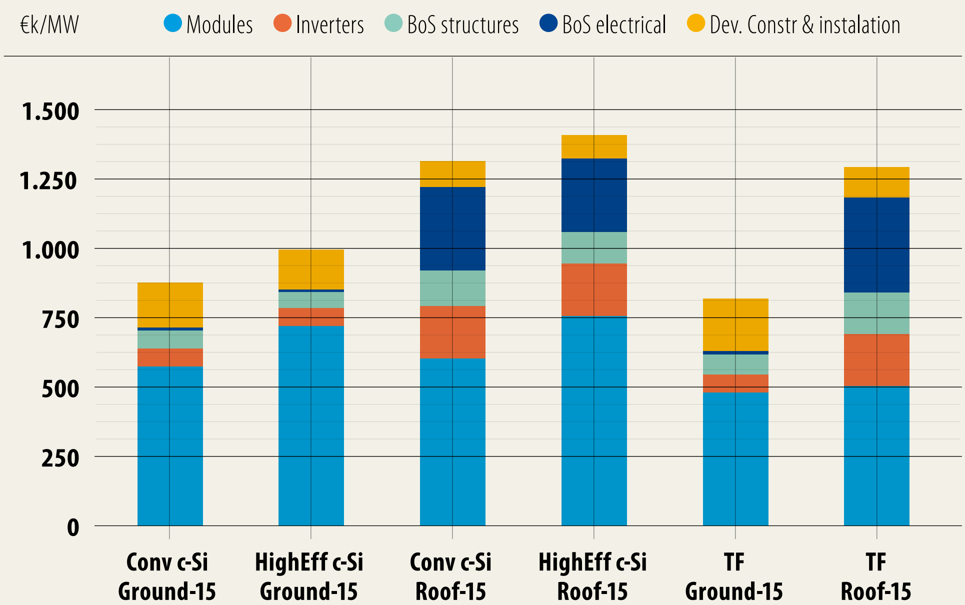
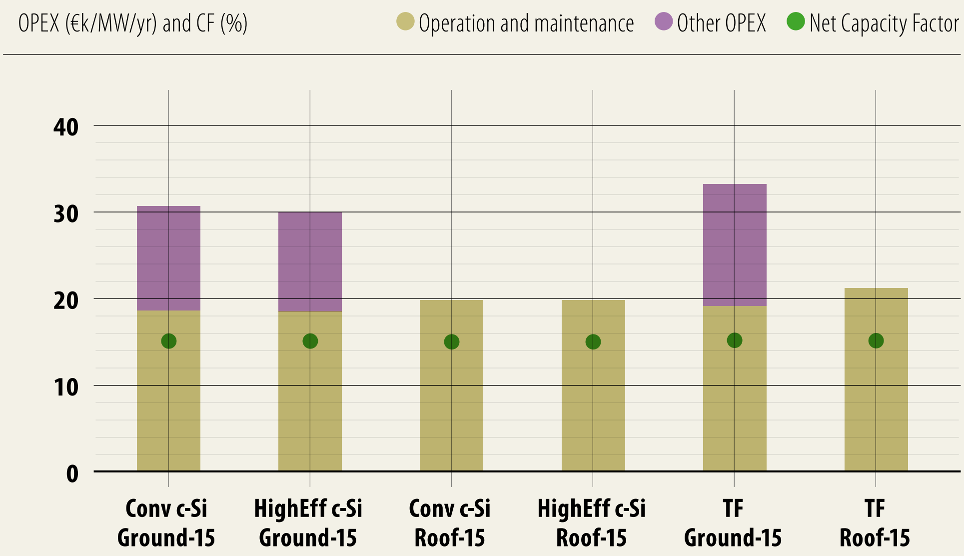


Figure 3.2 **Baseline OPEX and net capacity factor.**

Source: KIC InnoEnergy



Note that for rooftop installations, the other OPEX is equal to zero. This element mainly refers to leasing of land. This value is derived from the assumption that the rooftop installation has been installed and owned by the owner of the building.

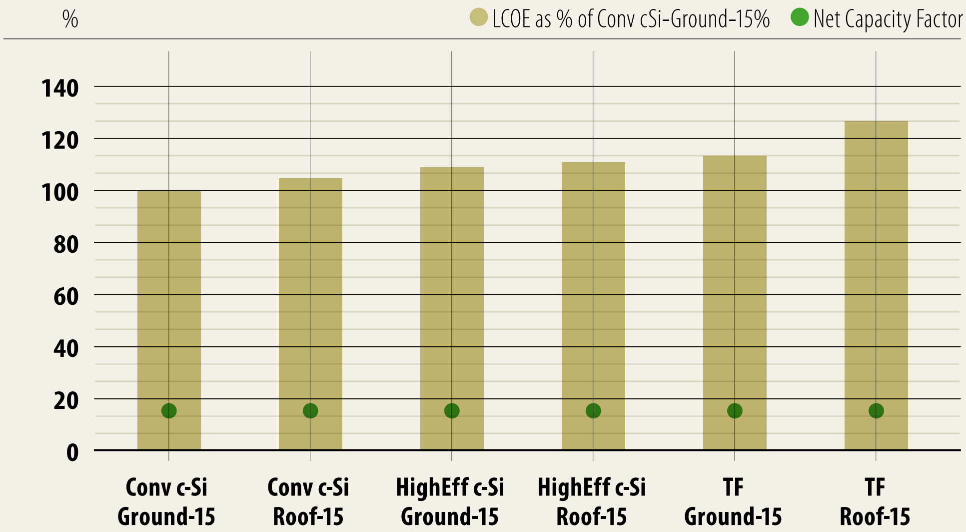
The timing profile of CAPEX and OPEX spent, which is important in deriving the LCOE, is presented in Appendix A.

These baseline parameters are used to derive the LCOE for the baseline PV installations. A comparison of the relative LCOE for each of the baseline PV installations is presented in Figure 3.3.

At this time, Conventional c-Si provides the lowest LCOE of the three Technology Types. High Efficiency c-Si may present an optimised cost structure with lower BoS costs, but it also has the highest module CAPEX costs. TF plants are the cheapest in terms of CAPEX, but their significantly lower power output (lower efficiency) raises the LCOE above the level of Silicon-based technologies.

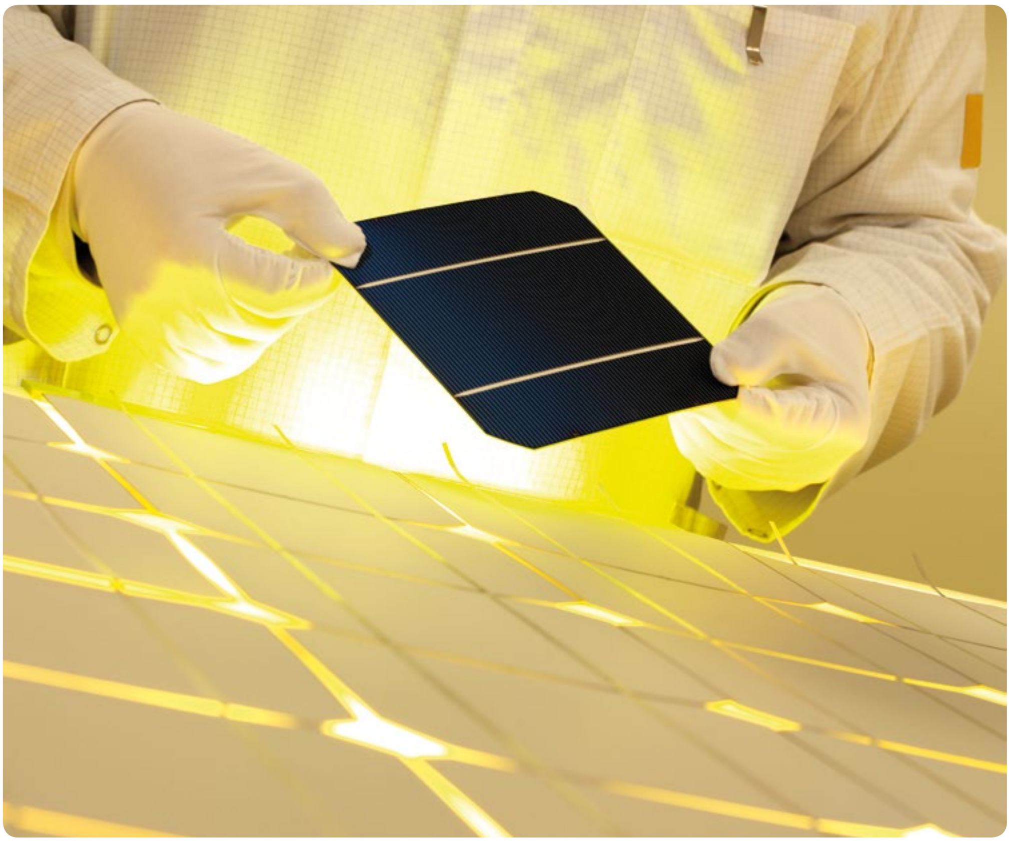
Figure 3.3 **Relative LCOE and net capacity factor for baseline PV installations with other effects incorporated** (Ref. Section 2.4).

Source: KIC InnoEnergy



Methodology note on emerging PV technologies

The cell technology development within the PV sector goes far beyond the three technologies mentioned in this report: Conventional c-Si, High Efficiency c-Si and TF. Other technology trends exist for PV modules, principally based on the use of different types of material and innovative concepts: organic PV, perovskites, dye sensitised, quantum dots, etc. and for specific applications such as CPV, BIPV or portable PV applications. In this report the methodology used is based on the study of PV installations using technology that is already well established in the market and commercially available. "Commercially available" means that it is technically possible to use such technology in volume and that it has been sufficiently prototyped and demonstrated in order to have a reasonable prospect of sale into a commercial scale project as defined in this study.



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4. Innovations in c-Si PV cell manufacturing

4.1. Overview

Innovations in PV cell manufacturing are anticipated to reduce the LCOE by 14% and 17% for Conventional cSi technology and around 22% for High Efficiency c-Si between FID 2015 and 2030. The savings are dominated by important improvements in the efficiency of the module that will in turn affect to other PV installation elements including CAPEX and OPEX.

Figure 4.1 shows that the impact on CAPEX and LCOE is greatest for PV installations using High Efficiency c-Si technology. This is because many of the most significant innovations in this area are only anticipated to be applied to emerging technologies. The Conventional cSi technology primarily benefits from evolutionary changes to current practice and hence shows smaller improvements.

Figure 4.1 **Anticipated impact of PV cell manufacturing innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**

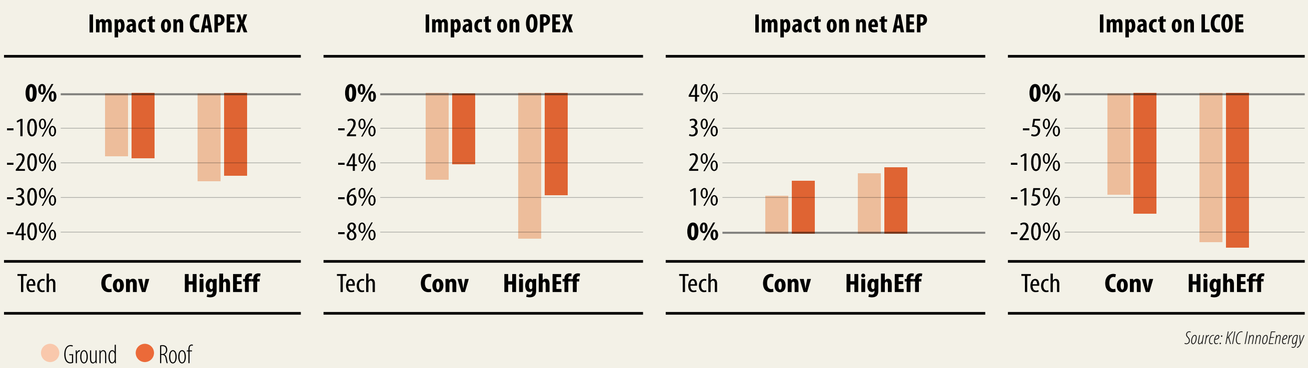
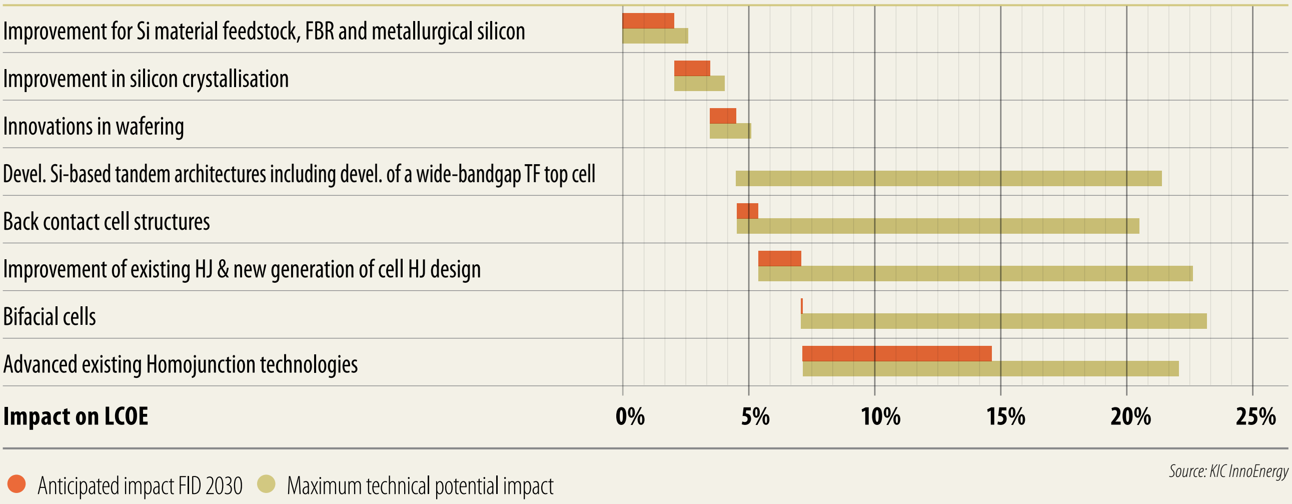


Figure 4.2 to Figure 4.3 and Table 4.1 to Table 4.2 show that the individual innovations with the largest anticipated impact by FID 2030 are mainly incremental innovations in relation to existing processes or manufacturing techniques. New concepts and technologies present high potential impact but their anticipated low market penetration will limit the advantage of these benefits by 2030.

4.1.1. Conventional cSi

Figure 4.2 **Anticipated and potential impact of PV cell manufacturing innovations for a ground mounted utility scale PV plant using conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

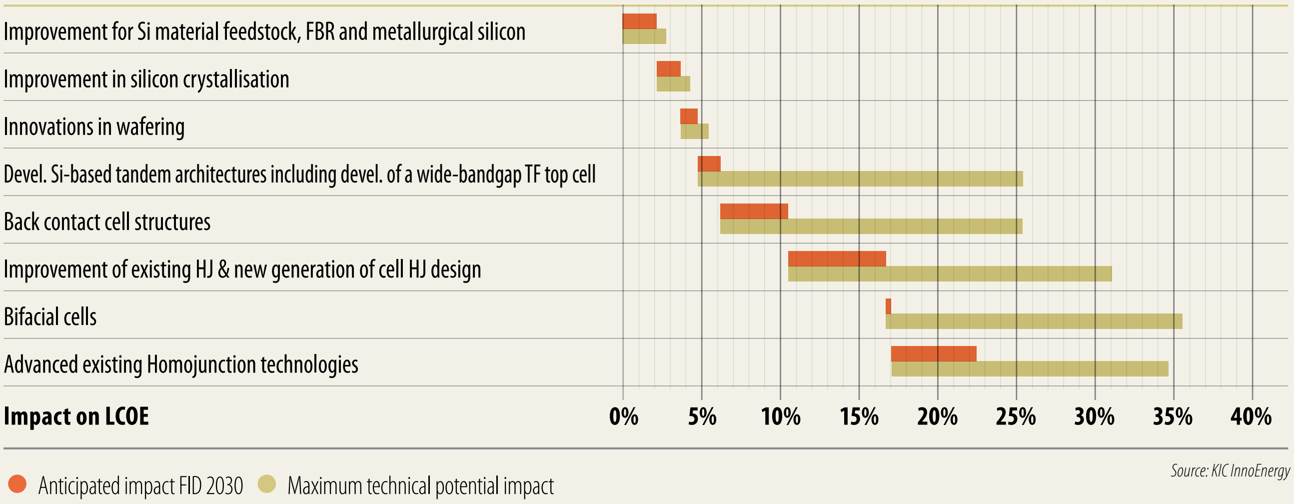
Table 4.1 **Anticipated and potential impact of PV cell manufacturing innovations for a ground mounted utility scale PV plant using conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Source: KIC InnoEnergy

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	OPEX	AEP	LCOE	CAPEX	OPEX	AEP	LCOE
Improvement for Si material feedstock, FBR and metallurgical silicon	4.0%	0.0%	0.0%	2.6%	3.2%	0.0%	0.0%	2.1%
Improvement in silicon crystallisation	3.1%	0.0%	0.0%	2.0%	2.2%	0.0%	0.0%	1.4%
Innovations in wafering	2.5%	0.0%	0.0%	1.7%	1.5%	0.0%	0.0%	1.0%
Development of Si-based tandem architectures including the development of a wide-bandgap TF top cell	18.9%	13.2%	0.0%	16.9%	0.0%	0.0%	0.0%	0.0%
Back contact cell structures	16.7%	9.2%	2.2%	16.0%	0.8%	0.5%	0.1%	0.8%
Improvement of existing heterojunction & new generation of cell heterojunction design	18.2%	9.2%	2.8%	17.3%	1.8%	0.9%	0.3%	1.8%
Bifacial cells	17.3%	7.2%	2.8%	16.1%	0.1%	0.0%	0.0%	0.0%
Advanced existing Homojunction technologies	17.3%	7.2%	1.4%	14.9%	8.6%	3.6%	0.7%	7.5%

4.1.2. High Efficiency c-Si

Figure 4.3 **Anticipated and potential impact of PV cell manufacturing innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

Table 4.2 **Anticipated and potential impact of PV cell manufacturing innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	OPEX	AEP	LCOE	CAPEX	OPEX	AEP	LCOE
Improvement for Si material feedstock, FBR and metallurgical silicon	4.4%	0.0%	0.0%	3.0%	3.5%	0.0%	0.0%	2.4%
Improvement in silicon crystallisation	3.4%	0.0%	0.0%	2.3%	2.4%	0.0%	0.0%	1.6%
Innovations in wafering	2.8%	0.0%	0.0%	1.9%	1.8%	0.0%	0.0%	1.3%
Development of Si-based tandem architectures including the development of a wide-bandgap TF top cell	19.3%	13.2%	0.0%	17.4%	1.3%	0.9%	0.0%	1.2%
Back contact cell structures	17.2%	9.1%	2.0%	16.3%	3.8%	2.0%	0.4%	3.6%
Improvement of existing heterojunction & new generation of cell heterojunction design	18.8%	9.1%	2.4%	17.7%	5.6%	2.7%	0.7%	5.4%
Bifacial cells	18.1%	7.1%	2.4%	16.7%	1.4%	0.5%	0.2%	1.3%
Advanced existing Homojunction technologies	18.1%	7.1%	1.2%	15.7%	5.6%	2.2%	0.4%	4.9%

Source: KIC InnoEnergy

4.2. Innovations

Innovations in PV cell manufacturing span a range of processes from the treatment of raw material to the development of new cell architecture. A subset of the more important of these has been modelled here.

Improvements for Si material feedstock, FBR and metallurgical silicon

Practice today: Nowadays, polysilicon material is obtained mainly through the Siemens Process. Although this technique is under constant improvement, it is highly electricity consuming and the CAPEX is very high.

Innovation: Improvement will involve silicon purification using alternative methods to the Siemens Process. There are two main alternative ways, the Fluidised Bed Reactors (FBR), on the one hand, and metallurgical solar grade silicon on the other. Both techniques are much more energy efficient and could also allow for substantial reduction in the manufacturing process with lower cost of equipment and better manpower optimisation needed for silicon purification, overall affecting the module's CAPEX. Both techniques are being implemented at the demonstration and pre-commercial levels. Still, the capacity to reach the same purification levels as the ones obtained with the Siemens Process must be demonstrated.

Relevance: The innovation is relevant for all sites and Technology Types using silicon as raw material.

Commercial readiness: About one third of the benefits of this innovation will be available for projects with FID in 2020, achieving full readiness (100%) for projects with FID in 2030.

Market share: Market share is anticipated to be about a 40% of projects with FID in 2020. This is anticipated to rise to 80% for projects with FID in 2030.

Improvements in silicon crystallisation

Practice today: Casting for multi-crystalline silicon and Czochralsky for mono-crystalline are the mainstream processes for silicon crystallisation. Both are highly electricity consuming and require long preparation time (for charge and discharge). The losses of raw material mixed with impurities around the edges are significant. The casting technology presents issues related to uniformity along the bricks.

Innovation: The continuous improvement of those techniques allows an increase in the yield together with a reduction in electricity needs, process timing and material losses, all in all impacting on CAPEX. On top of that, the normalisation of the use of reusable crucibles with lower impurities lead to further CAPEX reduction. Beside, improvements in float zone will lead to higher purity and uniformity at lower costs and to substantially higher efficiencies.

Relevance: The innovation is relevant for all sites and Technology Types using silicon as raw material.

Commercial readiness: About one third of the benefit of this innovation will be available for projects with FID in 2020, rising to full readiness (100%) for projects with FID in 2030.

Market share: Market share is anticipated to be about a half of projects with FID in 2020. This is anticipated to rise to 70% for projects with FID in 2030.

Innovations in wafering

Practice today: Current mainstream wafering techniques use wire saw equipment, cleaning processes and sorting and testing systems. The main issues to be addressed are Kerf losses, process control, wafer handling and the mitigation of defects.

Innovation: Wafering technique improvement seek to improve wafer handling, process control and reduce kerf loss in sawing (reduction of wire diameter and sawing pitch) such as the direct wafering method based on epitaxial lift-off. The objective is to aim at thinner and ultra-thin wafers (down to 100 microns) for advanced cell architecture. 100µm wafers are already possible today but the adaptation of cell and laminate processes still has to be improved. All these optimisations lead to module cost reduction. On top of that, the process improvement for fewer defects and high electronic silicon wafers (defects management) which lead to improved efficiency.

Relevance: The innovation is relevant for all sites and Technology Types using silicon as raw material.

Commercial readiness: About one third of the benefits of this innovation will be available for projects with FID in 2020, achieving full readiness (100%) for projects with FID in 2030.

Market share: Market share is anticipated to be about 30% of projects with FID in 2020. This is anticipated to rise to 60% for projects with FID in 2030.

Development of Si-based tandem architectures including the development of a wide-bandgap TF top cell

Practice today: Current Si-based solar cells in the market are single-junction devices, meaning that only one absorber material is used. This results is inevitable transmission and thermalisation losses due to the characteristic bandgap of the material. Further optimisation potential for single-junction cells exists. However, theoretical calculations lead to an upper efficiency limit of 29.4% for c-Si cells although the practical limit might be closer to 27%.

Innovation: Greater efficiency can be achieved through tandem structures, in which two solar cells with different band gaps are stacked. Each solar cell is optimised for a different part of the solar spectrum, thus reducing transmission and thermalisation losses. A promising concept is to use a Si-based bottom cell with a high band gap solar cell on top. For the top cells, Perovskites, III-V materials or Si quantum dots are interesting options. The impact of said improvements in efficiency will lead to CAPEX reduction at the module level and by scale effect to BoS, construction, OPEX and losses.

Relevance: The innovation is relevant for all sites and Technology Types using silicon as raw material.

Commercial readiness: 10% of the benefits of this innovation will be available for projects with FID in 2020, rising to 40% for projects with FID in 2030.

Market share: Market share is anticipated to be 1% for projects using High Efficiency c-Si technology with FID in 2020. This is then anticipated to rise to 17% for those projects with FID in 2030.

Back contact cell structures

Practice today: Standard Si solar cells have a full-area metal contact on the back and metal contacts (fingers and bus bars) on the front side. Contacts on the front side lead to shading losses as light falling on the contacts does not enter the absorbent layers of the solar cell.

Innovation: Novel solar cell structures allow both contacts to be on the back of the solar cell, which reduces shading losses and increases module efficiency affecting CAPEX and OPEX and reducing losses. In some approaches only the busbars are moved to the back (e.g. metal wrap through (MWT)) while others also place the fingers on the back (e.g. emitter wrap through (EWT) and interdigitated back contact cells (IBC)).

Relevance: The innovation is relevant for all sites and Technology Types using silicon as a raw material.

Commercial readiness: About two thirds of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 1% for projects using Conventional c-Si technology and 10% for those using High Efficiency c-Si technology with FID in 2020. This is then anticipated to adjust to 10% and around 22% respectively for projects with FID in 2030.

Improvement of existing heterojunction & new generation of cell heterojunction design

Practice today: In conventional Silicon solar cells a large proportion of charge carrier recombination takes place at the surface. Dielectric passivation layers can reduce the recombination rates (e.g. PERC), however, surface recombination will still play a major role.

Innovation: An advanced approach to reducing recombination at metal semiconductor interfaces is in the application of heterojunction. For example, a wider band gap semiconductor layer can be deposited on the c-Si base. One option for such a material is the depositing of amorphous silicon.

Relevance: The innovation is relevant for all sites and Technology Types using High-Efficiency silicon only.

Commercial readiness: About half to two thirds of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 2% for projects using Conventional c-Si technology and 20% for installations with High Efficiency c-Si technology with FID in 2020. This is then anticipated to rise to 20% and 30% respectively for projects with FID in 2030.

Bifacial cells

Practice today: State-of-the-art silicon solar cells have a backsheet that covers the complete back side of the cell. Hence light can only enter the front of the solar cell.

Innovation: Bifacial solar cells allow light to enter the front and the back sides. Instead of a full back contact they typically employ a front surface design similar to that used in industry-standard screen-printed solar cells, with the major difference being the structure of the rear surface contact. Rather than cover the entire back surface with a reflective aluminium contact, a 'finger' grid is used in its place in order to allow sunlight through the rear. This feature increases the efficiency of the cell which leads to reduced CAPEX per module, BoS and construction and OPEX, as well as reduced loss.

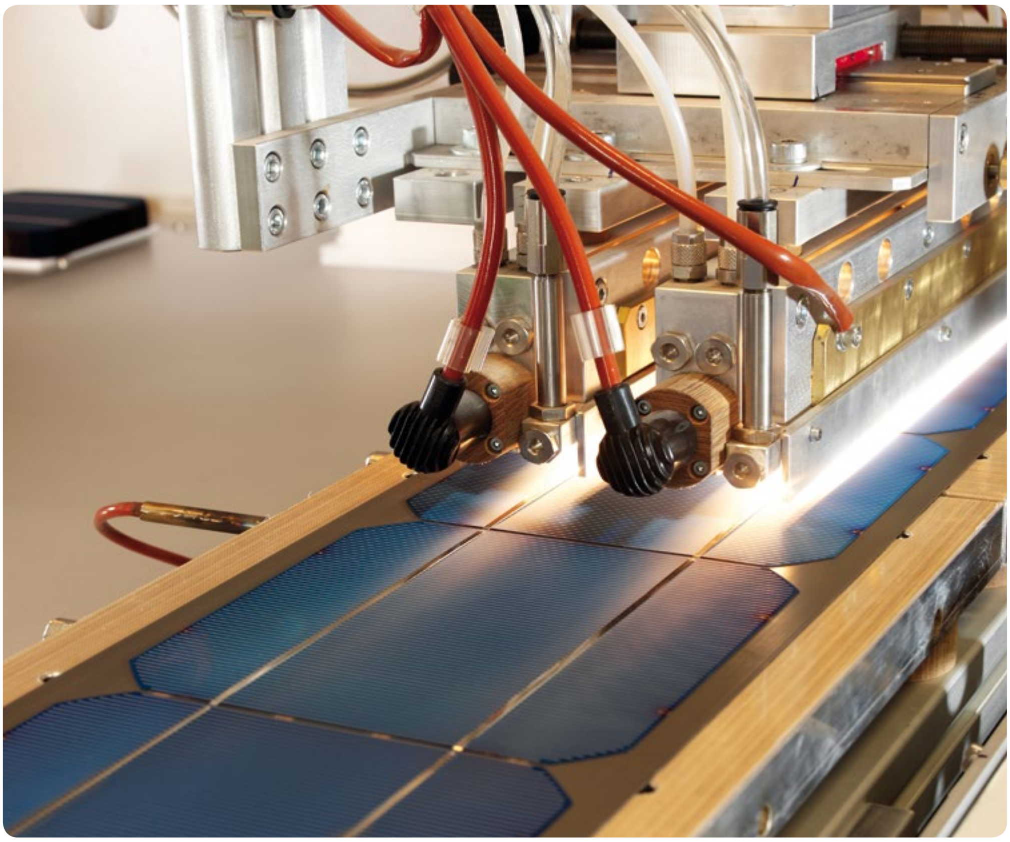
Relevance: The innovation is 20% relevant for conventional silicon technology while fully relevant for high efficiency technology in ground mounted large PV installations. When considering rooftop installations, relevance drops to 5%.

Commercial readiness: About half of the benefits of this innovation will be available for projects with FID in 2020, rising to 75% for projects with FID in 2030.

Market share: Market share is anticipated to be negligible for projects using Conventional c-Si and 4% for High Efficiency c-Si with FID in 2020. This is then anticipated to rise to 2% and 10% respectively for projects with FID in 2030.

Advanced existing homojunction technologies

Practice today: The workhorse of the PV industry has been the screen-printed Al-BSF cell on p-type silicon. It has an aluminium rear contact, leading to moderate passivation of the back side (back-surface field, BSF). The front typically has screen-printed Ag contacts, an anti-reflective coating and a pyramid structure for light guiding. The device has been improved over the years through evolutionary steps, like improved metal pastes and printing processes, better front surface passivation and optimised emitter layers.
Innovation: The limiting factor of the Al-BSF cell is the carrier recombination on the front and back. In addition, the internal reflection on the back is comparably low. Advanced homojunction technologies therefore include improved passivation on the back (e.g. partial rear contact, PRC) or on the front and rear side (PERC, PERL, LBSF, PERT). Several of these approaches are already in the advanced stages of development or even already on the market. These concepts imply the implementation of new production methods the cost of which is offset by increased efficiency at the module level which, all in all, leads to a module CAPEX improvement affecting BoS, construction, OPEX and losses.
Relevance: The innovation is relevant for all sites and Technology Types using silicon as raw material.
Commercial readiness: About half of the benefit of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.
Market share: Market share is anticipated to be 40% for projects using Conventional c-Si technology and 45% for projects using High Efficiency c-Si technology with FID in 2020. This is then anticipated to rise to 50% for project using Conventional c-Si technology and fall to 31% for projects using High Efficiency c-Si technology with FID in 2030.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5. Innovations in c-Si PV module manufacturing

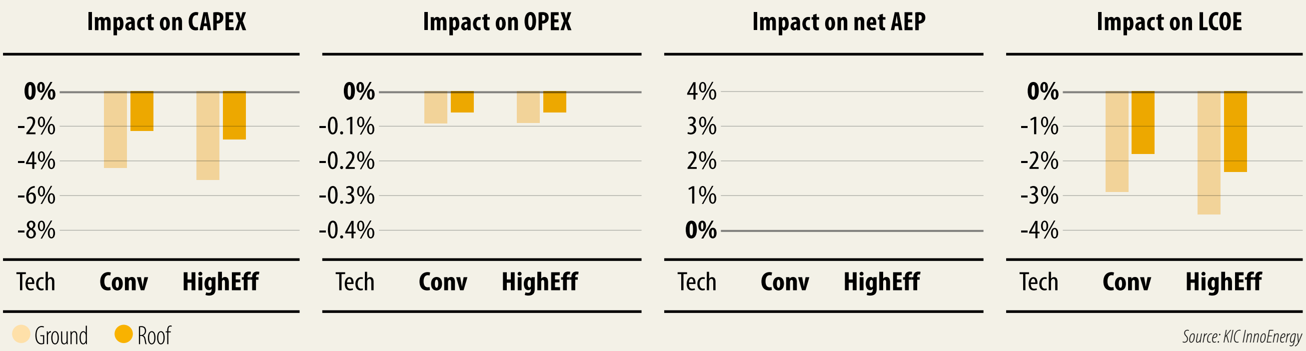
5.1. Overview

Innovations in the area of PV module manufacturing are anticipated to reduce the LCOE by around 2.5% between FID 2015 and 2030 for Conventional c-Si and 4% for High Efficiency c-Si. The savings are dominated by improvements in CAPEX, and additionally savings are also notable within OPEX.

Figure 5.1 shows that the impact on CAPEX, OPEX and LCOE is very much similar for Conventional c-Si and High Efficiency c-Si technologies. This is due to the fact that innovations in module production mostly apply equally to both technologies.

Figure 5.2 to Figure 5.3 and Table 5.1 to Table 5.2 show that the innovation anticipated to have the biggest impact for both Conventional c-Si and High Efficiency c-Si is the improvement of

Figure 5.1 **Anticipated impact of PV module manufacturing innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**

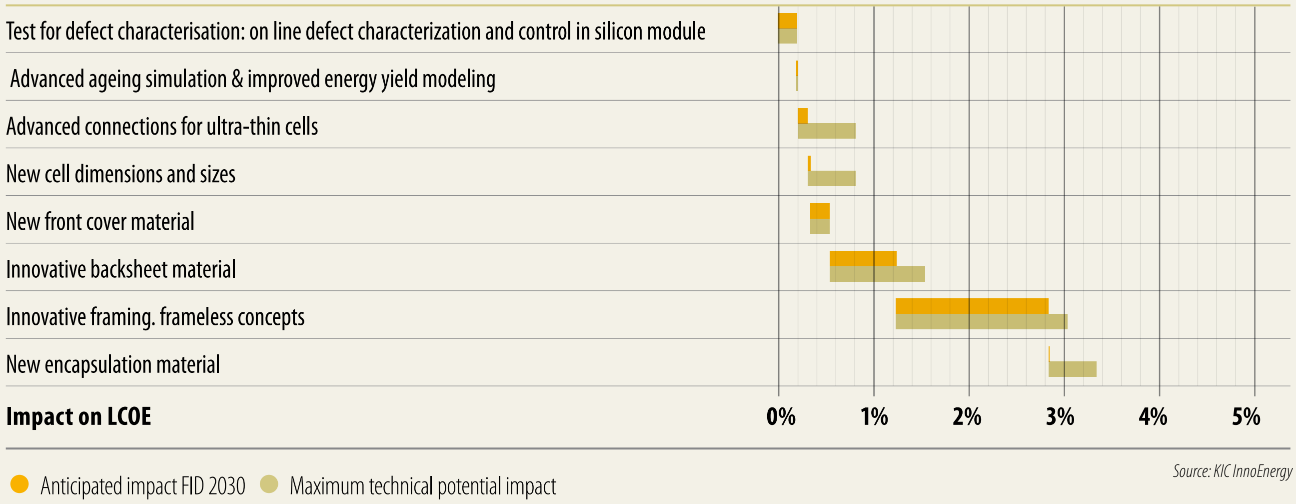


Source: KIC InnoEnergy

framing and especially the frameless technology that will allow interesting CAPEX reduction through savings in material.

5.1.1. Conventional c-Si

Figure 5.2 **Anticipated and potential impact of PV module manufacturing innovations for a ground mounted utility scale PV plant using Conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

Table 5.1 **Anticipated and potential impact of PV module manufacturing innovations for a ground mounted utility scale PV plant using Conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	OPEX	AEP	LCOE	CAPEX	OPEX	AEP	LCOE
Test for defect characterisation: on line defect characterization and control in silicon module	0.4%	0.0%	0.0%	0.2%	0.3%	0.0%	0.0%	0.2%
Advanced ageing simulation & improved energy yield modeling	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Advanced connections for ultra-thin cells	0.9%	0.0%	0.0%	0.6%	0.2%	0.0%	0.0%	0.1%
New cell dimensions and sizes	0.3%	0.7%	0.0%	0.5%	0.0%	0.0%	0.0%	0.0%
New front cover material	0.3%	0.0%	0.0%	0.2%	0.3%	0.0%	0.0%	0.2%
Innovative backsheet material	1.5%	0.0%	0.0%	1.0%	1.1%	0.0%	0.0%	0.7%
Innovative framing, frameless concepts	2.8%	0.0%	0.0%	1.8%	2.5%	0.0%	0.0%	1.6%
New encapsulation material	0.4%	0.7%	0.0%	0.5%	0.0%	0.1%	0.0%	0.0%

Source: KIC InnoEnergy

5.1.2. High Efficiency c-Si

Figure 5.3 **Anticipated and potential impact of PV module manufacturing innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

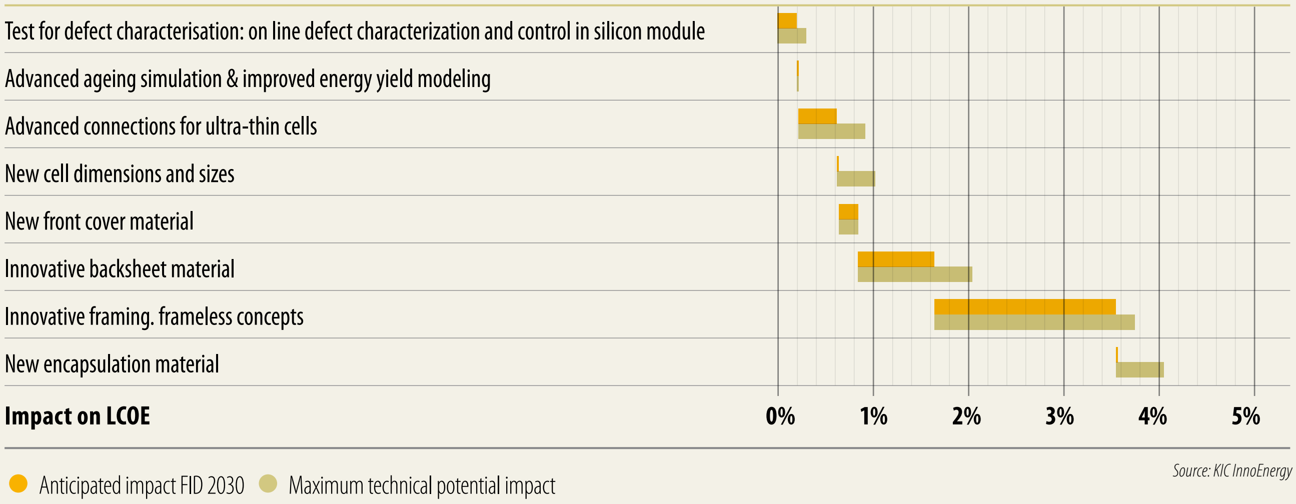


Table 5.2 **Anticipated and potential impact of PV module manufacturing innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Test for defect characterisation: on line defect characterization and control in silicon module	0.4%	0.0%	0.0%	0.3%	0.3%	0.0%	0.0%	0.2%
Advanced ageing simulation & improved energy yield modeling	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Advanced connections for ultra-thin cells	1.0%	0.0%	0.0%	0.7%	0.6%	0.0%	0.0%	0.4%
New cell dimensions and sizes	0.3%	0.7%	0.0%	0.4%	0.0%	0.0%	0.0%	0.0%
New front cover material	0.4%	0.0%	0.0%	0.2%	0.3%	0.0%	0.0%	0.2%
Innovative backsheet material	1.7%	0.0%	0.0%	1.2%	1.2%	0.0%	0.0%	0.8%
Innovative framing, frameless concepts	3.0%	0.0%	0.0%	2.1%	2.7%	0.0%	0.0%	1.9%
New encapsulation material	0.4%	0.7%	0.0%	0.5%	0.0%	0.1%	0.0%	0.0%

Source: KIC InnoEnergy

5.2. Innovations

Innovations in PV module manufacturing are primarily focused on the different components of the module and on the techniques to evaluate quality in the production process.

Tests for defect characterization: on line defect characterisation and control in silicon module

Practice today: In module manufacturing, the detection of defects and failures usually happens at the end of the production line when the modules are tested (IV curve). Together with quality, running such detection techniques at the end of the manufacturing chain means considerable costs when the modules are rejected.

Innovation: Integration of high throughput and controls for industrial processing and quality assurance during production will reduce costs, increase the manufacturing yield and reduce the quality risks, assuring performance and reducing the emergence of these defects and failures in the installations. This innovation basically combines a necessary characterisation of these defects and development and implementation of control during production. Examples of said techniques are: EL tests, hot spot tests and new production line tests for quality assurance before lamination.

Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.

Commercial readiness: About 25% of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 20% for projects with FID in 2020. For projects with FID in 2030, the market share is anticipated to rise to 70%.

Advanced ageing simulation & improved energy yield modelling

Practice today: It is currently well-accepted that the lifetime of silicon modules is at least 25 years – provided quality materials and good workmanship are employed. Within this lifetime it is also accepted that there will be degradation in the modules affecting the efficiency and therefore the performance of the PV system, but exact figures for this degradation are not known. Manufacturers give warranties ensuring degradation of less than 10% after 10 years and less than 20% after 20 years. These values are based on the existing experience gained with real modules producing energy for more than 30 years. Nevertheless, these modules were tested under different conditions and with different equipment than those available today. This makes it difficult to make consistent comparisons.

Innovation: It is extremely important to know the behaviour of the modules, lifetime and degradation with accuracy to know in advance what the performance of a PV system over time will be. This can be done through advanced ageing simulation to better understand degradation mechanisms and real lifetime up to a minimum of 30 years. All in all, this innovation allows for better understanding of the losses during module lifetime and more generally, the modules' behaviour over their lifetime (performance, degradation, losses, etc.). This could affect the design of the installations at some point meaning some improvement in CAPEX. Other effects on bankability (WACC reduction) or similar are not modelled here.

Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.

Commercial readiness: About 25% of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 20% for projects with FID in 2020. For projects with FID in 2030, the market share is anticipated to rise to 70%.

Advanced connections for ultra-thin cells

Practice today: PV module metallisation normally includes a certain number of busbars, usually 3. The busbars are responsible for the power collection from the cells but at the same time generate shading losses affecting the efficiency of the module.
Innovation: The trends in metallisation are towards the reduction of the photosensitive area covered by the metallisation. This is achieved by increasing the number of busbars, 4 to 5, and reducing their dimensions. Further techniques suggest directly eliminating said busbars and developing so-called busbarless designs such as multi-wire concept. Overall, this innovation will allow lower cell to module efficiency losses. The main impact would be in relation to CAPEX, obtained through increased efficiency and thanks to the savings in materials, all this implying that new metallisation techniques are more cost-efficient.
Relevance: The relevance of this innovation for traditional silicon technology is 40% while it is fully relevant for high-efficiency silicon technology.
Commercial readiness: About 30% of the benefits of this innovation will be available for projects with FID in 2020, rising to 70% for projects with FID in 2030.
Market share: Market share is anticipated to be around 70% for projects with FID in 2020. For projects with FID in 2030, the market share is anticipated to rise to 80%.

New cell dimension and size

Practice today: Today standard cell size is a square of 6 inches by 6 inches.
Innovation: Using half-sized cells will impact at the module level, with some variation in module dimensions on the one hand, but especially with much lower cell current allowing for a reduction in metallisation. A modelled increase in production costs coupled with a reduction in the use of material will lead to an overall reduction of CAPEX and increased efficiency resulting in relative CAPEX optimisation in BoS and OPEX.
Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.
Commercial readiness: About 10% of the benefits of this innovation will be available for projects with FID in 2020, rising to 50% for projects with FID in 2030.
Market share: As an emerging technology it is considered that the market penetration for projects with FID 2020 will be negligible, rising to a 10% market share for projects with FID in 2030

New front cover material

Practice today: The vast majority of manufacturers use a traditional glass front cover using anti reflective coated glass with a thickness of 3.2 mm.
Innovation: The innovation basically consists of the development of the use of thinner glass, in the range of 2mm and even 1.5mm, which could achieve lower prices than the existing ones leading to a reduction in CAPEX and resulting in better transmittance leading to greater efficiency.
Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.
Commercial readiness: About 70% of the benefits of this innovation will be available for projects with FID in 2020, rising to 50% for projects with FID in 2030.
Market share: As glass use is standardised, it is considered that the market penetration for projects with FID 2020 will be set to 80% and market share for projects with FID in 2030 will rise to 100%.

Innovative backsheet materials

Practice today: The current backsheet market is dominated by TPA and PET materials.
Innovation: Innovations will come in most cases through the improvement of the existing materials, basically decreasing costs and improving the reliability thereof. Aside from this, another option is to replace traditional backsheets with glass to develop the so called "glass-glass" modules, resulting in a positive impact on CAPEX through cost reduction and the corresponding increase in module efficiency in turn affecting the rest of the installation.
Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.
Commercial readiness: About 65% of the benefits of this innovation will be available for projects with FID in 2020, rising to 80% for projects with FID in 2030.
Market share: It is considered that the market penetration for projects with FID 2020 will be set to 80% and market share for projects with FID in 2030 will rise to 100%.

Innovative framing, frameless concepts

Practice today: Aluminium frames are mainstream technology to seal and protect the perimeter of modules.
Innovation: The innovation principally consists of improved frameless techniques that dramatically reduce the use of material without affecting the module lifetime. The impact on CAPEX is straightforward. It is considered that this innovation is not fully suitable for rooftop applications as it may require too much care in the module handling.
Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material. There is a difference between ground mounted PV installations where this innovation is expected to be 100% relevant compared with rooftop installations where the relevance will only reach 40%.
Commercial readiness: About 80% of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.
Market share: It is considered that the market penetration for projects with FID 2020 will be set to 80% and market share for projects with FID in 2030 will raise to 100%.

New encapsulation material

Practice today: EVA is the current mainstream encapsulation material with a very high market share.
Innovation: Several materials have been shown to present interesting characteristics that could replace EVA. Beyond these, the one analysed here is silicone as an innovative encapsulation material. The main anticipated benefits of silicone are linked to easier treatment involving substantially lower amounts of electricity and the potential to generate some efficiency improvements compared with EVA. These effects result in CAPEX reductions.
Relevance: The innovation is equally relevant to all Technology Types using silicon as raw material.
Commercial readiness: About 20% of the benefits of this innovation will be available for projects with FID in 2020, rising to 50% for projects with FID in 2030.
Market share: It is considered that the market penetration for projects with FID 2020 will be set to 3% and market share for projects with FID in 2030 will rise to 10%.

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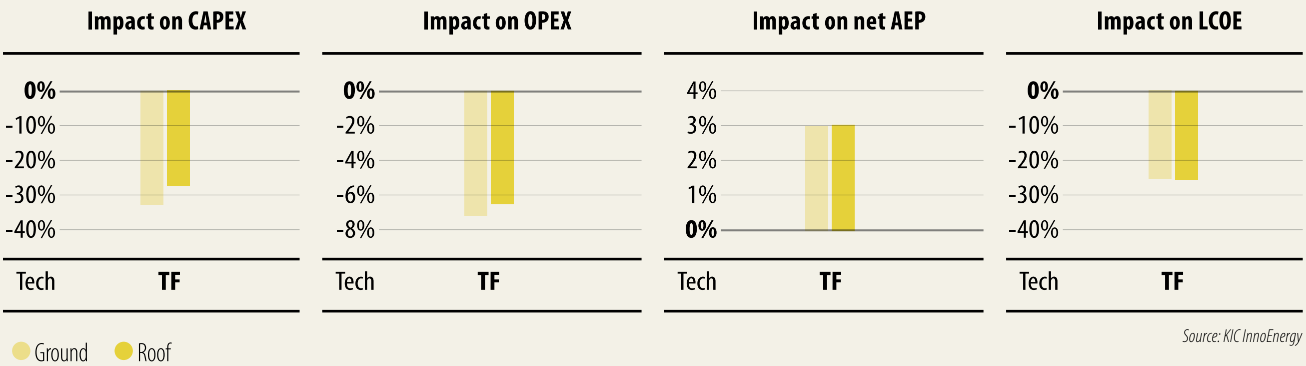
6. Innovation in TF module technology

6.1. Overview

Innovations in TF modules are anticipated to reduce the LCOE by around 25% for TF technology between FID 2015 and 2030. The savings are dominated by important improvements in efficiency of the module that will in turn affect other PV installation elements including CAPEX and OPEX.

Figure 4.1 shows that the impact on CAPEX is the greatest contributor to the LCOE reduction for PV installations using TF technology. This impact comes together with an important increase in efficiency that will have a cascade effect on all project elements within CAPEX and OPEX.

Figure 6.1 **Anticipated impact of TF module innovations with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**

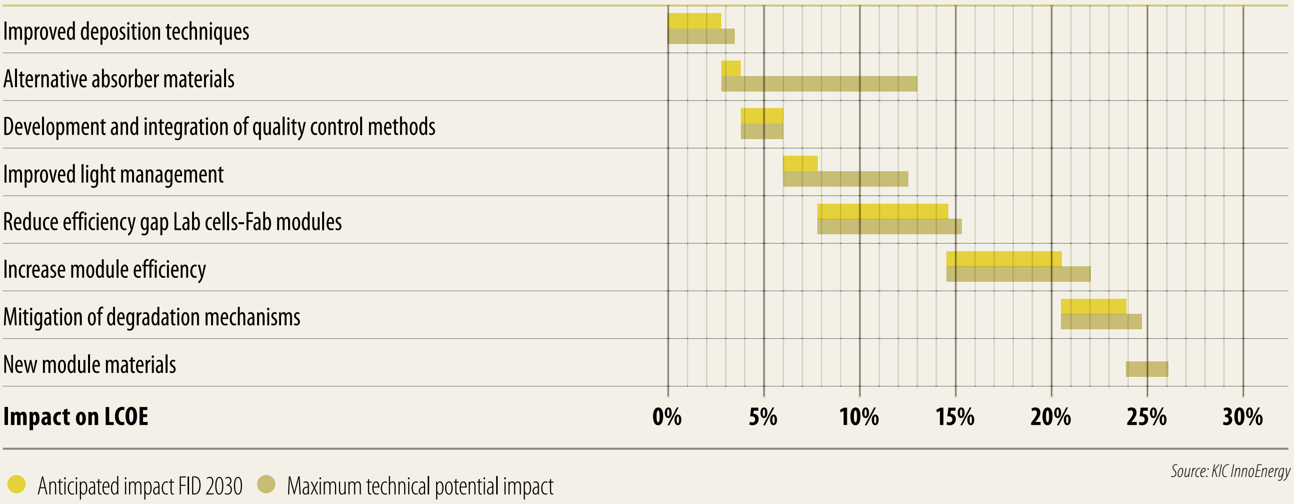


Source: KIC InnoEnergy

Figure 6.2 and Table 6.1 show that the individual innovations with the largest anticipated impact by FID 2030 are mainly incremental innovations of existing processes or manufacturing techniques. New and alternative concepts present high potential impact but their anticipated limited commercial readiness and low market penetration are obstacles to taking advantage of those benefits by 2030.

6.2. Innovations

Figure 6.2 **Anticipated and potential impact of TF module innovations for a ground mounted PV installation using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

Table 6.1 **Anticipated and potential impact of TF module innovations for a ground mounted PV installation using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Improved deposition techniques	4.5%	2.0%	0.0%	3.5%	3.6%	1.6%	0.0%	2.8%
Alternative absorber materials	13.3%	5.2%	0.0%	10.2%	1.3%	0.5%	0.0%	1.0%
Development and integration of quality control methods	3.5%	0.0%	0.0%	2.2%	3.5%	0.0%	0.0%	2.2%
Improved light management	10.6%	0.0%	0.0%	6.5%	3.0%	0.0%	0.0%	1.8%
Reduce efficiency gap Lab cells-Fab modules	10.8%	2.2%	0.0%	7.5%	9.7%	2.0%	0.0%	6.8%
Increase module efficiency	10.8%	2.2%	0.0%	7.5%	8.7%	1.7%	0.0%	6.0%
Mitigation of degradation mechanisms	0.0%	1.7%	3.7%	4.2%	0.0%	1.4%	3.0%	3.4%
New module materials	3.5%	0.0%	0.0%	2.2%	0.0%	0.0%	0.0%	0.0%

Source: KIC InnoEnergy

Innovations in PV cell manufacturing span a range of processes from the treatment of the raw material to the development of new cell architecture. A subset of the more important of these has been modelled here.

Improved deposition techniques

Practice today: There is still a big gap in efficiency between small-area lab cells and large-area industrial modules for both CIGS and CdTe technology. One reason for this are the homogeneity problems of large-area deposition tools/processes currently used which result in varying properties of the layers which in turn leads to lower module efficiencies. This limits the size of modules that can currently be produced at high efficiency.
Innovation: By improving deposition techniques, functional layers with optimal properties can be deposited homogeneously on larger areas leading to greater efficiency and allowing larger module areas to be developed. This will improve throughput which will lead to a CAPEX reduction for modules with a cascade effect on BoS and OPEX
Relevance: The innovation is relevant for all TF Technology Types.
Commercial readiness: About 20% of the benefits of this innovation will be available for projects with FID in 2020, rising to 80% for projects with FID in 2030.
Market share: Market share is anticipated to be as high as 80% for projects with FID in 2020. This is then anticipated to rise to 100% for projects with FID in 2030.

Alternative absorber materials

Practice today: Currently the main absorber materials used in industry for thin film modules are CIGS and CdTe. The main alternatives being investigated are CZTS (kesterites) and perovskites. The maximum lab efficiencies obtained for these technologies for small cells are ~11% (CZTS) and ~20% (perovskites),
Innovation: The absorber material in commercial TF modules is replaced by the new absorber material (mentioned above), leading to greater efficiency and/or lower production costs. Moreover, scarce elements such as Te and In should not be used in these novel materials, allowing for much lower limitations for the deployment of said technologies. The CAPEX of modules will be reduced thanks to the use of cheaper material and will also be affected by increased efficiency, in turn affecting BoS and OPEX.
Relevance: The innovation is relevant for all TF Technology Types.
Commercial readiness: About 10% of the benefits of this innovation will be available for projects with FID in 2020, rising to 40% for projects with FID in 2030
Market share: This innovation will not affect the market of projects with FID in 2020. This is then anticipated to rise to 25% for projects with FID in 2030.

Development and integration of quality control methods

Practice today: As with crystalline silicon technologies, quality control usually takes place at the end of the manufacturing process.
Innovation: The development and integration of improved control methods that may provide information on separate processes to improve the quality evaluation during the manufacturing process. The main trends are looking at the following techniques: in situ quality control during production, non-destructive methods, optical, etc. The aim is to increase yield and then reduce

CAPEX. Note that the improvement of quality may also affect other parameters such as the WACC although this is not modelled here.

Relevance: The innovation is relevant for all TF Technology Types.

Commercial readiness: About 40% of the benefits of this innovation will be available for projects with FID in 2020, rising to 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 75% for projects with FID in 2020. This is then anticipated to rise to 100% for projects with FID in 2030.

Improved light management

Practice today: Currently, CIGS and CdTe modules do not use advanced light trapping since this is not really needed as the absorber materials in question present very good light absorption properties.

Innovation: By introducing advanced light management, the active layer thickness of the devices could be reduced which would increase the throughput of the deposition tools, while aiming at maintaining the same efficiency level, resulting in a substantial reduction of CAPEX at the module level.

Relevance: The innovation is relevant for all TF Technology Types.

Commercial readiness: About 20% of the benefits of this innovation will be available for projects with FID in 2020, rising to 70% for projects with FID in 2030.

Market share: Market share is anticipated to be 10% for projects with FID in 2020. This is then anticipated to rise to 40% for projects with FID in 2030.

Reduced efficiency gap Lab cells-Fab modules

Practice today: The typical efficiency gap between the best lab cells and best commercial modules is 25% (e.g. 15% module vs 20% cell).

Innovation: By improving manufacturing processes (implementing best lab practices into production) and mitigating all efficiency-reducing factors not inherent in the difference in area, the target gap reduction can be close to around 10% (e.g. 20% module and 22% cell). The impact on efficiency primarily affects the throughput and the module CAPEX, with a cascade effect on to the rest of the installation: BoS and OPEX principally.

Relevance: The innovation is relevant for all TF scenarios.

Commercial readiness: About half of the benefits of this innovation will be available for projects with FID in 2020, rising to 90% for projects with FID in 2030.

Market share: Market share is anticipated to be as high as 100% for projects with FID in 2020 and for projects with FID in 2030.

Increased module efficiency

Practice today: Aperture area efficiency for TF modules varies with the technology. Typical values for mature, glass-based products are: 12-15% for CIGS and CdTe. For flexible products the range drops to 7-10%.

Innovation: This innovation covers a wide range of activities such as: the improvement of absorber materials (already addressed in section 4 of this document), interfaces and transparent conductors; the reduction of the proportion of inactive (interconnection) areas; applications of light management (already addressed in section 4), and more. Efficiency may rise to 18-

24% for CIGS and CdTe and 15-20% for flexible products. Considerable increases in efficiency are modelled as decreasing module CAPEX together with a cascade effect on the rest of the installation: BoS and OPEX principally.

Relevance: The innovation is relevant for all TF scenarios.

Commercial readiness: About 40% of the benefits of this innovation will be available for projects with FID in 2020, rising to 80% for projects with FID in 2030.

Market share: Market share is anticipated to be as high as 100% for projects with FID in 2020 and for projects with FID in 2030.

Mitigation of degradation mechanisms

Practice today: Degradation mechanisms have been studied and understood in detail for TFSi, where they are most prominent, but not for CIGS and CdTe where they may be product-related rather than typical for the technology as such.

Innovation: To understand and mitigate, or at least accurately predict, degradation mechanisms under field operating conditions to be able to address them. The basic improvement would be in relation to the reduction of the degradation mechanism leading to an overall higher AEP over the lifetime of the installation and reduced loss.

Relevance: The innovation is relevant for all TF scenarios.

Commercial readiness: About 20% of the benefits of this innovation will be available for projects with FID in 2020, rising to 80% for projects with FID in 2030.

Market share: Market share is anticipated to be 80% for projects with FID in 2020. This is then anticipated to rise to 100% for projects with FID in 2030.

New module materials

Practice today: Current practices in module manufacturing usually use glass-glass or glass-plastic configurations with aluminium frames.

Innovation: Significant cost reduction potential for rigid modules is limited, since most of the materials in question are mature products. As for Conventional c-Si and High Efficiency c-Si technology, frameless designs and the reduction of the thickness of the glass from 3mm to 1.5mm are options that could lead to lower prices than the existing ones leading to CAPEX reduction and resulting in better transmittance leading to greater efficiency.

Relevance: The innovation is relevant for all TF scenarios.

Commercial readiness: About 60% of the benefits of this innovation will be available for projects with FID in 2020, rising to 80% for projects with FID in 2030.

Market share: Market share is anticipated to be 80% for projects with FID in 2020. This is then anticipated to rise to 100% for projects with FID in 2030.

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7. Innovations in inverters

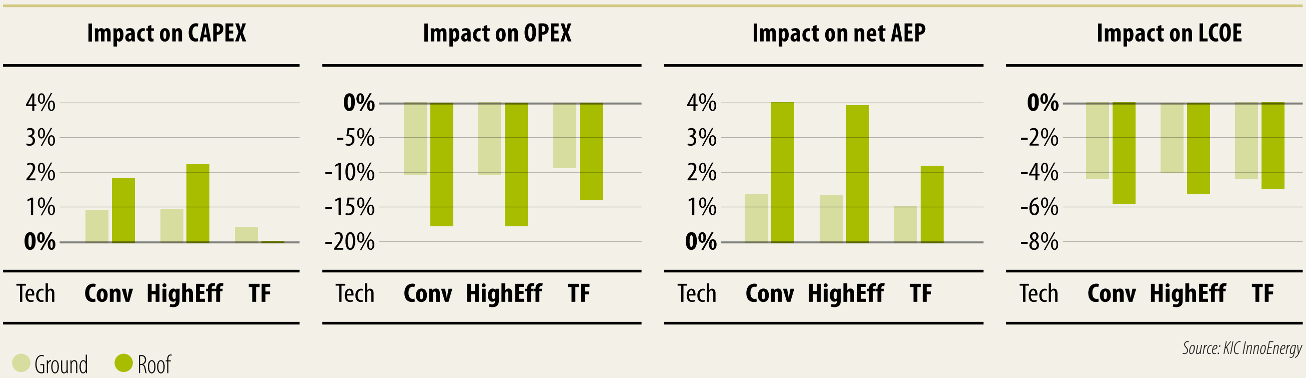
7.1. Overview

Innovations in the area of inverters are anticipated to reduce the LCOE by around 4.0% to 5.9% between FID 2015 and 2030. The savings will be mainly as a result of considerable improvements in OPEX and a substantial increase in AEP.

Figure 7.1 shows that the impact is broadly consistent between the Technology Types but variations are observed between ground-mounted installations and rooftop ones as the latter includes the effects of innovations almost specific to rooftop installation.

Figure 7.2 to Figure 7.4 and Table 7.1 to Table 7.3 show that the single innovation anticipated to deliver the greatest savings in this area is the improvement of inverter lifetime and reliability which could result in major savings. Specific developments targeting rooftop applications are also expected to result in interesting OPEX reductions and increased AEP for such installations.

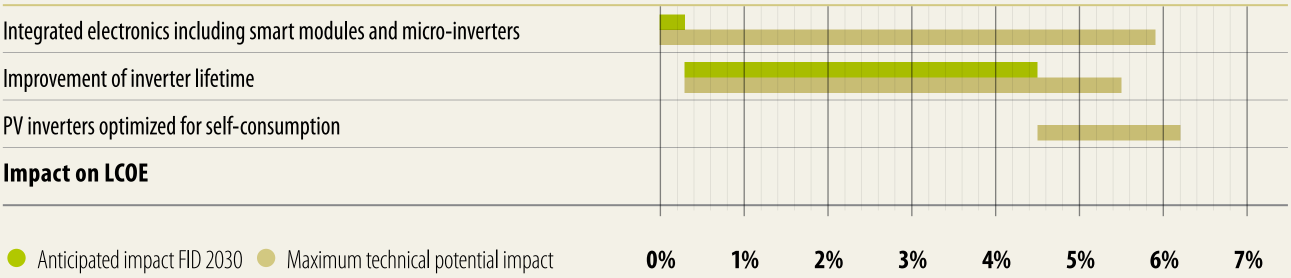
Figure 7.1 **Anticipated impact of inverter innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**



Source: KIC InnoEnergy

7.1.1. Conventional c-Si

Figure 7.2 **Anticipated and potential impact of inverter innovations for a ground mounted utility scale PV plant using Conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

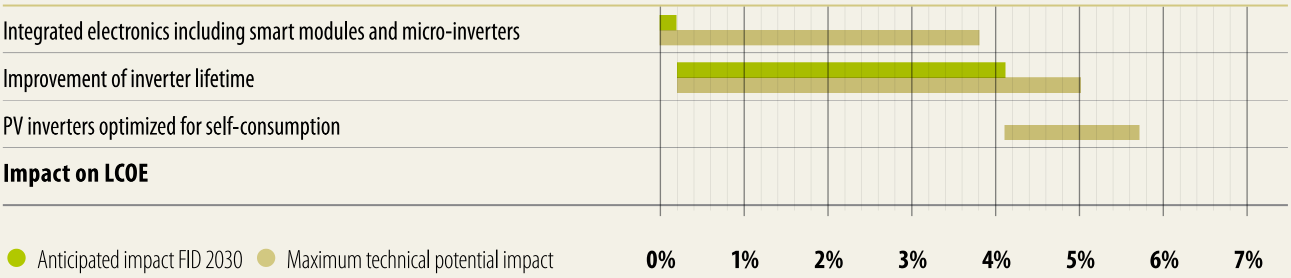
Table 7.1 **Anticipated and potential impact of inverters innovations for a ground mounted utility scale PV plant using Conventional c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Integrated electronics including smart modules and micro-inverters	-16.4%	15.3%	12.0%	5.9%	-0.7%	0.6%	0.5%	0.3%
Improvement of inverter lifetime	-0.4%	12.2%	1.3%	5.2%	-0.3%	9.8%	1.0%	4.2%
PV inverters optimized for self-consumption	0.7%	0.0%	1.3%	1.7%	0.0%	0.0%	0.0%	0.0%

Source: KIC InnoEnergy

7.1.2. High Efficiency c-Si

Figure 7.3 **Anticipated and potential impact of inverter innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

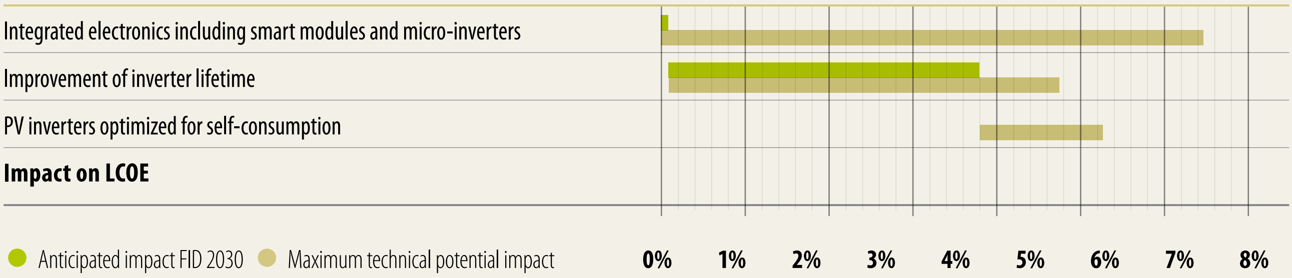
Table 7.2 **Anticipated and potential impact of inverter innovations for a rooftop PV installation using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	OPEX	AEP	LCOE	CAPEX	OPEX	AEP	LCOE
Integrated electronics including smart modules and micro-inverters	-18.1%	15.4%	11.7%	3.8%	-0.7%	0.6%	0.5%	0.2%
Improvement of inverter lifetime	-0.3%	12.3%	1.2%	4.8%	-0.3%	9.9%	1.0%	3.9%
PV inverters optimized for self-consumption	0.6%	0.0%	1.2%	1.6%	0.0%	0.0%	0.0%	0.0%

Source: KIC InnoEnergy

7.1.3. Thin Film

Figure 7.4 **Anticipated and potential impact of inverter innovations for a ground mounted PV installation using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

Table 7.3 **Anticipated and potential impact of inverter innovations for a ground mounted PV installation using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	OPEX	AEP	LCOE	CAPEX	OPEX	AEP	LCOE
Integrated electronics including smart modules and micro-inverters	-14.7%	14.5%	11.9%	7.5%	-0.1%	0.1%	0.1%	0.1%
Improvement of inverter lifetime	-0.4%	11.6%	1.2%	5.4%	-0.3%	9.3%	1.0%	4.3%
PV inverters optimized for self-consumption	0.8%	0.0%	1.2%	1.7%	0.0%	0.0%	0.0%	0.0%

Source: KIC InnoEnergy

7.2. Innovations

Innovations in inverters encompass a range of improvements to this crucial equipment in any PV installation, focusing particularly on reliability and lifetime extension. Within these innovations we also address the new development in integrated microelectronics allowing the emergence of the so-called smart module.

Integrated electronics including smart module and micro-inverters

Practice today: Today, the high efficiencies obtained with electronic equipment, >98.8% for power optimisers and >95% for micro-inverters, together with their relatively moderate cost and reliability make them serious options to be pushed forward for implementation in PV installations. Together with these promising technical characteristics, further interesting potential lies in the fact that these devices can offer value-added features to PV plants such as monitoring and communication systems at the PV module level.

Innovation: The improvement of these devices must address new design strategies and new materials to reduce costs. On top of this, reliability assessments should allow smooth and consistent integration into the PV module. Additionally, the development of fault detection algorithms and safety features should help to get the maximum value from monitoring and control at the PV module level.

Relevance: This innovation is fully relevant for rooftop installations; whilst only reaching a relevance of 20% in the case of ground-mounted PV plants.

Commercial readiness: the commercial readiness is expected to be 80% for projects with FID in 2020 and 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 10% for projects with FID in 2020. For projects with FID in 2030, the market share is anticipated rise to be 20%.

Improvement of inverter lifetime

Practice today: Nowadays, inverters are one of the key issues in O&M and their relatively reduced lifetime of around 15 years imply major work and expense to replace such.

Innovation: The first aspect involves developing new designs and using new materials to reduce the stress on components, overall increasing inverter reliability and lifetime to achieve a lifespan of over 30 years to match PV modules' own lifetime as closely as possible. Additionally, monitoring strategies could ease preventive and predictive maintenance through early fault detection. Overall, these strategies would make room for considerable CAPEX and OPEX optimisation in relation to this equipment

Relevance: This innovation is considered 80% relevant for rooftop applications, while fully relevant in the case of ground mounted PV plants.

Commercial readiness: the commercial readiness is anticipated to be 70% for projects with FID in 2020 and 100% for projects with FID in 2030.

Market share: Market share is anticipated to be 60% for projects with FID in 2020. For projects with FID in 2030, the market share is anticipated rise to be 80%.

PV inverter optimised for self-consumption

Practice today: The availability of High Efficiency (98%) and relatively low cost PV inverters with optimisation of self-consumption is growing and manufacturers are working on designing adapted products for the distributed energy generation market.

Innovation: Improved designs and the use of alternative materials like innovative semiconductors (SiC or GaN) allowing higher switching frequencies, higher power density (2 kg/kW), higher voltage levels and improved efficiency. These improvements combine with CAPEX reductions and further optimisation in electric BoS.

At the same time, although not modelled here, these devices are key in extracting the value of PV, alone or coupled with storage. Thus, the strategy focuses on lifetime assessment and reduction of lifecycle costs of storage technologies. PV forecasting, energy management and automated building, like active inverters able to control the insertion of electric loads according to PV production.

Relevance: This innovation is 100% relevant for rooftop applications and not relevant at all for ground-mounted scenarios.

Commercial readiness: the commercial readiness is anticipated to be 90% for projects with FID in 2020 and reaching 100% for projects with FID in 2030.

Market share: the market share is anticipated to reach 60% in 2020 and to raise to 75% in 2030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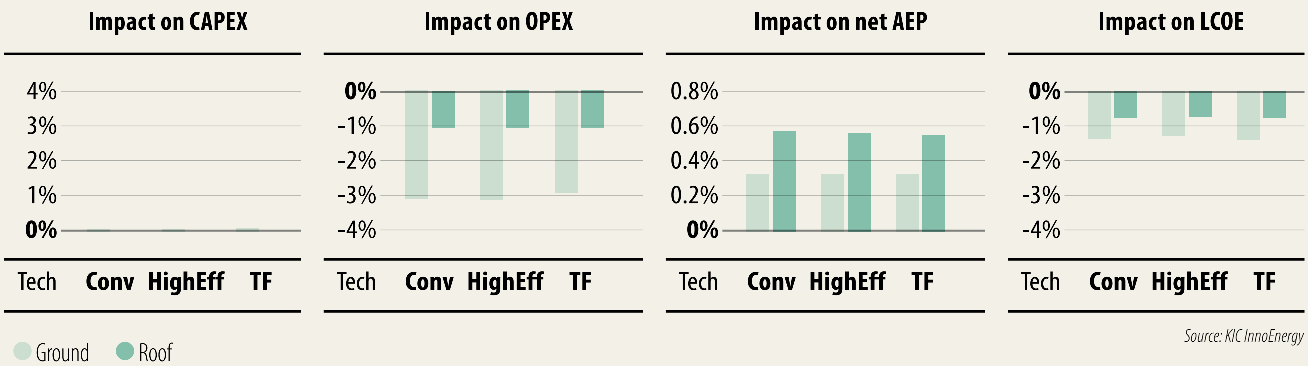
8. Innovations in operations, maintenance and service

8.1. Overview

Innovations in operations, maintenance and service (OMS) are anticipated to reduce the LCOE by 0.8% to 1.4% between 2015 and 2030. The savings are dominated by improvements in OPEX and power plant availability, and hence net AEP.

Figure 8.1 shows that the impact on OPEX is consistent across technologies.

Figure 8.1 **Anticipated impact of OMS innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**

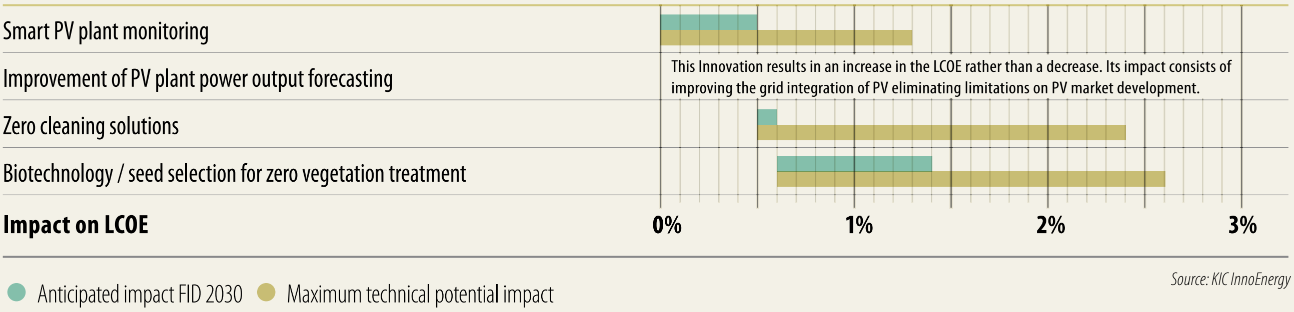


Source: KIC InnoEnergy

Figure 8.2 to Figure 8.4 and Table 8.1 to Table 8.3 show that the individual innovations with the greatest anticipated impact by FID 2030 related to the introduction of solutions to reduce maintenance activities in relation to vegetation treatment as well as smart plant monitoring to check the condition of solar equipment and ensure the management of power quality parameters. Through improved control strategies and better interaction between single components of power plants, the irradiation collected can be maximised therefore increasing the AEP. This not only improves the efficiency of power plants but will also significantly lower the LCOE.

8.1.1. Conventional c-Si

Figure 8.2 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using conv c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

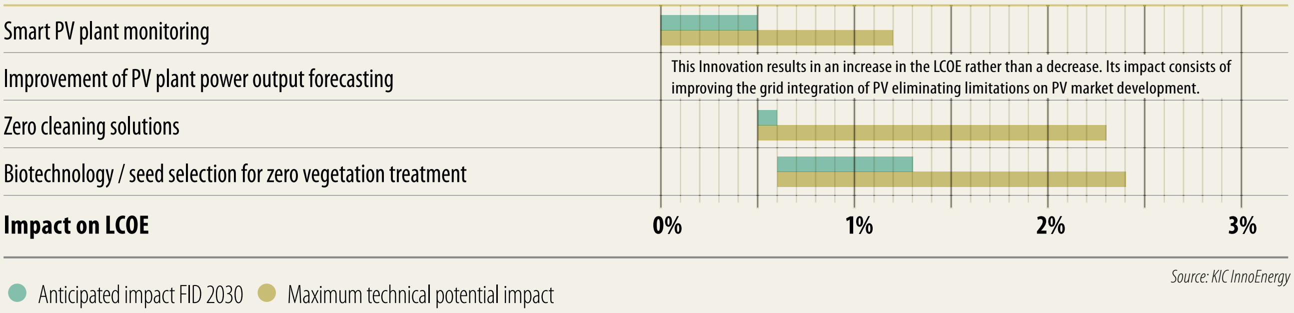
Table 8.1 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using conv c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Smart PV plant monitoring	0.0%	1.6%	0.7%	1.3%	0.0%	0.7%	0.3%	0.5%
Improvement of PV plant power output forecasting	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zero cleaning solutions	0.0%	0.0%	1.9%	1.9%	0.0%	0.0%	0.1%	0.1%
Biotechnology / seed selection for zero vegetation treatment	-0.2%	6.1%	0.0%	2.0%	-0.1%	2.4%	0.0%	0.8%

Source: KIC InnoEnergy

8.1.2. High Efficiency c-Si

Figure 8.3 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

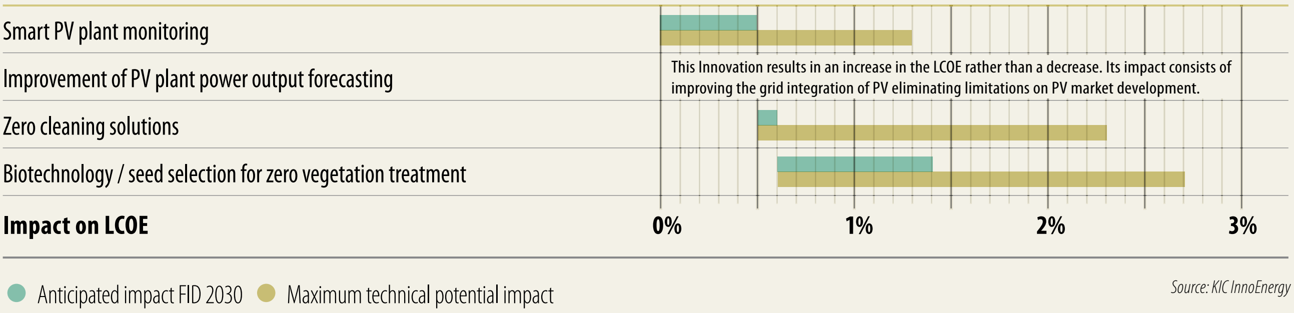
Table 8.2 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using High Efficiency c-Si technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Smart PV plant monitoring	0.0%	1.7%	0.7%	1.2%	0.0%	0.7%	0.3%	0.5%
Improvement of PV plant power output forecasting	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zero cleaning solutions	0.0%	0.0%	1.8%	1.8%	0.0%	0.0%	0.1%	0.1%
Biotechnology / seed selection for zero vegetation treatment	-0.1%	6.2%	0.0%	1.8%	-0.1%	2.5%	0.0%	0.7%

Source: KIC InnoEnergy

8.1.3. Thin Film

Figure 8.4 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**



Source: KIC InnoEnergy

Table 8.3 **Anticipated and potential impact of OMS innovations for a ground mounted utility scale PV plant using TF technology with FID in 2030, compared with an installation with the same nominal power on the same Site Type with FID in 2015.**

Innovation	Maximum technical potential impact				Anticipated impact FID 2030			
	CAPEX	**OPEX**	**AEP**	**LCOE**	**CAPEX**	**OPEX**	**AEP**	**LCOE**
Smart PV plant monitoring	0.0%	1.6%	0.7%	1.3%	0.0%	0.6%	0.3%	0.5%
Improvement of PV plant power output forecasting	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%	0.0%
Zero cleaning solutions	0.0%	0.0%	1.9%	1.8%	0.0%	0.0%	0.1%	0.1%
Biotechnology / seed selection for zero vegetation treatment	-0.2%	5.8%	0.0%	2.1%	-0.1%	2.3%	0.0%	0.8%

Source: KIC InnoEnergy

8.2. Innovations

Innovations in PV installation OMS vary considerably from highly practical to deeply technical issues. A subset of the more important of these has been modelled here.

Smart PV plant monitoring

Practice today: Today, monitoring systems are mainly used for (i) remote production management, (ii) maintenance management (alarms), planning and reporting and (iii) performance ratio (PR) calculation. Systems generally consist of (i) an on-site datalogger that collects electrical data (inverter, strings, meters, etc.) and a meteorological station (radiation, temperature) for PR calculation and (ii) monitoring/management software that displays and manages said data. These systems fail to detect the root causes of performance and availability problems, leading to plants' underperformance and lack of availability.
Innovation: Innovations in this field include advances in single plant and system portfolio monitoring and management including:

- automated maintenance (preventive and emergency), intervention management and (re) scheduling, based on parameters such as alarms and performance data.
- algorithms for equipment or plant behaviour and reliability predictions based on historical failure data and simulation models to prevent failures and optimise preventive maintenance.
- optimisation of O&M portfolio management, according to contractual obligations and KPIs and linked to alarms and technical staff real time positioning (GPS).

These improvements principally lead to lower OPEX and have also a positive impact on AEP and the reduction of loss.
Relevance: The innovation is equally relevant to all scenarios.
Commercial readiness: Around 60% half of the potential impact will be available for projects with FID in 2020. For projects with FID in 2030, the readiness rises to 100%.
Market share: 20% of projects with FID in 2020 and 40% of projects with FID in 2030 will use the innovation.

Improvement of PV plant power output forecasting

Practice today: Electricity generation from PV plants is limited by the varying availability of the sun's radiation. Despite the fact that grid operators are generally obliged to dispatch PV plant production at all times, the growing penetration of PV may force new regulations to guarantee grid stability and the correct balancing of electricity supply and consumption at all times, causing unpredictable losses to plant owners.
Innovation: The prediction of PV production will become an essential tool to capture economies in a market with large penetration of non-predictable energy (wind and solar). The innovation consists of the development of proper software based on algorithms that are able to match weather forecasts with PV plant characteristics in order to predict the energy production of PV plants on an hourly basis for at least the next 48 hours. This will allow (i) participation in the power balancing market where remuneration is higher (ii) integration with storage if/when applicable and (iii) the determining of when maintenance interventions have less impact on cost. Prediction also affects the consumption profiles (in self-consumption scenarios)
Relevance: The innovation is equally relevant to all scenarios.
Commercial readiness: Around 60% half of the potential impact will be available for projects with FID in 2020. For projects with FID in 2030, the readiness rises to 100%.

Note that this innovation is responsible for an increase in the LCOE and is therefore not modelled here as the model used does not take such innovations into account

Market share: 15% of projects with FID in 2020 and 25% of projects with FID in 2030 will use the innovation.

Zero cleaning solutions

Practice today: Regular module washing is common practice in PV plants. The effect of soiling on a fixed-tilt solar plant in Europe (with enough rain) causes an average 2% power loss. This power loss can be as high as 11% in non-rainy environments but returns to 2% once it rains. Frequency of washing should be higher in flat modules located on roofs.

Innovation: Anti-soiling catalysts can be used in module manufacturing or applied as retrofits to existing plants. Despite concerns in relation to transmittance that can be reduced, this practice can increase production, particularly in rainy, polluted sites with no inorganic soiling which will degrade the catalyst. The rain is needed in order to clean the degraded organic pollution. Without rain, the dirt remains on the module. With a negligible impact on CAPEX, the main positive effect of this innovation is on the AEP and loss.

Relevance: The innovation is fully relevant for rooftop applications while only 20% relevant for ground-mounted installations.

Commercial readiness: 30% of the potential impact will be available for projects with FID in 2020. For projects with FID in 2030, the readiness rises to 50%.

Market share: 10% of projects with FID in 2020 are expected to utilise the innovation. For projects with FID in 2030, the market share is anticipated to rise to 30%.

Biotechnology / seed selection for zero vegetation treatment

Practice today: Ground-mounted PV plants may suffer from shading if vegetation inside and outside the plant is not properly controlled. Natural vegetation, particularly in Southern Europe, requires costly treatments. On average, perimetral vegetation (along the security system devices) needs cutting every 15 days from March to September, while the grass inside the plant needs cutting at least three times a year.

Innovation: The main lines in this area seek to reduce the maintenance required and exclude the use of pesticides or dangerous chemicals. Specifically:

- selection of seeds the growth of which is slow and limited in height so as to avoid the need for frequent maintenance.
- weed control fabrics inside the plant, under the modules and around the perimeter in order to limit woven growth: such products combine soil erosion control and weed control into a single product, thereby reducing the amount of maintenance of green areas to a minimum

Relevance: The innovation is principally relevant to ground-mounted installation scenarios.

Commercial readiness: 80% of the potential impact will be available for projects with FID in 2020. For projects with FID in 2030, the readiness rises to 100%.

Market share: 25% of projects with FID in 2020 are expected to utilise the innovation. For projects with FID in 2030, the market share is anticipated to rise to 40%.

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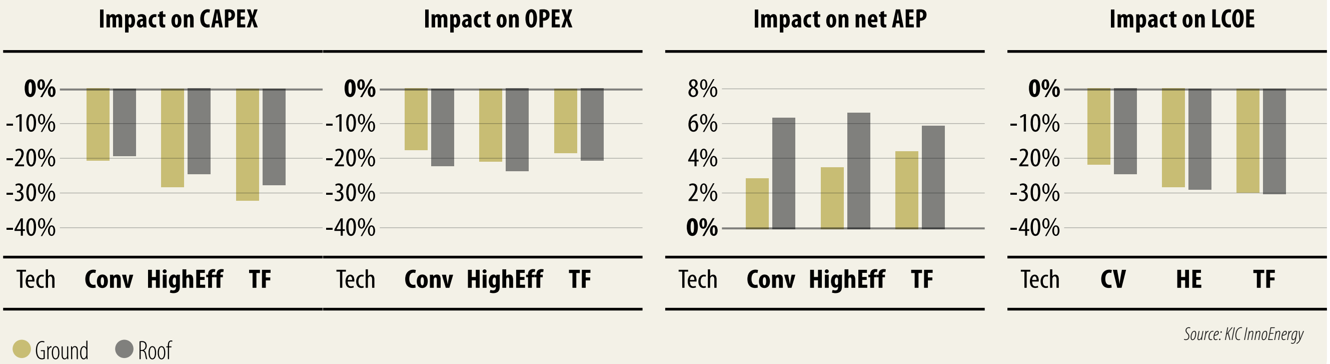
9. Summary of the impact of innovations

9.1. Combined impact of innovations

Innovations across all elements of PV installations are anticipated to reduce the LCOE by around 22% for Conventional c-Si, 28% for High Efficiency c-Si and 30% for TF amongst projects with FID in 2015 and 2030. Figure 9.1 shows that the savings are generated through a balanced contribution of reduced CAPEX and OPEX and increased AEP.

It is important to note that the impact shown in Figure 9.1 is an aggregate of the impact shown in Figure 4.1 to Figure 8.1 and as such excludes any other effects such as supply chain or scale effects. These are discussed in Section 9.3. The largest like-for-like reductions available for the same Technology Type are for projects using TF. Nonetheless, both of the other Technology Types also show a relevant total impact on LCOE for projects with FID in 2030.

Figure 9.1 **Anticipated impact of all innovations by Technology Type with FID in 2030, compared with a plant with the same nominal power with FID in 2015.**



Source: KIC InnoEnergy

9.2. Relative impact of cost of each STE plant element

In order to explore the relative cost of each PV installation element, Figure 9.2 shows the cost of all CAPEX elements for all scenarios and Figure 9.3 reflects the same for OPEX and the net capacity factor. These figures show the reduction in costs and increased capacity factor over time for a given Technology Type, as well as the relative costs between different technologies.

Figure 9.2 **CAPEX for PV installations with FID in 2015, 2020 and 2030.** *Source: KIC InnoEnergy*

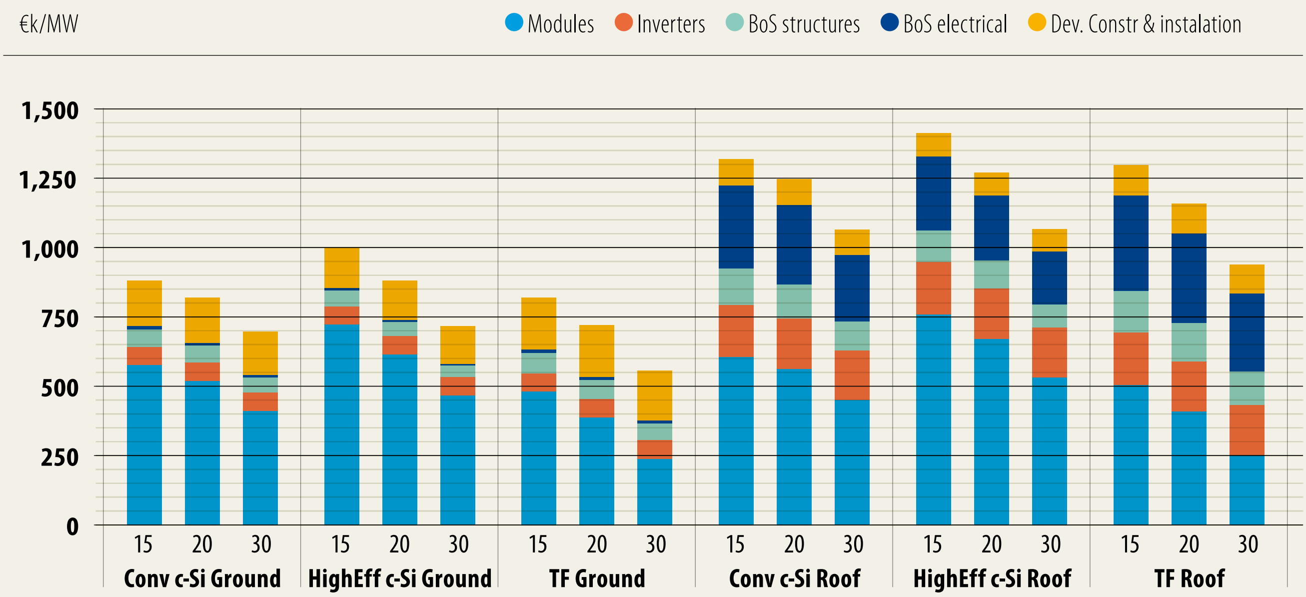
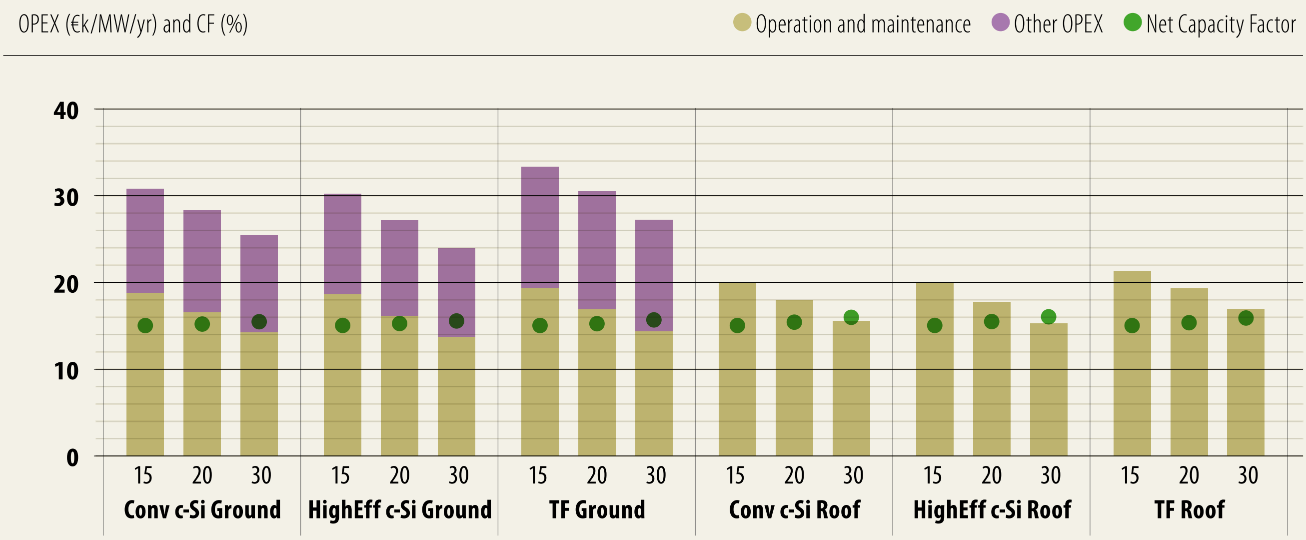


Figure 9.3 **OPEX and net capacity factor for PV installations with FID in 2015, 2020 and 2030.** *Source: KIC InnoEnergy*

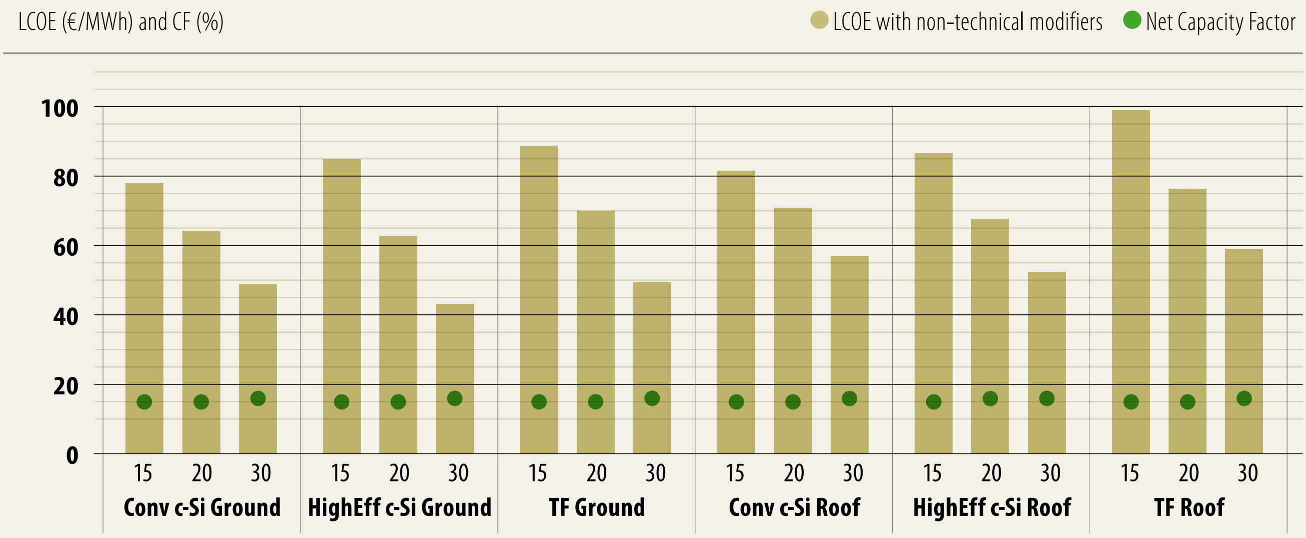


9.3. LCOE including the impact of other effects

In order to compare LCOE, Figure 9.4 also incorporates the other effects discussed in Section 2.4. It shows that, with the benefit of increasing capacity factor over time, all Technology Types experience almost the same trend.

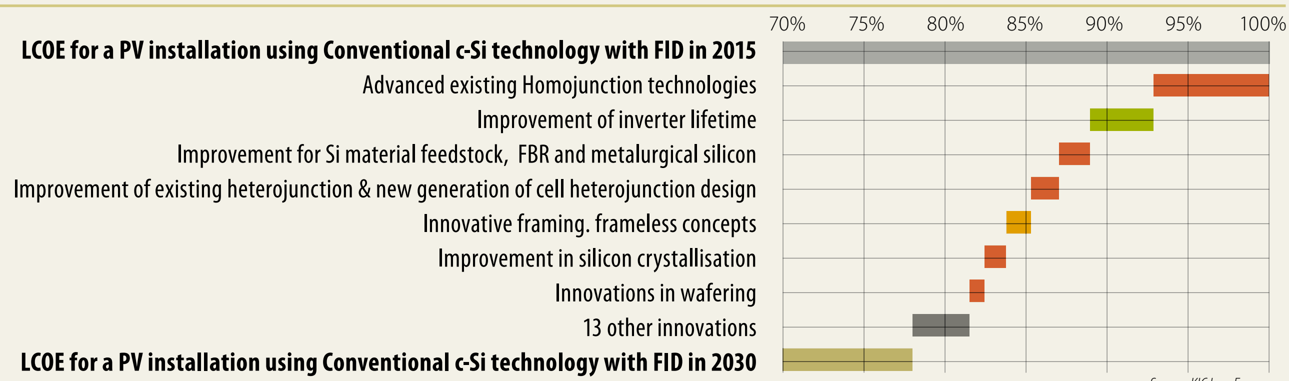
Figure 9.4 **LCOE for PV installations with FID 2015, 2020 and 2030 with other effects incorporated,** (Ref. Section 2.4.).

Source: KIC InnoEnergy



The contribution of innovations in each element to this LCOE reduction is presented in Figure 9.5 to Figure 9.7. It shows that innovations in cell and module manufacturing have a dominant effect on LCOE.

Figure 9.5 **Anticipated impact of technology innovations for a ground mounted PV Installation using Conventional c-Si technology and with FID in 2030, compared with a PV installation with FID in 2015.**



Source: KIC InnoEnergy

Figure 9.6 **Anticipated impact of technology innovations for a ground mounted PV Installation using High Efficiency c-Si technology and with FID in 2030, compared with a PV installation with FID in 2015**[2]**.**

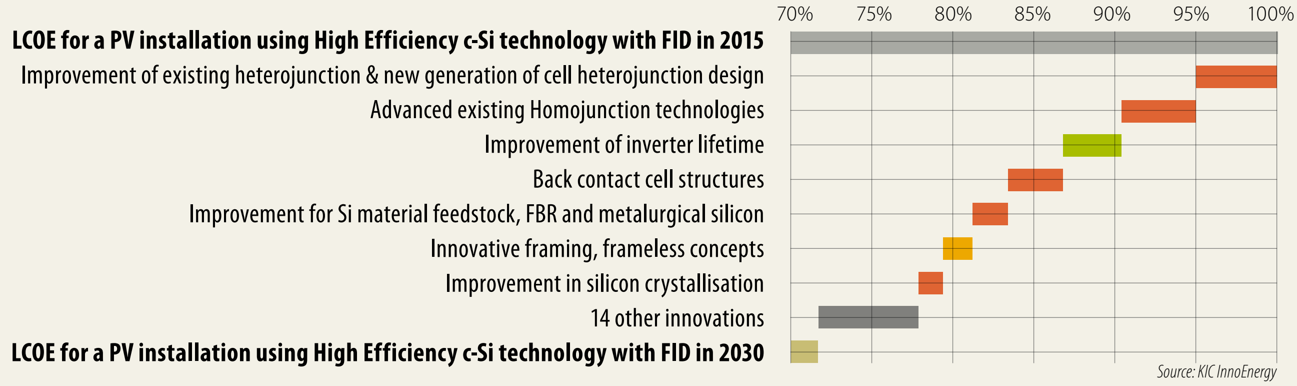
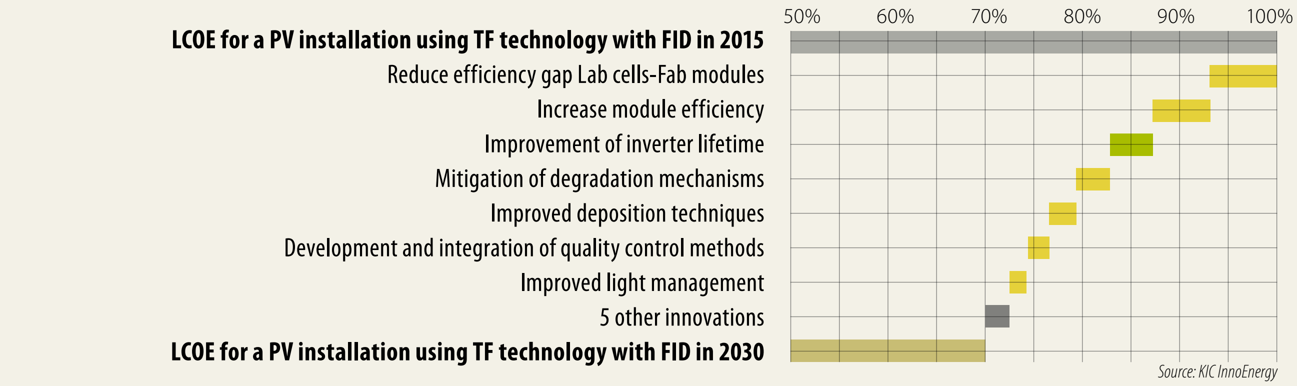
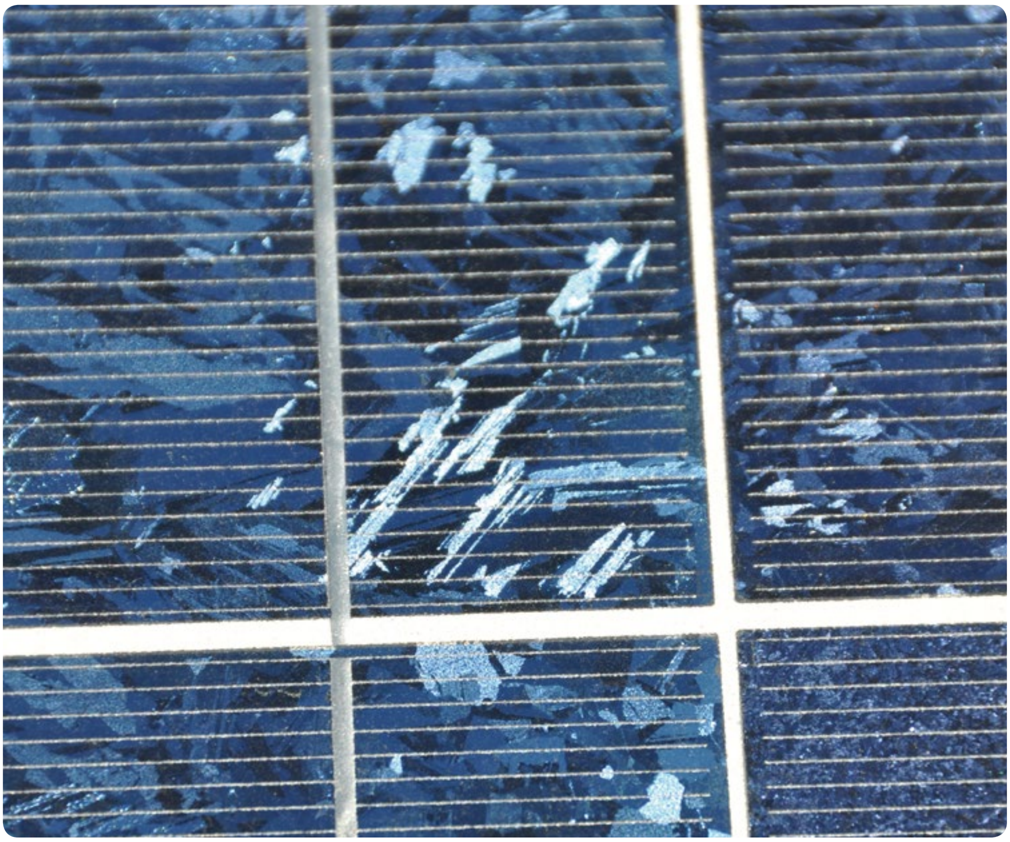


Figure 9.7 **Anticipated impact of technology innovations for a ground mounted PV Installation using TF technology and with FID in 2030, compared with a PV installation with FID in 2015.**

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10. Conclusions

In Sections 4.1 to 8.1, a large number of innovations with the potential to reduce the LCOE by FID 2030 are considered. Within these, a number of distinct themes emerge, which will be the focus of the industry's efforts to reduce costs:

- The improvement of homojunction technology
- The improvement of existing heterojunction technology & the new generation of cell heterojunction design
- The improvement of inverter lifetime
- At the thin film level, the reduction of the gap between lab scale sample and modules.

Although we have looked separately at polysilicon purification, crystallisation, wafering and cell and module design and production, these are closely linked. The potential of some innovations to reduce the LCOE has therefore been analysed taking into consideration the influence these might have on other innovations as they are technically linked.

The analysis performed in this report has assessed the impact of a list of selected innovations on the LCOE, mainly based on the CAPEX, OPEX and AEP. The results obtained are therefore very useful to detect those innovations with greater potential for LCOE reduction, however, both the impact of the analysed improvements on the LCOE and other important aspects such as the impact on the power system must be considered. For example, there are improvements with a low or negative impact on the LCOE but with significant potential improvements in PV generated electricity integration. Such improvements would be very helpful to increase the value of PV and therefore eliminate barriers to the growth of the PV market, especially in countries where this technology has already reached high levels of penetration. Therefore, the interest of RD&D topics for the PV sector should not be based solely on their potential impact on the LCOE but also on those other aspects. A good example of this type of innovation is the development of more efficient PV plant power output forecasting, which would have a negative impact on the LCOE while significantly increasing the value of PV electricity and easing its system and market integration.

According to the results, the current massively used conventional crystalline silicon technology is anticipated to be partly replaced in the future by different options such as high efficiency c-Si technology and also by thin film technology. This technology diversification will allow a better addressing of the needs of existing specific market segments like rooftop installations and the increasing of the market size with new market opportunities. The expected growth of the BIPV market is an illustration of this last point and will require additional work on variable geometry and flexible modules. These evolutions will impact the demand side with enhanced product offer but also a new paradigm for the whole supply chain, where it is expected to move from a "one size fits all" mass scale production model to a more differentiated approach adapting to applications and geographies.

To sum up, a shift is required from a technology evolution based on cost reduction, as extensively described in this report, to a more systemic approach, designing for multi-level integration, with grids, buildings, etc. delivering the best value at the lowest cost.

Beyond these technical considerations, the evolution of the market also has to be taken into account. The development of new, large PV installations is being driven more and more by tender processes where the LCOE throughout the whole project life is key for the preparation of bids. There is increased acceptance among developers that the LCOE should be the key aspect in assessing technology choices, hence the inclusion of a more thorough assessment of OPEX and AEP to balance the assessment of CAPEX, recognising that the certain and immediate CAPEX will remain a more powerful driver over time than the uncertain OPEX. More efficient technology inherently has higher CAPEX per watt-peak but module manufacturers have reported concerns that this is not fully appreciated by their customers.

According to these statements, PV module manufacturers have demanding requirements for their factories. Investment in existing production lines or in new production facilities will be needed if the full potential impact of innovations on the LCOE is to be achieved. If the demand is not secured and stabilised, the issue of market confidence will be critical to unlock many of the technology savings under development through sufficient levels of supply chain development.

More than 30 technological innovations have been identified as having the potential to cause a substantial change in the design of hardware, software and processes, with a resulting quantifiable impact on the cost of energy. Many more technical innovations are under development and therefore some of those described in this report may well be superseded by others. Overall, however, industry expectation is that the reduction in LCOE is expected in ranges according to the numbers described in this report. Indeed, in most cases, the expected impact of each innovation has been significantly moderated downwards in order to give overall LCOE reduction levels in line with industry expectations. The availability of such a range of innovations with the potential to impact LCOE more than shown gives us confidence that the picture described is achievable. In addition, it is important to remember that LCOE reductions are available through the other effects considered in Section 2.4, although these are not expected to have the same degree of impact as technological innovations.

NASA Earth Observatory image by Robert Simmon

11. About KIC InnoEnergy

The challenge is big, but our goal is simple: to achieve a sustainable energy future for Europe. Innovation is the answer. New ideas, products and solutions that make a real difference, new businesses and new people to deliver them to market.

At KIC InnoEnergy we support and invest in innovation at every stage of the journey – from classroom to customers. With our network of partners we build connections across Europe, bringing together inventors and industry, entrepreneurs and markets, graduates and employers, researchers and businesses.

We work in three essential areas of the innovation mix:

- Education to help create an informed and ambitious workforce that understands what sustainability demands and industry needs – for the future of the industry.
- Innovation Projects to bring together ideas, inventors and industry in collaboration to enable commercially viable products and services that deliver real results.
- Business Creation Services to help entrepreneurs and start-ups who are creating sustainable businesses to grow rapidly to contribute to Europe's energy ecosystem.

Together, our work creates and connects the building blocks for the sustainable energy industry that Europe needs.

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KIC InnoEnergy partners across Europe.

KIC InnoEnergy is committed to reducing costs in the energy value chain, increasing security and reducing CO_2 and other greenhouse gas emissions. To achieve this, the company focuses its activities around eight technology areas:

- **Electricity Storage**
- **Energy from Chemical Fuels**
- **Sustainable Nuclear and Renewable Energy Convergence**
- **Smart and Efficient Buildings and Cities**
- **Clean Coal Technologies**
- **Smart Electric Grid**
- **Renewable Energies,** and
- **Energy Efficiency.**

For more information on KIC InnoEnergy please visit: www.kic-innoenergy.com

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KIC InnoEnergy is supported by the EIT, a body of the European Union

Appendix A

Further details of methodology

A detailed set of project assumptions was distributed to project participants in advance of their involvement in interviews and workshops.

A.1 Definitions

Definitions of the scope of each element are provided in Sections 4 to 8 and summarised in Table A.1, below.

Table A.1 **Definitions of the scope of each element.**

Parameter	Definition	Unit
CAPEX		
PV modules	Payment to PV module manufacturer for the supply of the modules to the point of connection to the array cables (can be crystalline-Si or Thin-Film technology). INCLUDES • All production costs (cell supply [cell cost excluded], workforce, power, machinery, etc.) • Delivery to installer's warehouse • 10 years warranty + 25 years degradation warranty • Commissioning costs EXCLUDES • Support structures • OMS costs • RD&D costs	**€/W**
Inverters	INCLUDES • Payment to inverter manufacturer for the supply of the equipment to the point of connection to the array cables. • Delivery to installer's warehouse • 5 years warranty • Commissioning costs EXCLUDES • OMS costs • RD&D costs	**€/W**
BoS > structures	INCLUDES • Payment to supplier for the supply of the support structure comprising the foundation and the support structure (fixed or tracker) • Delivery to installer's warehouse • 5 years warranty EXCLUDES • OMS costs • RD&D costs	**€/W**
BoS > collection grid	INCLUDES • Payment to manufacturer of electrical material (cables & other electrical elements, grid code compliance devices) • Delivery to installer's warehouse • 5 years warranty EXCLUDES • OMS costs • RD&D costs	**€/W**

Development, Construction and installation	INCLUDES • Development and consenting work paid for by the developer up to the point of WCD. - Internal and external activities such as environmental and wildlife surveys, resource evaluation (includes metering devices), land negotiation, engineering (pre-FEED) and planning studies up to FID. - Further site investigation and surveys after FID - Engineering (FEED) studies - Project management (work undertaken or contracted by the developer up to WCD) - Other administrative and professional services such as accountancy and legal advice • Transportation of all equipment from warehouse to site • Transportation of equipment once on construction site • All installation work for support structures, modules, inverters and array cables • Commissioning work for the whole installation except PV modules and inverters • Warranty • Commissioning costs EXCLUDES • Any reservation payments to suppliers • Construction phase insurance • Suppliers own project management • Installation of substation and transmission assets • OMS • R&D costs	**€/W**
OPEX		
Operation and maintenance	Starts once first module is commissioned. INCLUDES: • Operational costs in relation to the day-to-day control of the PV plant including control room activities and admin/financial services • Condition monitoring if applied • Planned preventive maintenance, including module cleaning (once a year) and vegetation maintenance where applicable • Health and safety inspections • Corrective maintenance and replacement of broken equipment • Security (remote surveillance and patrolling) • Inverter extended warranty when applicable	**€/W/yr**
Other OPEX	Starts once first module is commissioned. INCLUDES: Leasing of land or roof Contributions to community funds including all types of tax where applicable. Monitoring of the local environmental impact of the PV farm if applicable.	**MWh/yr/MW**
AEP		
Gross AEP	The gross AEP in the first year of the PV plant's life at output of the modules and inverters. Excludes electrical array losses and other losses.	**MWh/yr/MW**
Losses	INCLUDES • Performance ratio components: - Temperature losses - Inverter losses - Electrical array losses to the metering point - Potential induced degradation (PID) and Light induced degradation (LID) - Losses due to lack of availability of PV plant elements. - Shadows - Low radiation losses Effect of degradation factor EXCLUDES: Transmission losses.	**%**
Net AEP	The net AEP averaged over the STE plant life at the metering point at entry to the substation.	**MWh/yr/MW**

A.2 Assumptions

Baseline costs and the impact of innovations are based on the following assumptions for solar photovoltaics.

Global assumptions

- Real (mid 2015) prices
- Commodity prices fixed at the average for 2015
- Exchange rates fixed at the average for 2015
- Energy prices fixed at the current rate
- Market expectation "mid-view" (15% as CAGR)

PV installations assumptions

Site attributes are defined as follows, in line with the state of the market for today and the next years.

Table A.2 **Summary of Site Types.**

Site Types	**Installed capacity** (kWh/m^2/yr)	**Global radiation**	**Type of support**	**Other characteristics**
Ground	5 MW	1,320	Ground mounted	Orientation optimal south
Roof-top	< 100 kW	1,320	Roof mounted	Roof mounted on factory or warehouse Orientation south but some shading problems

General. The general assumptions are:

- Installations'' capacity as indicated in the table
- Depreciation time used is 30 years
- An EPC contract approach is used to contracting for construction

Spend profile

Table A.3 **CAPEX spend profile.**

Year	**-5**	**-4**	**-3**	**-2**	**-1**	**0**
CAPEX Spend	0%	0%	0%	0%	15%	85%

Year 1 is defined as year of first full generation. AEP and OPEX are assumed as 100% for years one through 30.

Module technologies description

- Conv c-Si: poly-crystalline silicon technology, average cell efficiency in the range of 17%, module efficiency in the range of 15.5% in 2015 (245 Wp/module)
- High Efficiency c-Si: mono crystalline with average cell efficiency in the range of 19 to 20%, module efficiency in the range of 17 to 18% in 2015 (270 Wp/module)
- Thin Film: average module efficiency in the range of 13 to 14% in 2015 (100Wp / module)
  - CdTe technology for ground mounted site types
  - CIGS technology for rooftop site type

Inverters

- Ground mounted site types: in the 500 kW range
- Building mounted site type: in the 20 kW range

Support structures

- Ground mounted installations: fixed aluminium structure with concrete foundations
- Rooftop installations: roof racking

Array electrical

- Ground mounted installations: medium voltage wiring for collection system
- Rooftop installations: low voltage wiring for collection system

Construction

EPC contracting ensure transport on a just in time basis and construction.

O&M

- Ground mounted installations: local service team within 1 hour driving distance, with 7-day working within office hours and remote management control room with data access via SCADA system.
- Rooftop installations: low cost O&M strategy, no remote access.

A.3 Other effects

The table below corresponds to definitions made in Section 2.4. These figures are derived from the results of the KIC InnoEnergy technology strategy and roadmap work stream and the consultation to experts lead afterwards, they are provided for completeness. They do not form an integral part of the study.

DECEX includes:

- Planning work and design of any additional equipment required
- Removal of the plant and PV installation foundations to meet legal obligations, and
- Further environmental work and monitoring, if required.

Table A.4 **Summary of the impact of other effects.**

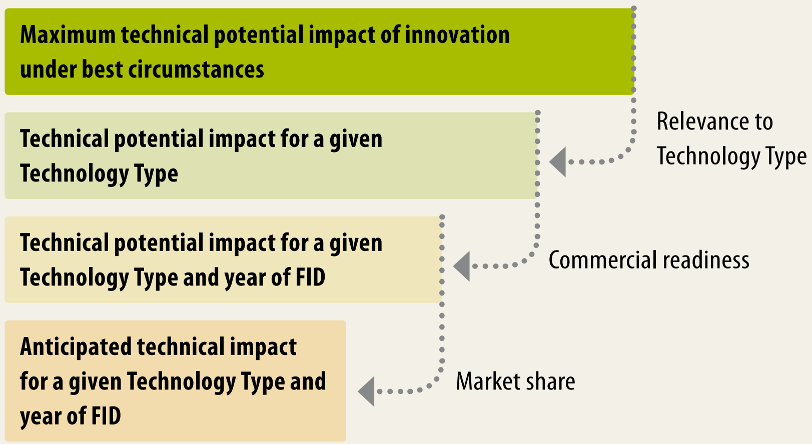
Tech-Site-FID	Transmission	Pre-FID risk	Supply chain	Decommission-ing costs	WACC
Conv c-Si-Ground-15	8.0%	0.5%	-1.0%	0.2%	6.0%
High Efficiency c-Si-Ground-15	8.0%	0.5%	-0.5%	0.2%	6.0%
Conv c-Si-Roof-15	12.0%	0.0%	-1.0%	0.2%	4.0%
High Efficiency c-Si -Roof-15	12.0%	0.0%	-0.5%	0.2%	4.0%
Conv c-Si-Ground-20	7.0%	0.4%	-3.0%	0.2%	5.0%
High Efficiency c-Si -Ground-20	7.0%	0.4%	-8.0%	0.2%	5.0%
Conv c-Si-Roof-20	9.0%	0.0%	-3.0%	0.2%	4.0%
High Efficiency c-Si -Roof-20	9.0%	0.0%	-8.0%	0.2%	4.0%
Conv c-Si-Ground-30	5.0%	0.3%	-5.0%	0.2%	4.0%
High Efficiency c-Si -Ground-30	5.0%	0.3%	-15.0%	0.2%	4.0%
Conv c-Si-Roof-30	8.0%	0.0%	-5.0%	0.2%	4.0%
High Efficiency c-Si -Roof-30	8.0%	0.0%	-12.0%	0.2%	4.0%
TF-Ground-15	8.0%	1.0%	0.0%	0.2%	8.0%
TF-Building-15	12.0%	0.0%	0.0%	0.2%	6.0%
TF-Ground-20	6.0%	1.0%	-2.0%	0.2%	7.0%
TF-Building-20	9.0%	0.0%	-1.0%	0.2%	5.0%
TF-Ground-30	5.0%	1.0%	-3.5%	0.2%	6.0%
TF-Building-30	8.0%	0.0%	-2.0%	0.2%	5.0%

A.4 Example calculation of change in LCOE for a given innovation

The following example is intended to show the process of derivation and moderation of the impact of an innovation. There is some explanation of the figures used, but the focus is on methodology rather than content. The example used is the impact of innovation in "Biotechnology / seed selection for zero vegetation treatment" for a 1 MW PV Conventional c-Si ground power plant.

To consider the impact of a technology innovation, a measure of LCOE is used, based on a fixed WACC. The CAPEX spend profile is annualised by applying a factor of 0.066, which is based on a discount rate of 5%.

Figure A.4 **Four-stage process of moderation applied to the maximum potential technical impact of an innovation to derive the anticipated impact on the LCOE.**



Maximum technical potential impact

Based on work in the KIC InnoEnergy technology strategy and roadmap, we derive the maximum potential impact of improvements in Biotechnology on a PV plant to be -2.5% and 10.0% as respective impacts on BoS structure costs and OPEX.

Relevance to Technology Type

The relevance for the innovation in the PV technology is anticipated to be 100% on ground installations and to be 0% on roof type installations, as this innovation will not affect this type of PV plants. These values are applied both to conv c-Si and High Efficiency c-Si, since the innovation is not technology dependant.

Commercial readiness

This innovation is considered to have a fast development potential therefore 80% of the benefits are anticipated to be available to project with FID in 2020, while the potential of the innovation is expected to be fully exploited for in 2030 with a 100% effect by this FID date.

Market share

For a 2020 time horizon, it is anticipated that 25% of ground PV projects will implement this innovation whereas, in 2030, this technology is expected to be implemented in 40% of the installations.

The anticipated LCOE impact is evaluated by comparing the LCOE calculated for the baseline case with the LCOE calculated for the target case. The target case includes the impact of the innovation on the costs for each element and AEP parameters, as well as the effects of relevance to Site Type, commercial readiness and market share. Target case impacts are calculated as follows:

Impact for ground PV on BoS structure for conv c-Si	= Maximum potential impact (-2.5%) x Relevance to ground projects (100%) = -2.5% x Commercial readiness at FID in 2030 (100%) = -2.5% x Market share for project with FID in 2030 (40%) = -1.0%
Impact for fixed OPEX	= Maximum potential impact (10.0%) x Relevance to ground projects (100%) = 10.0% x Commercial readiness at FID in 2030 (100%) = 10.0% x Market share for project with FID in 2030 (40%) = 4.0%

The LCOE for the baseline and target cases then is calculated as in Table A.6. The anticipated impact of the innovation on the LCOE for this case is therefore (67.31 – 66.77) / 67.31= 0.8% reduction in LCOE.

Table A.6 **Calculation of the LCOE from cost and AEP data.**

Parameter	Baseline case Conv c-Si 2015	Target case Conv c-Si 2030
PV BoS structures (k€/MW)	63.45	63.45 x (1 - (-0.01)) = 64.08
Other CAPEX (€k/MW)	816.0	816.0
Total CAPEX (€k/MW)	879.45	880.08
Fixed OPEX (€k/MW/yr)	18.8	18.8 x (1 – 0.04) = 18.05
Other OPEX (€k/MW/yr)	12.0	12.0
Total OPEX (€k/MW/yr)	30.8	30.05
Net AEP (MWh/yr/MW)	1,320	1,320
LCOE (€/MWh)	(879.55 x 0.066 + 30.8) x 1,000 / 1,320 = 67.31	(880.08 x 0.066 + 18.05) x 1,000 / 1,320 = 66.77

A.5 References

PV LCOE in Europe 2014-30 – Final Report, 23 June 2015, European PV Technology Platform Steering Committee, PV LCOE Working Group.

International Technology Roadmap for Photovoltaic (ITRPV) - 2014 Results. April 2015.

Renewable Energy, Strategy & Roadmap 2015-2019 v2.0, July 2014, KIC InnoEnergy.

Appendix B

Data supporting tables

Table B.1 **Data relating to Figure 3.1.**

Element	Units	Conv cSi Ground-15	High Eff cSi Ground-15	Conv cSi Roof-15	High Eff cSi Roof-15	TF Ground-15	TF Roof-15
Modules	€k/MW	576	722	604.8	758.1	481	505.05
Inverters	€k/MW	65	65	188	188	65	188
BoS structures	€k/MW	63.45	56.19	130	115.14	72.85	149.26
BoS electrical	€k/MW	11.1	9.83	300	265.71	12.74	344.44
Dev. Constr & instalation	€k/MW	164	145.26	95	84.14	188.30	109.07

Table B.2 **Data relating to Figure 3.2.**

Element	Units	Conv cSi Ground-15	High Eff cSi Ground-15	Conv cSi Roof-15	High Eff cSi Roof-15	TF Ground-15	TF Roof-15
Operation and maintenance	€k/MW/yr	18.8	18.6	20	20	19.3	21.3
Other OPEX	€k/MW/yr	12	11.6	0	0	14	0
Net Capacity Factor	%	15.07	15.07	15.07	15.07	15.07	15.07

Table B.3 **Data relating to Figure 3.3.**

Element	Units	Conv cSi Ground-15	Conv cSi Roof-15	High Eff cSi Ground-15	High Eff cSi Roof-15	TF Ground-15	TF Roof-15
LCOE with non-technical modifiers	€/MWh	77.7	81.4	84.7	86.4	88.6	98.9
LCOE as % of Conv cSi-Ground-15	%	100	104.7	109.1	111.1	114.0	127.2
Net capacity factor	%	15.1	15.1	151	15.1	15.1	15.1

Table B.4 **Data relating to Figure 4.1.**

Impact of innovation on...	Conv cSi Ground	Conv cSi Roof	High Eff cSi Ground	High Eff cSi Roof
CAPEX	-18.20%	-18.83%	-25.39%	-23.91%
OPEX	-4.98%	-4.08%	-8.38%	-5.88%
Net AEP	1.08%	1.50%	1.72%	1.88%
LCOE	-14.52%	-17.29%	-21.37%	-22.16%

Table B.5 **Data relating to Figure 5.1.**

Impact of innovation on...	Conv cSi Ground	Conv cSi Roof	High Eff cSi Ground	High Eff cSi Roof
CAPEX	-4.40%	-2.21%	-5.20%	-2.78%
OPEX	-0.09%	-0.06%	-0.09%	-0.06%
Net AEP	0.00%	0.00%	0.00%	0.00%
LCOE	-2.90%	-1.80%	-3.59%	-2.30%

Table B.6 **Data relating to Figure 6.1.**

Impact of innovation on...	TF Ground	TF Roof
CAPEX	-32.59%	-27.40%
OPEX	-7.18%	-6.52%
Net AEP	2.99%	3.03%
LCOE	-25.11%	-25.47%

Table B.7 **Data relating to Figure 7.1.**

Impact of innovation on…	Conv cSi Ground	Conv cSi Roof	High Eff cSi Ground	High Eff cSi Roof	TF Ground	TF Roof
CAPEX	0.95%	1.85%	0.98%	2.25%	0.46%	0.06%
OPEX	-10.38%	-17.80%	-10.47%	-17.80%	-9.42%	-14.05%
Net AEP	1.48%	4.26%	1.45%	4.17%	1.11%	2.34%
LCOE	-4.41%	-5.85%	-4.02%	-5.26%	-4.38%	-4.99%

Table B.8 **Data relating to Figure 8.1.**

Impact of innovations on…	Conv cSi Ground	Conv cSi Roof	High Eff cSi Ground	High Eff cSi Roof	TF Ground	TF Roof
CAPEX	0.07%	0.00%	0.06%	0.00%	0.09%	0.00%
OPEX	-3.10%	-1.07%	-3.13%	-1.08%	-2.94%	-1.08%
Net AEP	0.34%	0.59%	0.34%	0.58%	0.34%	0.57%
LCOE	-1.37%	-0.78%	-1.28%	-0.76%	-1.41%	-0.78%

Table B.9 **Data relating to Figure 9.1.**

Impact of innovation on…	Conv cSi Ground	Conv cSi Roof	High Eff cSi Ground	High Eff cSi Roof	TF Ground	TF Roof
CAPEX	-20.72%	-19.33%	-28.21%	-24.55%	-32.13%	-27.62%
OPEX	-17.53%	-22.05%	-20.71%	-23.52%	-18.29%	-20.52%
Net AEP	2.90%	6.35%	3.51%	6.62%	4.42%	5.89%
LCOE	-21.88%	-24.62%	-28.36%	-29.07%	-29.93%	-30.30%

Table B.10 **Data relating to Figure 9.2.** (€k/MW)

Element	Conv c-Si Ground			HighEff c-Si Ground			TF Ground		
	15	20	30	15	20	30	15	20	30
Modules	576.00	518.96	410.36	722.00	614.53	465.99	481.00	387.37	238.74
Inverters	65.00	66.35	67.42	65.00	66.35	67.42	65.00	66.37	67.60
BoS structures	63.45	60.35	52.47	56.20	49.37	39.82	72.85	68.01	59.34
BoS electrical	11.10	10.50	9.06	9.83	8.59	6.88	12.74	11.84	10.28
Dev. Constr & instalation	164.00	162.23	158.00	145.26	141.58	136.53	188.30	185.50	180.54

Element	Conv c-Si Roof			HighEff c-Si Roof			TF Roof		
	15	20	30	15	20	30	15	20	30
Modules	604.80	562.45	449.64	758.10	669.69	531.55	505.05	408.04	253.18
Inverters	188.00	180.96	179.43	188.00	180.96	179.43	188.00	181.01	179.92
BoS structures	130.00	122.87	103.33	115.14	101.15	82.67	149.26	138.65	120.38
BoS electrical	300.00	285.00	239.59	265.71	234.61	191.68	344.44	321.68	279.88
Dev. Constr & instalation	95.00	93.95	91.07	84.14	82.09	79.36	109.07	107.45	104.58

Table B.11 **Data relating to Figure 9.3.**

Element	Units	Conv c-Si Ground			HighEff c-Si Ground			TF Ground		
		15	20	30	15	20	30	15	20	30
Operation and maintenance	€k/MW/yr	18.80	16.57	14.27	18.60	16.15	13.73	19.30	16.89	14.34
Other OPEX	€k/MW/yr	12.00	11.74	11.13	11.60	11.02	10.21	14.00	13.59	12.87
Net capacity factor	%	15.07	15.24	15.51	15.07	15.30	15.60	15.07	15.28	15.73

Element	Units	Conv c-Si Roof			HighEff c-Si Roof			TF Roof		
		15	20	30	15	20	30	15	20	30
Operations and Planned Maintenance	€k/MW/yr	20.00	18.00	15.59	20.00	17.75	15.30	21.30	19.31	16.93
Unplanned Service and Other OPEX	€k/MW/yr	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Net capacity factor	%	15.07	15.46	16.02	15.07	15.53	16.07	15.07	15.40	15.96

Table B.12 **Data relating to Figure 9.4.**

	Units	Conv c-Si Ground			HighEff c-Si Ground			TF Ground		
		15	20	30	15	20	30	15	20	30
Net capacity factor	%	15	15	16	15	15	16	15	15	16
LCOE with non-technical modifiers	€/MWh	77.71	64.11	48.69	84.75	62.70	43.09	88.60	69.94	49.28

	Units	Conv c-Si Roof			HighEff c-Si Roof			TF Roof		
		15	20	30	15	20	30	15	20	30
Net capacity factor	%	15	15	16	15	16	16	15	15	16
LCOE with non-technical modifiers	€/MWh	81.36	70.73	56.71	86.36	67.61	52.26	98.87	76.26	58.88

Table B.13 **Data relating to Figure 9.5.**

Innovation	Relative impact of innovation on LCOE
LCOE for a PV installation using Conventional c-Si technology with FID in 2015	100%
Advanced existing Homojunction technologies	7.1%
Improvement of inverter lifetime	3.9%
Improvement for Si material feedstock. FBR and metalurgical silicon	1.9%
Improvement of existing heterojunction & new generation of cell heterojunction design	1.7%
Innovative framing. frameless concepts	1.5%
Improvement in silicon crystallisation	1.3%
Innovations in wafering	0.9%
13 other innovations	3.5%
LCOE for a PV installation using Conventional c-Si tech with FID in 2030	78.1%

Table B.13 **Data relating to Figure 9.6.**

Innovation	Relative impact of innovation on LCOE
LCOE for a PV installation using High Efficiency c-Si technology with FID in 2015	100%
Improvement of existing heterojunction & new generation of cell heterojunction design	5.0%
Advanced existing Homojunction technologies	4.6%
Improvement of inverter lifetime	3.6%
Back contact cell structures	3.4%
Improvement for Si material feedstock, FBR and metalurgical silicon	2.2%
Innovative framing. frameless concepts	1.8%
Improvement in silicon crystallisation	1.5%
14 other innovations	6.2%
LCOE for a PV installation using High Efficiency c-Si tech with FID in 2030	71.6%

Table B.14 **Data relating to Figure 9.7.**

Innovation	Relative impact of innovation on LCOE
LCOE for a PV installation using TF technology with FID in 2015	100%
Reduce efficiency gap Lab cells-Fab modules	6.8%
Increase module efficiency	6.0%
Improvement of inverter lifetime	4.3%
Mitigation of degradation mechanisms	3.4%
Improved deposition techniques	2.8%
Development and integration of quality control methods	2.2%
Improved light management	1.8%
5 other innovations	2.5%
LCOE for a PV installation using TF technology with FID in 2030	70.1%

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