EUROPEAN COMMISSION
DIRECTORATE-GENERAL
JOINT RESEARCH CENTRE
Strategic Energy Technologies Information System (SETIS)

Key Performance Indicators for the Solar Europe Industrial Initiative

SETIS - EPIA – ESTELA

Version: 1

Date: 20 October 2011

Contents:

1. INTRODUCTION

1.1. Background

In March 2010 the Member States agreed to launch six EIIs of the SET-Plan and called for the establishment of a common set of principles and practices for their implementation, which include the development and systematic use of key performance indicators (KPIs). In response to this, the SET-Plan Information System (SETIS) has engaged with all the EII Teams to contribute to the identification and quantification of a preliminary set of KPIs, which were incorporated in the Implementation Plans for 2010-2012.

1.2. Scope

The present document describes the approved approach for monitoring the progress of the SEII projects.

It is intended to be used by SEII projects during planning (setting targets) and execution (periodic monitoring).

It has been developed by Commission staff representing SETIS, together with representatives of the photovoltaic and solar thermal electricity trade organisations, EPIA and ESTELA respectively. The key features (common to all the European Industrial Initiatives) are:

- An overarching KPI based on the levelised cost of electricity (LCOE), used to monitor the overall progress of the SEII towards increased cost competitiveness.

- Activity KPIs for measuring progress at project level – these address specific technological and system performance aspects, as detailed in the Implementation Plans for 2010-2012. Many of these have an impact on the LCOE parameter, but some may not.

- Targets (projections) for the KPIs for 2020, as well as any milestones deemed necessary.

- Guidance on reporting, including roles and data flow

In the following sections the KPIs for photovoltaics and solar thermal electricity are addressed separately, since they have separate implementation plans.

1.3. LCOE as overarching key performance indicator

Given that the initiative's main aim is to improve cost competitiveness, the use of the levelised cost of electricity parameter is deemed appropriate for monitoring the overall progress. It is stressed that the LCOE KPIs is not intended to be used in cost inter-comparisons with other technologies or EIIs.

The definition of the LCOE model for the SEII projects is based on the following considerations:

a) Given the restricted purpose of the LCOE KPI, a simplified calculation method is applied, whereby impact of a project's results is evaluated in comparison to a specified baseline case. Only the parameters relevant to a given project are varied, and all others are fixed as in the baseline case. N.B. This approach does not give valid absolute values because of the distortion created by the discount factor.

b) While both ESTELA and EPIA run sophisticated predictive LCOE models developed in collaboration with the consultants AT Kearney, for the purpose of the SEII KPIs simplified calculations can be run to assess the impact of specific variables. Sufficient information on the approach should be available to allow independent verification of the stated values.

c) In general, the LCOE KPIs do not take into account the calculation of any project risk. The societal costs and benefits of solar energy are neither quantified nor taken into consideration. The model does not deal with any revenues from the integration of solar energy into the grid system.

d) Because the objective of the model is to "monitor the technology progress", the discount rates is decided from the onset and not changed irrespective of the changing economic situation.

Definition of LCOE parameters for SEII Projects

- Capital investment cost (CAPEX): This is the project specific capital costs in euro per kWp of installed capacity. The system which determines capital costs includes all the elements needed to provide the grid with electricity according to the respective grid code standards. Plant costs include all the parts necessary for its functioning, including internal grid and substation and civil works: roads and other works, foundations, installation. When determining the LCOE for a number of reference plants as to assess the progress of the projects financed under the SEII, the capital investment cost should not includeAdministrative costs, permitting cost, costs related to the connection to the external grid,
  - Civil works outside the installation i.e. outside roads,
  - Financing costs,
  - Decommissioning costs.

Annualised O&M costs (OPEX): These costs include:
- Operation and maintenance costs including both fix and variable annual costs,
- Preventive and corrective maintenance,
- Condition monitoring,
- Any component replacement expected during the plant lifetime.

Annualised energy production is calculated on the basis of the average annual irradiation at the plant location and a capacity factor.
- Average annual irradiation: location dependent value of the average annual irradiation (direct normal irradiation is used for solar thermal electricity plants and concentrator photovoltaic installations; global horizontal irradiation under optimal inclination is used for flat-plate photovoltaics)

- Capacity factor can be expressed as follows:
    - Load factor: % of hours per year out of 8760 hours a plant delivers its rated power capacity
    - Performance Ratio: expressed as a % to indicate how much the PV system is producing under real conditions (in kWh AC) compared to how much the system should theoretically produce without any losses (thermal or conduction losses) under the same irradiation. Independent of location, the performance ratio is a measure of the quality of a PV plant. It is typically used in conjunction with the value of annual irradiation in kWh/m^2 for a specific location to arrive at the kWh/kWp electrical energy output.

Discount rate: A synthetic interest rate value used for a reference technology, which may or may not reflect various factors associated with technical risks and expected rates of return. As such the values presented for different technologies cannot be directly compared.

Project lifetime: This parameter is influenced by both economic and technical factors and therefore different definitions are feasible. For photovoltaics, the period of guaranteed power output is used as estimation of the lifetime of a PV projects. At the moment, most module manufacturers offer such guaranteed power output for a number of years. The current standard is 90% of the rated capacity after 10 years and 80% after 25 years. These values are however more conservative than the actual lifetime of certain PV projects, which is 30 years or even higher. For concentrated solar thermal plants a design lifetime of 40 years is used, which is comparable to that of fossil fuel power plants.

2. PHOTOVOLTAICS

Since many of the objectives of the projects under the SEII directly or indirectly contribute to lowering the cost of PV technologies; the generation cost of PV electricity is an appropriate indicator to assess the performance of different KPIs all-together. However, this does not mean that all KPIs are reflected in the generation cost of PV. Therefore, a two-step approach seems appropriate:

– The generation cost serves as a baseline 'umbrella' KPI that covers many different 2nd tier activity KPIs,
– Other activity KPIs that do not clearly affect the generation cost are listed separately.

2.1. LCOE KPI

At the moment, the LCOE values for PV systems in Europe cover quite a large range. This reflects not only the differences in the irradiation levels, but also:
- National differences in financial stability (reflected in the discount factor),
- National differences in installation cost and in O&M costs,
- Differences in technologies, market segments & type of applications (residential, commercial, industrial and utility-scale).

We have therefore selected six different reference plants, based on typical existing installations in three of the main EU markets. They include the four different market segments with their typical sizes. In addition there are two more reference systems, namely for concentrator photovoltaics (CPV) and building-integrated photovoltaics (BIPV). For the former, the reference values have been estimated based on experience with the first large-scale CPV installations in Spain. For BIPV, however, it is not yet possible to formulate a representative reference case given the large variety of designs used up to now. The characteristics of these six reference plants and the assumptions for calculation of the LCOE KPI are indicated in Table 1.

Table 1 Proposed Reference Key Performance Indicators for PV

PV REFERENCE SYSTEM	Residential rooftop (Germany)	Commercial rooftop (Italy)	Industrial rooftop (Germany)	Utility scale (Spain)	Concentrator photovoltaics-CPV (Spain)	Building-integrated photovoltaics-BIPV
System size (kWp)	3	100	500	2500	2500	-
Average Global Horizontal Irradiation (kWh/m²)	±1150	±1550	±1150	±1550	N/A	-
Average irradiation at optimal inclination (kWh/m²)	±1300	±1800	±1300	±1800	±2050[1]	-
Technology	c-Si	c-Si	TF	c-Si	CPV	BIPV
Capital investment cost (€/W)	3.11	2.52	2.44	2.16	3.50	-
O&M costs (expressed as fixed annual cost in €/W, excluding inverter replacements)[2]	0.016	0.027	0.027	0.027	0.028	-
Performance Ratio (%)	75	80	80	80	76	-
Discount rate (%)	4.4	6.5	6.5	6.5	6.5	-
Guaranteed power output time (years)	25	25	25	25	25	-
Baseline (2010) LCOE[3]	0.26	0.19	0.25	0.17	0.20	-

---

[1] For CPV systems the direct normal irradiation (DNI) is the relevant measure.

[2] For the calculation of the LCOE other cost elements related to O&M are included, such as 1 inverter replacement and a profit margin for O&M executors.

[3] LCOE varies depending on the financing conditions (discount rate) and location (irradiation). Moreover, there are significant differences between the countries in terms of administrative costs, VAT and the cost for grid connection. Finally also the installed system cost and the cost for O&M are not similar across the countries. However, because these differences are related to market and/or legal conditions, they have not been taken into account in the calculation of the baseline LCOE, neither in the calculation of the targets for 2015 and 2020.

2.2. KPIs and Targets

The KPIs and their targets are listed in the tables below. The first table indicates the state-of-the art of the LCOE as well as the targets for the six reference cases. The second table outlines the KPIs that impact LCOE and are divided into the three sub-initiatives as identified in the Implementation Plan 2010-2012 (May 2010). The third and last table shows the KPIs that do not directly impact LCOE, but are nonetheless highly important.

Table 2 LCOE Baseline and targets for the six PV reference cases

Description	Metric	BASELINE	TARGETS	
		2010	2015	2020
Competitiveness	Ref. Case 1 (3 kWp, Germany, c-Si)	0.26	0.18	0.13
	Ref. Case 2 (100 kWp, Italy, c-Si)	0.19	0.13	0.10
	Ref. Case 3 (500 kWp, Germany, TF)	0.25	0.16	0.12
	Ref. Case 4 (2500 kWp, Spain, c-Si)	0.17	0.12	0.09
	Ref. Case 5 (2500 kWp, Spain, CPV)	0.20	0.11	0.09
	Ref. Case 6 (3 kWp, Germany, innovative BIPV) – delta[4]	Demo phase	+50%	+25%

[4] It is at the moment not feasible to present a reference case for innovative BIPV, because of the diversity of products (and prices) on the market today. Therefore, we have expressed the targets for 2015 and 2020 as a “delta”, which expresses the difference in LCOE between a 3kWp BAPV (reference case 1) and a 3kWp innovative BIPV installation. This “delta” represents the additional generation cost (in €/kWh) of an innovative BIPV system compared to a BAPV system of the same size. It takes into account the differences in terms of electricity production and costs but not other additional benefits of BIPV because they are difficult to quantify. As such, the replacement of other building materials is not considered; moreover it is not relevant for the KPIs within the SEII, because it is a benefit that should be considered separate from any PV technology enhancements.

Table 3 Activity KPIs and associated targets for PV

Description	Metric		BASELINE	TARGETS	
			2010	2015	2020
A.Cost reduction	CAPEX for large systems – 2.5 MWp (€/Wp)[5]		2.3	1.6	1.3
	Module efficiency[6]	c-Si (high efficiency[7])	13-16% (19%)	14-18% (21%)	16-20% % (23%)
		TF	6-12%	8-14%	10-16%
		CPV	25-28%	28-33%	33-40%
	Inverter lifetime (years)		15	20	>25
	Module 80% guaranteed power output time (years)[8]		25	30	>35
	System performance ratio (%)[9] (private investor - business investor)		75-80	78-83	81-86
B.1.System integration - grids	Private self consumption/Grid export[10]		30%/70%	40%/60%	50%/50%
	Grid support		MW grid support	LV grid support	LV grid support
	Production forecasting for short-term demand management		Demo phase	Hourly	15 min integrated at TSO level.
B.2.System integration – innovative building integration	Energy output (kWh/m²)		80	105	130
C.Preparing for cost and penetration beyond 2020 levels[11]	Efficiency for emerging technologies		<7-12% Lab-scale	10-15% Lab-scale	>10% commercial
			<5% Pre-commercial	<10% Pre-commercial	
	Efficiency for novel technologies		NA	NA	>25%
	Performance stability[12]		<5	5-15	>15
	Commercial module cost for emerging technologies (€/Wp)		NA	NA	0.5-0.8

---

5 The system price depends not only on technology advances but also on the maturity of the market (which includes industry infrastructure as well as administrative costs).

6 The efficiency as expressed here represents the total area efficiency of the module. The module efficiency affects the BoS (balance of system) cost. However, many more parameters that impact the efficiency at PV array level also define the level of BoS costs.

7 The efficiency as indicated between brackets refers to high efficiency c-Si PV modules, which are also sold at higher prices compared to the other c-Si PV modules.

8 Because the lifetime of a PV project is rather difficult to estimate, we prefer to approach this by using the guaranteed power output. At the moment, most module manufacturers offer such guaranteed power output for a number of years. The current standard is 90% of the rated capacity after 10 years and 80% after 25 years. These values are however more conservative than the proven lifetime of certain PV projects which can be 30 years or even higher. Moreover, 25 years represents a conservative industry-wide average, including all PV technologies.

9 In reality the performance ratio does not only depend on the type of investor, but on the technology, the specificities of the installation, the components used, etc.

10 This is only the case for residential systems. Storage, demand side management and PV system design are the main drivers behind this KPI. For other applications, such as commercial/industrial rooftops, the level of self-consumption can be significantly higher.

11 Emerging technologies include organic photovoltaics, dye-sentisized solar cells and advanced inorganic thin film technologies. Novel technologies include quantum technologies and technologies using nanoparticles. Lab-scale:

Table 4 Additional KPIs (not directly related to LCOE) for PV

Description	Metric	BASELINE	TARGETS	
		2010	2015	2020
Sustainability	Energy Payback time (1700 kWh/m², rooftop system, optimal inclination)	0.5<...<1.4	<1	<0.5
	Availability recycling process/technology for TF and novel technologies	R&D phase	Pilot line	Commercial
Standardisation	IT and ancillary services for smart grid application	Key area in which R&D and demonstration projects are highly recommended.		
	Compliance of BIPV products with building regulation			
Progress parameters	Demonstration of high-quality, versatile integration of PV in buildings and infrastructural objects	0	KPIs: Number + size of the projects	
	# of advanced pilot lines for ultra-low cost (printable) PV technologies			
	# of proofs of concept for very-high efficiency novel PV technologies			
	# of proofs of concept for very high levels of PV penetration			
	Large-scale CPV power plant (20MW) with tracking system			
	Large-scale CIGS power plant (40MW)			
	Large-scale tandem/triple junction TF silicon power plant (40MW)			
	Demonstration of high penetration in urban and isolated environments			

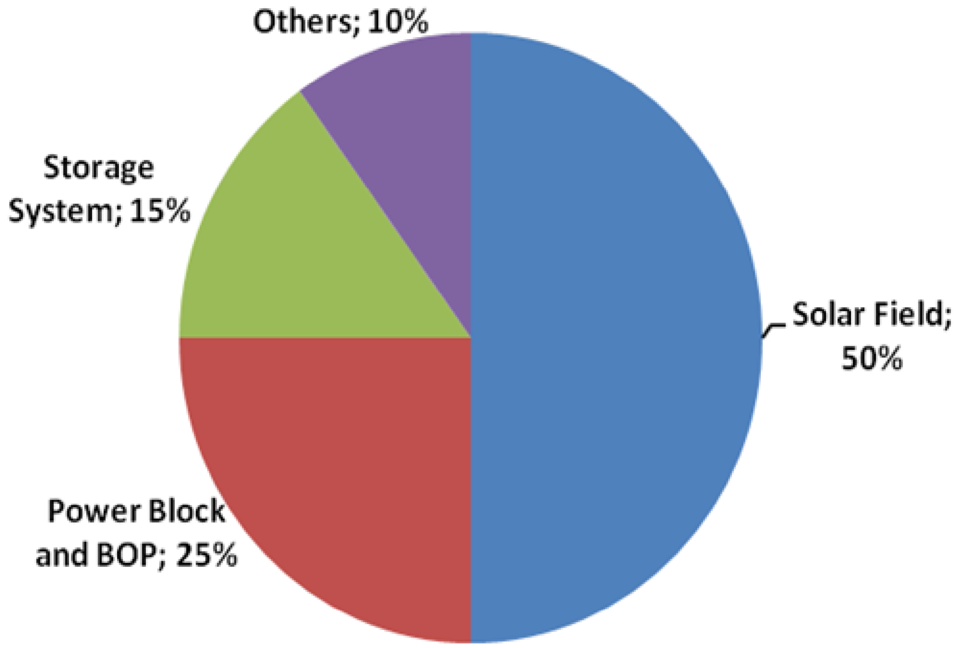
cell area below 10cm²; Pre-commercial: Sub-module area (combination of ~10 cells) below 0.1m² for consumer application; Commercial: real scale module size > 0.5m²

[12] This encompasses the intrinsic stability of the materials used in the active layer, the stability of the cells' nanomorphology and the stability of the contact between metal conductors and organic semiconductors.

3. SOLAR THRMAL ELECTRICITY

3.1. LCOE KPI Baseline

For the purpose of SEII project monitoring, the baseline/reference Solar Thermal Electricity plants is 50 MW[13] parabolic trough installation located in the south of Europe, with DNI of around 2050 kWh/m². The simplified cost breakdown structure of a 50 MW STE plant with 7,5 hours of storage is considered as follows:



.

Table 5 below shows the assumptions for calculation of the reference LCOE KPI.

[13] The plant size (50 MW) reflects restrictions imposed by current licensing requirements in Spain, the location of majority of European demonstration plants.

Table 5: CSP Reference Case Assumptions (reference year is 2010)

CSP REFERENCE SYSTEM	DNI 2050, kWh/m².
Technology	Trough
Plant capacity (MW)	50 MW
Capital investment cost (€/kW)	5,600 €/kW
O&M costs (inc. fixed annual costs, €/MWh)	35 €/MWh
Capacity factor (%)	38.8
Discount rate (%)	9[14]
Project lifetime	40 years
Baseline LCOE for 2010	**22 c€/kWh**

Notes:

1) Even though Solar Thermal Electricity includes four different technologies (parabolic trough, Fresnel, tower and dish), the LCOE KPI is established for parabolic trough technology only. This is because there are not enough installations of the other technologies so as to set a reference value. Nevertheless, in the near future, baselines will be set for all technologies.

2) As previously mentioned the reference plant has a 50MW capacity and the established KPIs have been established based on it together with the targets for 2020. Nevertheless, it should be noted that with an increase in capacity the costs fall considerably. This is true not just because of the fact that a 100MW turbine is less expensive than two 50MW but also because of savings in piping and components that are proportionally cheaper as the turbine increases in size.

3.2. <u>KPIs and Targets</u>

The following table summarises the proposed targets.

[14] With a Discount Rate of 6.5% the LCOE would go down to 16 c€/kWh

Table 6: KPIs and associated targets for concentrated solar thermal plants

OVER-ARCHING KPI				
Description	**Metric**	**Values**		
		BASELINE	**TARGETS**	
		2010	**2013**	**2020**
Competitiveness	Levelized cost of electricity (c€/kWh) for a 50 MW plant located in southern Europe with a local DNI of 2050 kW/h m².	22 c€/kWh	-10%	-35%
ACTIVITY KPIs				
Description	**Metric**	**BASELINE**	**TARGETS**	
		2010	**2013**	**2020**
1. Increase efficiency and reduce costs	Increased solar to electricity conversion efficiency	15% Trough 8.5% Fresnel 17% Dish 12.5% Tower	(relative to baseline) +5% Trough +5% Dish +50% Tower	(relative to baseline) +20% Trough +30% Fresnel +20% Dish +15% Tower[15]
	Increase Heat Collecting Fluid Temperature.	400°C Trough 280°C Fresnel 750°C Dish 250°C Tower	560°C Tower	>500°C Trough 500°C Fresnel >900°C Dish >900°C Tower
	Reduce cost of installed products and O&M for state-of-the-art commercial plants	6 M€/annually	-10%	-20%
	Number of "down-time" hours per year (plant reliability).	100 hrs/annually	+20%	
2. Increase Dispatchability [Figures concerning storage are based only on molten salts technology].	Investment cost of storage, €/MWht	35,000 €/MWht	20,000	15,000
	Increase efficiency of storage %	94%		96%
	Decrease size of storage, m3/MWht.	28 m3/MWht	-30%	-50%
3. Improve the environmental profile	Substantial reduction of water consumption with only minor loss of performance relative to current water cooling system	3.5 liters/kWh		< 1 liter/kWh

[15] Relative to 2013 value, after technological breakthrough

4. REPORTING

The practical implementation of the monitoring system requires a flow of information from the projects to the SEII Team and to SETIS.

Project Planning Stage

In collaboration with SETIS, each project defines how its targets relate to the activity KPIs defined in the implementation plan, and therefore implicitly also to the overarching LCOE KPI.

The reporting requirements and deadlines in relation to progress on the KPIs is agreed (this may be part of the periodic or annual reporting obligations to the funding authorities, or a specific communication to SETIS).

Project Execution

The project provides the agreed reporting data to SETIS.

Data Management

Unless otherwise agreed, the data on KPIs provided to SETIS will remain confidential to the SEII team and the SET-Plan steering group.