UNIVERSIDAD DE JAÉN

ESCUELA POLITÉCNICA SUPERIOR
DE JAÉN
DEPARTAMENTO DE INGENIERÍA
ELECTRÓNICA Y AUTOMÁTICA

TESIS DOCTORAL

TECHNICAL ISSUES IN THE FINANCING OF UTILITY-SCALE PHOTOVOLTAICS PROJECTS

PRESENTADA POR:
D. PABLO ÁNGEL VALERA MARTÍNEZ

DIRIGIDA POR:
DR. D. GABINO ALMONACID PUCHE
DR. D. VICENTE SALAS MERINO

JAÉN, 29 DE SEPTIEMBRE DE 2016

ISBN 978-84-9159-023-1

To Piedad, my wife,
to my children, Andrea and Pablo,
and to my parents Antonio and Angela

ACKNOWLEDGEMENTS

A million thanks to my wife, Piedad, to my children, Andrea and Pablo, they have been my inspiration to reach this particular goal in my life. Without their love and care throughout my journey of growth, I would not be what I am today.

Thanks also to my father, Antonio, and my mother, Angela, for raising me with their unconditional love and always reminding me about the importance of working hard to gain knowledge. They have sacrificed so much in order to provide the best environment for me to concentrate on study without worrying too much about financial problems. This is the same thing I want to remind my children, the importance of working hard to gain knowledge every minute of their life.

Thanks also to my brothers (Antonio, Javier and Ignacio) and my shareholder partner in ATA, Oscar (like a brother for me), whose have been a reference all the time.

I would like to express my sincere gratitude to my thesis supervisors, Prof. Gabino Almonacid and the Associate Prof. Vicente Salas for giving valuable sources of knowledge and unlimited encouragement throughout this research, especially when I encountered difficult situations in the process. The motivations given by them have greatly strengthened my confidence in continuing this research and thesis.

I wish to thank ATA staff. They have given supportive in the collection of results of the different projects shown in this PhD document.

I do not want to forget my experience in Abengoa company where I learnt how to manage projects and either to my good friend Manuel Cabrerizo with who I learnt how Project Finance works. And I would also like to thank greatly to my good friend Esteban Fernández Rozado which showed me that friends are when they are needed.

Finally, kisses to the rest of my family Valera and Martínez, and also for Lola, Linda and Misi, the family pets.

ABREVIATIONS

Abbreviations	**Description**
AM	Capital Expenditures
BoS	Balance of System
CAPEX	Capital Expenditures
DD	Due Diligence
EAC	It is the actual energy produced by the PV system in a given period of time (typically one year)
EPC	Engineering, Procurement and Construction
ESS	Energy Storage System
FAC	Final Acceptance Certificate
GHI	Available Global Radiation
GOES	Geostationary Operational Environmental (Satellite)
IDD	Insurance Due Diligence
ITA	Independent Technical Advisory
ITC	Investment Tax Credit
LDD	Legal Due Diligence
LCOE	Levelized Cost Of Electricity
MFG	Meteosat First Generation (satellites)
MRA	Maintenance Reserve Account
MSG	Meteosat Second Generation (satellites)
NTP	Notice to Proceed
EPC	Engineering, Procurement and Construction
LCC	Life-Cycle Cost
OE	Owners Engineering
O&M	Operation and Maintenance
OPEX	Operating Expenditures
PAC	Provisional Acceptance Certificate
PDD	Product Due Diligence
PLA	Permits, Licenses & Authorizations
PPA	Power Purchase Agreement
QA	Quality Assurance
QC	Quality Control
PR	Performance Ratio
SPV	Special Purpose Vehicle
SR & E	Solar Resource Analysis and Energy Estimation
TDD	Technical Due Diligence
TMY	Time Meteorological Year

Título: Aspectos Técnicos en la Financiación de Proyectos de Grandes Plantas Fotovoltaicas

ÍNDICE

Introducción

El aprovechamiento de las energías renovables en general, y la Energía Solar Fotovoltaica (ESFV) en particular, se caracteriza por tener muy bajos costes de operación y mantenimiento (O&M), pero a cambio requieren grandes inversiones iniciales. Por tanto, su utilización y desarrollo están ligados a un adecuado sistema de financiación con planes específicos de amortización que permitan, por una parte afrontar la inversión inicial, y por otra, el pago de la deuda con los beneficios que supone la generación de energía con un coste de O&M muy reducido [1] [2].Los proyectos de energía fotovoltaica a gran escala han experimentado un enorme crecimiento en el mundo en los últimos años; especialmente en EE.UU., China, Sudáfrica, Chile, India y Japón. El presupuesto considerable de este tipo de proyectos requiere el desarrollo de métodos de financiación especialmente adaptados a esta necesidad.

Como se analizará más adelante, existen diferentes mecanismos de financiación para proyectos fotovoltaicos de tamaño de mega-vatios de potencia, pero el más común es el llamado "*Project Finance*" (o financiación de proyectos). Ésta se puede definir como la financiación a largo plazo de infraestructuras, proyectos industriales o de servicio público -en nuestro caso, grandes proyectos fotovoltaicos- en base a una estructura financiera con recursos propios limitados, donde la deuda que se utiliza para financiar el proyecto se paga con el flujo de caja generado por el proyecto. El objetivo es la financiación de la instalación fotovoltaica sin riesgos para el interesado.

Este mecanismo financiero comienza a utilizarse en las últimas décadas del siglo pasado para financiación de inversiones de gran envergadura y que se sustenta tanto, en la capacidad del proyecto para generar flujos de caja que puedan atender la devolución de los préstamos, como en contratos entre diversos participantes que aseguran la rentabilidad del proyecto [3] [4] [5]. El aumento de grandes inversiones en infraestructuras y la tendencia de los gobiernos a reducir sus niveles de déficit presupuestario, ha sido un hecho fundamental en el desarrollo del "*Project Finance*". Esta herramienta financiera ha sido de uso generalizado en la implantación del sector de las telecomunicaciones. Sin embargo, en la actualidad, ha tomado mucha fuerza en otros sectores como el eléctrico y la generación de energía. Más concretamente, grandes parques fotovoltaicos y eólicos son financiados mediante esta modalidad, pues la propia naturaleza de este tipo de proyectos se adapta plenamente a la filosofía del "*Project Finance*".

Para poder utilizar este tipo de financiación, avalada por el propio proyecto, es esencial evaluar a fondo los aspectos técnicos del mismo para asegurar que la inversión se basa en los datos verificados y fiables de proyecto [6] [7]. Por lo tanto, un objetivo principal en una planta de energía fotovoltaica financiada con esta herramienta es asegurar que la planta funciona de forma continua y fiable, para generar la máxima energía y el máximo rendimiento económico.

El enorme crecimiento de instalaciones de grandes plantas fotovoltaicas que tuvo lugar en España (2008), Alemania (entre 2010 y 2012) e Italia (2011), a menudo ha creado expectativas poco realistas de los beneficios que la energía solar era capaz de producir. La crisis de la eurozona y, por tanto, la retirada de las subvenciones estatales están obligando a tener una visión más realista de las cosas y orientando a aprovechar, con más éxito, las ventajas de la fotovoltaica a largo plazo. Cada vez más inversores están reconociendo el hecho de que la tecnología ha madurado y el riesgo de impago es bajo. La inversión y los precios de la energía no están vinculados a las incertidumbres del mercado del petróleo. Y el sol suministra su energía en forma gratuita, lo que da a la energía fotovoltaica una ventaja fundamental. Todo ello está motivando un disminución creciente del precio de la electricidad procedente de grandes instalaciones fotovoltaicas, especialmente en Estados Unidos de América, Figura R.1.

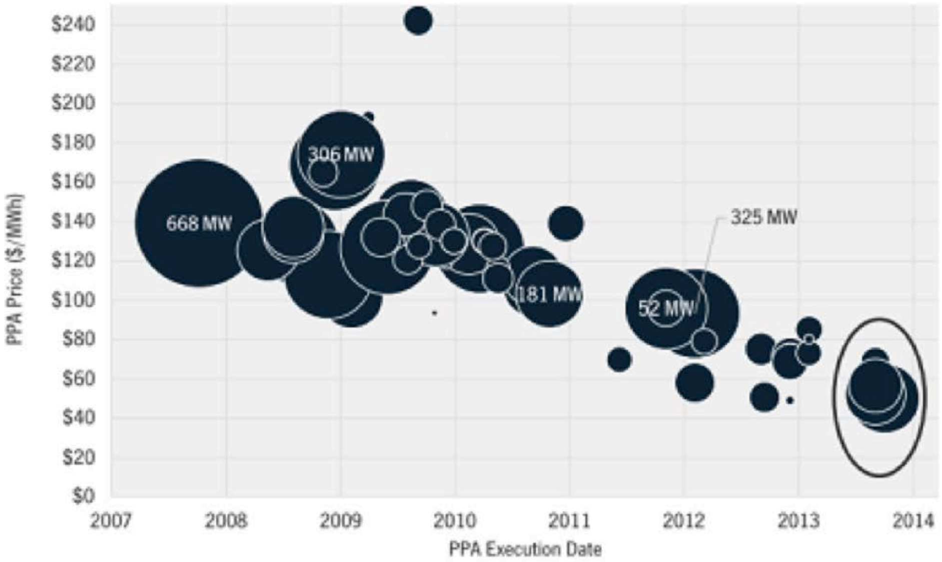


Figura R.1: Evolución del PPA ($/MWh) en los Estados Unidos de América (Fuente: GTM Research)

Un dato significativo es que el pasado mes de julio de 2015 una red eléctrica de Nevada (Warren Buffett) ha puesto en la línea eléctrica lo que puede ser la electricidad más barata en los EE.UU, procedente de una planta FV. Esta empresa eléctrica acordó pagar 3,87 centavos de dólar por kilovatio-hora de energía procedente de un proyecto de 100 megavatios que está desarrollando First Solar Inc. [8]. Otro ejemplo significativo fuera de los estados Unidos es, por ejemplo, el acuerdo por 25 años firmado entre *Dubai Electricity and Water Authority* (DEWA) y los accionistas del *Mohammed bin Rashid Al Maktoum Solar Park* para una ampliación de la instalación de 200 MW, con el hito de generar a una tarifa de 5.84 c$/kWh [9]. Recientemente, se han publicado precios de energía para una licitación fotovoltaica de 800 MW en Oriente Medio cercanos a los 3 US$/kWh.

En todo caso, los bancos requieren incluir en el contrato algunas exigencias para que éste sea considerado adecuado en el ámbito bancario. Como se muestra en esta tesis, la validez bancaria de estos proyectos no se limita únicamente a incluir un modelado de su rendimiento energético basado en una campaña de mediciones in situ [10] [11] [12]. Es necesario analizar más aspectos. Con ese fin, las *"Due Diligences"* (diligencia debida) (DD) es una herramienta que se utiliza como el recurso más frecuente para la gestión de riesgos. Este proceso a menudo se divide en tres: *Legal Due Diligence* (LDD), *Technical Due Diligence* (TDD) e *Insurance Due Diligence* (IDD). La *Due Diligence* Técnica (TDD) comprende todos los aspectos técnicos de un proyecto, antes del cierre financiero, desde la estimación de la producción a los acuerdos contractuales y los costes. Por lo tanto, los objetivos principales de la TDD son: identificar los riesgos técnicos que podrían comprometer el funcionamiento y la rentabilidad del proyecto, asegurarse de su viabilidad técnica y de que todos los factores se han tenido en cuenta en el proceso de desarrollo [13] [14].

Con el fin de identificar adecuadamente, gestionar y minimizar los diferentes riesgos es muy útil disponer de soporte técnico cualificado. Una Asesoría Técnica Independiente (ITA) es imprescindible para prestar los servicios de soporte técnico y elaborar la TDD. La TDD es un trabajo intenso de revisión y evaluación que puede, potencialmente, estar sujeto al sesgo del revisor individual o asesor técnico [15]. En ese sentido se hace necesario desarrollar métodos y/o herramientas de asistencia al proceso que ayuden a reducir la subjetividad y permitan comparaciones y evaluaciones objetivas [16] [17].

En el proceso de financiación, estos proyectos pasan por diferentes etapas, anteriores y posteriores al acuerdo de financiación (*Cierre Financiero*). La TDD es una tarea clave en la etapa previa al acuerdo. Además, en las etapas posteriores requieren otras actividades de asesoramiento técnico, tales como el seguimiento de la construcción, Certificación de la Recepción Provisional (PAC), Certificación y pruebas de Aceptación Final (FAC), Seguimiento del Periodo de Garantía y Monitorización de la Operación y el Mantenimiento (O&M) de la planta. En definitiva el objetivo del asesoramiento técnico independiente es determinar primero y asegurar después la viabilidad técnica del proyecto propuesto.

Por otra parte, aunque la tecnología fotovoltaica basada en el silicio cristalino se puede considerar una tecnología madura, no deja de ser una tecnología nueva con pocos años de experiencia que, especialmente en grandes instalaciones conectadas a red, casi no alcanza los diez años en un contexto mundial. La revisión y el análisis de funcionamiento de grandes plantas FV es una tarea en marcha que necesita todavía estudio y trabajo, fundamentalmente tecnológico. Se necesita obtener conclusiones que permitan conocer mejor: la detección de fallos y errores de funcionamiento, la optimización de diseños y el perfeccionamiento de alguno de los dispositivos que interviene en la instalación. Éstas son tareas específicas de desarrollo e innovación adecuadas para una investigación de carácter tecnológico. En definitiva, la tecnología FV basada en el Si es un campo dónde un tecnólogo tiene todavía mucho que hacer. En este momento además, con la masiva instalación de grandes plantas FV durante los últimos años, -no sólo en España, dónde este proceso se ha detenido bruscamente, sino también en otros países, donde se ha producido de forma más ordenada y sigue creciendo continuamente-, se ha propiciado un campo de estudio teórico y experimental que es necesario abordar [18] [19]

De acuerdo con las consideraciones anteriores, el objetivo de este trabajo de tesis es: en primer lugar, analizar a fondo, y comprender, los procesos técnicos y de gestión de grandes proyectos de energía fotovoltaica, y luego, estructurar las diferentes fases del proceso para identificar adecuadamente las tareas de asesoramiento técnico necesario para hacerlo viable para una financiación basada en el proyecto; En segundo lugar, y teniendo en cuenta este estudio, se propone una forma de hacer las cosas para la Asesoría Técnica Independiente (ITA), con fases, tareas y acciones claramente definidas -incluido TDD-, de manera que se reduce la subjetividad del proceso, permitiendo una ITA objetiva y de alta calidad, para reducir los riesgos y asegurar los resultados y el éxito del proyecto.

Resumen

Para ello, en el Capítulo 2 hemos hecho una revisión previa del estado del arte de los grandes generadores fotovoltaicos y sus fundamentos. En él se revisan algunas de las mayores plantas FV en el mundo hasta 2015, y algunos otros datos de mercado en el sector FV, Tabla R.1.

Tabla R.1: Top 5 de las mayores plantas fotovoltaicas conectadas a red en el mundo

Nombre	País	Capacidad (MW)
Gujarat Solar Park	India	590
Solar Star (I and II)	E.E.U.U.	579
Topaz Solar Farm	E.E.U.U.	550
Desert Sunlight	E.E.U.U.	550
Copper Mountain Solar Facility	E.E.U.U.	458

También se revisan conceptos teóricos, importantes para este análsis, tanto técnicos: eficiencia, productividad, factor de comportamiento, pérdidas, etc.; como económicos: paridad de red, coste del ciclo de vida, coste normalizado de la electricidad (Levelized Cost Of Electricity, LCOE)

En el Capítulo 3 se ha realizado un profundo análisis del proceso de desarrollo e implementación de grandes proyectos de energía fotovoltaica, y también de la estructura de gestión para ejecutarlo. En este capítulo se establecen las principales fases y tareas de un gran proyecto fotovoltaico; además, se han estructurado y temporalizado, con el fin de estudiar y definir las tareas, funciones y responsabilidades de la asesoría técnica independiente, Figura R.2.

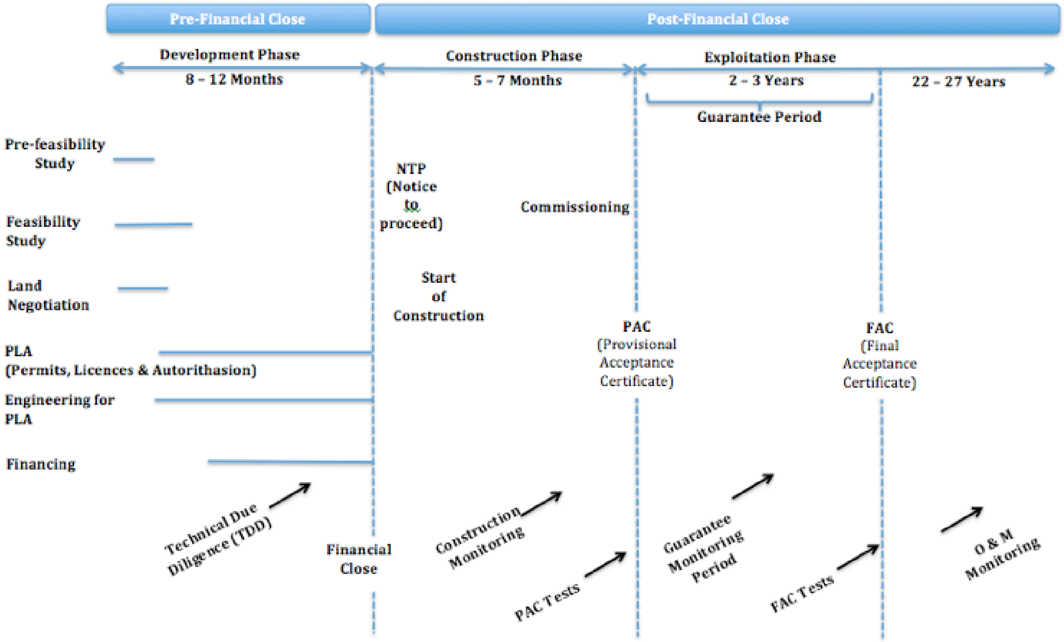


Figura R.2: Esquema temporal de una gran planta fotovoltaica de 20 MW

En el Capítulo 4 se plantean los mecanismos de financiación, centrándose en la financiación de proyectos (“*Project Finance*”) como la principal herramienta para la financiación de proyectos fotovoltaicos de gran tamaño. En este capítulo se presenta el gráfico denominado Constelación del "*Project Finance*" que es un instrumento muy adecuado para entender, y resumir gráficamente, la totalidad de los actores involucrados en este proceso, Figura R.3. En él, no sólo se identifican los participantes, sino que también se describe la interrelación entre ellos y las misiones, tareas y deberes principales de cada uno.

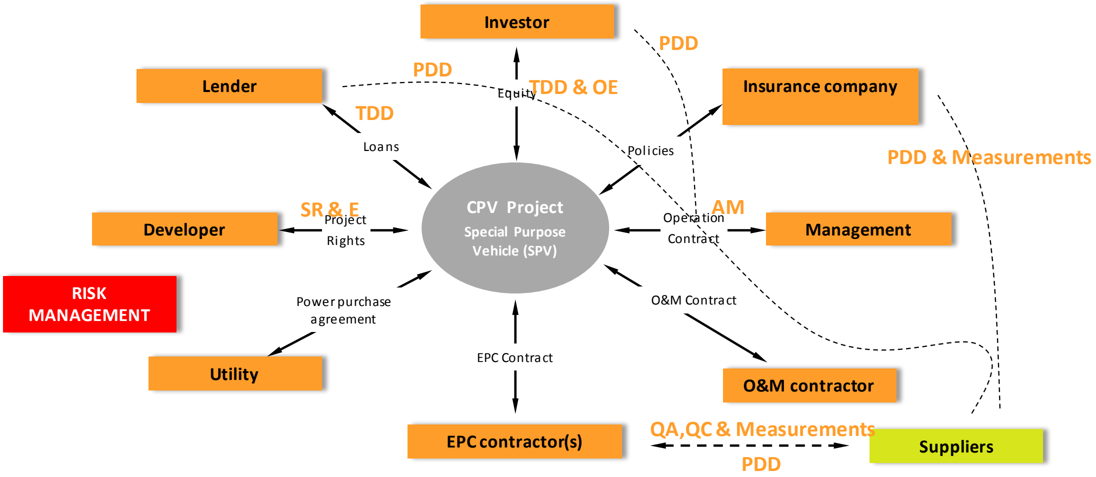


Figura R.3: Constelación de un “*Proyect Finance*” implementado en un proyecto de una gran planta fotovoltaica

En el Capítulo 5 se estudian los principales riesgos técnicos en un proyecto fotovoltaico de gran tamaño y se describe el asesoramiento técnico independiente, con el desglose y descripción de todas sus tareas y actividades, planteándose como la principal herramienta para identificar, evaluar, controlar y mitigar dichos riesgos.

Por último, -antes de plantear las conclusiones que se incluyen en el siguiente apartado de este resumen-, en el Capítulo 6 se presenta la metodología para la estimación del recurso solar y producción energética de una planta FV, con aplicación a un caso real (proyecto de 182 MW conectado a la red en Moree, Australia). Además, se han contrastado los resultados del procedimiento con las medidas experimentales en cinco proyectos distribuidos en diferentes zonas del mundo, Tabla R.2.

Tabla R.2: Comparación de los PR (calculados y reales) para varias plantas FV

PR (UPDATED PR CALCULATION Vs REAL)						
Project	**Updated Estimation 1st year**	**REAL 1st year**	**Updated Estimation 2nd year**	**REAL 2nd year**	**Deviation 1st year**	**Deviation 2nd year**
A	82,2%	87,1%	82,3%	85,9%	5,9%	4,3%
B	79,0%	78,5%	79,2%	77,9%	-0,7%	-1,6%
C	83,7%	87,0%	-	-	3,9%	-
D	84,1%	85,5%	-	-	1,6%	-
E	84,6%	87,7%	-	-	3,7%	-

En esta memoria se incluyen finalmente una relación de las publicaciones generadas durante la realización de los trabajos de esta tesis.

Este trabajo se ha desarrollado en el marco del Centro de Estudios Avanzados en Energía y Medio Ambiente (CEAEMA) de la Universidad de Jaén, en colaboración con el Departamento de Tecnología Electrónica de la Universidad Carlos III de Madrid (UC3M) y con la empresa Astrom Téchnical Advisors (ATA). Este entorno, ha propiciado un soporte científico y tecnológico adecuado para el desarrollo de esta tesis, y se han podido aprovechar los datos, la experiencia y el conocimiento de grupos tan consolidados como el Grupo IDEA de Investigación en Energía Solar de la UJA [20] [21], el Grupo de Sistemas Electrónicos de Potencia (GSEP) de la UC3M [22] [23]; y de la empresa ATA, esta última con una ya larga experiencia en análisis de proyectos de inversión en sistemas FV mediante TDD y en seguimiento de los mismos, con evaluación de la O&M de grandes plantas FV [16] [24] [25]. Especialmente esto último ha permitido la validación de los procedimientos y resultados de la misma.

Conclusiones

El precio de la electricidad procedente de FV está disminuyendo hasta alcanzar valores competitivos con los de la electricidad convencional, no sólo a nivel de consumo, sino también a nivel de generación. Por lo tanto, las centrales fotovoltaicas de gran tamaño están creciendo en todo el mundo. El presupuesto de estos proyectos de gran escala (MW) requiere herramientas específicas de financiación. Estas herramientas, basadas en el flujo de efectivo generado por el proyecto para responder a la deuda, hacen necesario un asesoramiento técnico exhaustivo y de alta calidad para asegurar la fiabilidad del proyecto.

Por otro lado, a pesar de que los sistemas fotovoltaicos basados en tecnología de Si han alcanzado un alto nivel de desarrollo y madurez, no hay, sin embargo, experiencia suficiente sobre el funcionamiento y las prestaciones de este tipo de grandes instalaciones fotovoltaicas. Esto hace que sea necesario un Asesoramiento Técnico Independiente (ATI) objetivo y de calidad, con procedimientos y las tareas bien definidas.

Ése ha sido el enfoque y el marco de los trabajos realizados en esta tesis, cuyas principales conclusiones y aportaciones se pueden resumir en:

1. Se ha hecho una revisión de los fundamentos y el estado actual de las grandes plantas de energía fotovoltaica. Se ha referenciado un precio de la electricidad procedente de FV tan bajo como 3,87 centavos de dólar por kilovatio-hora de energía. Esto demuestra que el crecimiento emergente de grandes instalaciones fotovoltaicas está sólo en sus inicios.

2. Se ha realizado un análisis exhaustivo para identificar y entender los procesos técnicos y de gestión de grandes proyectos de energía fotovoltaica y, a continuación, hemos realizado un estudio del proceso de desarrollo de grandes proyectos de energía fotovoltaica y de la estructura de gestión para ejecutarlos. Hemos estructurado las diferentes fases del proceso y la programación de los tiempos, en relación con los trabajos para el ATI; con el fin de estudiar y definir las tareas, funciones y responsabilidades del asesor técnico independiente. Hemos mostrado todo ello: estructura de gestión, fases tareas, programación temporal, etc., a través de un gráfico relativamente sencillo y fácil de entender.

3. Se han analizado la estructura, instituciones participantes, fases, tareas, etc. y su interrelación en un modelo típico de "*Project Finance*". Todo ello se muestra y resume en el llamado *"Constelación del Project Finance"*; en él no sólo se identifican los intervinientes, sino que también se describen la interrelación entre ellos y las misiones, tareas y deberes de cada uno.

4. Se ha hecho un análisis de riesgos técnicos de las grandes plantas de energía fotovoltaica y los procedimiento para identificar, evaluar, controlar y mitigar el dichos riesgos a través del de asesoramiento técnico independiente (ATI).

5. Tenido en cuenta todos los anteriores análisis, desarrollos y contribuciones, se propone un procedimiento de actuación para el Asesoramiento Técnico Independiente (ATI), con fases, tareas – incluida la TDD-, acciones y responsabilidades claramente definidas; de modo que se reduzca la subjetividad del proceso, y contribuya a un ATI objetivo y de calidad, para reducir los riesgos y asegurar los resultados y el éxito del proyecto.

6. Se ha realizado por último la evaluación de varios casos de estudio experimentales para contrastar y verificar los procedimientos.

Las futuras líneas y las obras derivadas de este estudio pueden ser:

1. Estandarizar inspecciones en plantas en operación para asignarles un “rating” técnico similar al que asignan las agencias de calificación de “rating” financieras tipo Estándar and Poors o Fitch. Esto ayudaría bastante en operaciones tipo “*Project Finance Bond*” (“*Project Finance*” con emisión de bonos sobre un activo)
2. Optimización de estimaciones y cálculos de estimación de recurso solar y producción, utilizando técnicas de Big Data y/o iteraciones de datos reales vs estimaciones
3. Optimización en la estimación de vida de los componentes y vida de las plantas a través de técnicas de simulación basadas en tasas de fallos reales vs estimadas
4. Optimización de técnicas de diagnóstico de plantas con problemas a través de análisis de datos estadísticos

Referencias

[1] S. J Pickle, Financing investments in renewable energy: the impacts of policy design, Renewable and Sustainable Energy Reviews, Volume 2, Issue 4, 1 December 1998, Pages 361-386, ISSN 1364-0321 R. H Wiser, , 1998.

[2] E. Menichetti. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research R. Wüstenhagen, *Energy Policy*, vol. Volume 40, pp. Pages 1-10, January 2012.

[3] M. Dailami and D. Leipziger, "“Infrastructure project finance and capital flows: A new perspective”," *World Development*, vol. Volume: 26, no. Issue: 7, pp. Pages: 1283-1298, 1998.

[4] S.L. “A practical guide to transactional project finance - basic concepts, risk identification, and contractual considerations”, Business Lawyer, Vol.: 45, Issue: 1, nov 1989, pp: 181-232 Hoffman, , 1989.

[5] C.R. Beidleman, D. Fletcher, and D. “On allocating risk - the essence of project finance”, Sloan Management Review, vol.: 31, iss.: 3, 1990,pp.: 47-55 Vesbosky, , 1990.

[6] G. Pollio., "Project finance and international energy development," *ENERGY POLICY*, vol. 26, no. 9, pp. 687-697, 1998.

[7] K. “Renewable energy investment and the clean development mechanism”, Energy Policy, Vol.: 40, Jan. 2012, pp.: 81-89, ISSN 0301-4215 Zavodov, , 2012.

[8] *Buffett Scores Cheapest Electricity Rate With Nevada Solar Farms, Bloomberg Business.*, July 7, 2015.

[9] *DEWA and ACWA Power consortium sign solar park PPA by Utilities ME Staff on Mar 26, 2015.*

[10] *J. Leloux, et al A bankable method of assessing the performance of a CPV plant.*: Applied Energy, 2014, vol. 118.

[11] J. Morgenson, *Defining Bankability for Utility-scale PV.*: Power Engineering, 2011, vol. 115.

[12] B. Marshall, *Management, Assessing Bankability in Utility-Scale PV The Key Role of the Inverter in Project Risk, SMA America, 2011.*

[13] R. Fagiani, J. Barquín, and R.”Risk-based assessment of the cost-efficiency and the effectivity of renewable energy support schemes: Certificate markets versus feed-in tariffs”, Energy Policy, Vol.: 55, April 2013, pp.: 648-661, ISSN 0301-4215 Hakvoort, , 2013.

[14] Essential Due-Diligence Steps for Utility-Scale Photovoltaic Projects. Solar Inustry, Vol.5, nº 6, pp.:54-62 Bouaziz Ait-Driss, , 2012.

[15] A. Masini and E. “The impact of behavioral factors in the renewable energy investment decision making process: Conceptual framework and empirical findings”, Energy Policy, Vol.: 40, Jan. 2012, pp.: 28-38, ISSN 0301-4215 Menichetti, , 2012.

[16] P., et all., Solar energy: comparative analysis of solar technologies for electricity production. Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, pp. 2482 - 2485 Valera, , vol. 3, 2003.

[17] C., Entrepreneurial Financing and Costly Due Diligence. Financial Review, 44: 137–149. doi: 10.1111/j.1540-6288.2008.00213.x Yung, , 2009.

[18] M.J."Renewable energy policy and landscape management in Andalusia, Spain: The facts" , Energy Policy, Volume 38, Issue 11, November 2010, Pages 6900-6909, ISSN 0301-4215 Prados, , 2010.

[19] S. Ruiz Romero, A. Colmenar Santos, and M. A. “EU plans for renewable energy. An application to the Spanish case”, Renewable Energy, Vol.: 43, July 2012, pp.: 322-330, ISSN 0960-1481 Castro Gil, , 2012.

[20] M. et al. "Univer Project. A grid connected photovoltaic system of 200 kW at Jaén University. Overview and performace analysis". Solar Energy Materials and Solar Cells, Volume 91, Issue 8, 4 May 2007, Pages 670–683 Drif, , 2007.

[21] J.C. Hernández, P.G. Vidal, and G., Almonacid, "Photovoltaic in grid-connected building. Sizing and economics analysis. ," *Renewable Energy*, vol. 15, no. 1-4, pp.

562-565, 1998.

[22] J. et al., "A bankable method of assessing the performance of a CPV plant". Applied Energy 118, pp. 1.11 Leloux, , 2014.

[23] V Salas and E. Olías, "Overview of the state of technique for PV inverters used in low voltage," *Renewable and Sustainable Energy Reviews 15 (2011) 1250–1257. 2011. 2011.*, vol. 15, pp. 1250–1257, 2011.

[24] Technical aspects of project finance in solar energy projects – methodology to improve the technical due diligences. 28th European PV solar Energy Conf. Paris. Valera P. et al., , 2013.

[25] et al. P. Valera, "Review of independent technical advisory in utility-scale PV projects," Jaén (Spain), PhD Thesis 2014.

[26] *GTM Research, 2014*.

ABSTRACT

The use of the renewables energies in general, and the photovoltaic energy in particular, is characterized by having low operation and maintenance (O&M) cost. However, large investment is required. Then, their use and development is linked with a properly financed system that is able on one hand to face to the initial investment and on the other hand the debt payment with the benefits that are assumed by the photovoltaic energy with a very low O&M.

Utility-scale PV projects have experienced tremendous growth in the world in the last years; in the US, China, South Africa, Chile, India and Japan, above all. The considerable budget of such projects requires special development and financing methods.

A successful photovoltaic project requires careful consideration of financing options. Financing stands or falls with the actual annual solar power yield fed into the grid. Usually, banks expect a return on project investment of 9 % or possibly higher. The strong market for large-scale PV plants that prevailed at times in Spain (2008), Germany (between 2010 and 2012) and Italy (2011) often created unrealistic expectations of the returns that solar power was able to yield.

The investment, and thus the prices it can achieve on the power market, is not linked to the uncertainties of the oil market. So for instance in the latest years the tendency of the price of the electricity coming from large PV plants is to fall, above all in the USA. And the sun supplies its energy for free, which gives to energy photovoltaic a fundamental advantage.

Outside of the US the cost is a little bit more expensive, although it must be noted that in the US it is usual to finance with tax equity investors that improve the project's profitability.

Different financing mechanisms can be implemented in those installations. The budget of MW size projects requires debt financing either by way of balance sheet/corporate guarantee or by project financing. As will be analysed later in this document, there are different financing mechanisms for utility-scale photovoltaic projects, but the most common is the *Project Finance*. It can be defined as the financing of long-term infrastructure, industrial projects or public services - in our case utility-scale photovoltaic projects - based upon a non-recourse or limited recourse financial structure where the project debt and equity used to finance the project are paid back from the cashflow generated by the project. The aim is to finance the PV plant without risks for the stakeholder. This financial mechanism was used in the last decades for the financing of large investments and is subtended as much of the capacity of the project to generate cash flows that can meet the repayment of loans as in the contracts between the diverse parties that ensures the profitability of the project. The increase of the large investments in infrastructures and the tendency of the governments to reduce their levels of budget deficit, has been a fundamental fact in the development of the *Project Finance*. This finance tool has been of widespread use in the implementation in the telecommunication sector. However, nowadays that tool has taken large importance in the electric sector and in the energy generation. More specifically, large PV and wind turbines plants are usually financed by means of this modality because the very nature of this type of project is adapted properly to this philosophy of the *Project Finance*. In order to use this type of financing supported by the project itself, it is essential to thoroughly evaluate all technical aspects to ensure that the investment is based on the verified and reliable project data.

Therefore, a primary objective for any photovoltaic power plant is to ensure that the plant continuously and reliably operates, thereby generating the maximum economic and energy performance returns.

However, the lenders will require some elements to be included for a contract to be considered 'bankable': a fixed completion date, a fixed completion price, no or limited technology risk, output guarantees, liquidated damages for both delay and performance + security from the contractor and/or its parent, large caps on liability (ideally, there would be no caps on liability, however, given the nature of EPC contracting and the risks to the contractors involved there are almost always caps on liability) or restrictions on the ability of the contractor to claim extensions of time and additional costs.

Such projects must pass through a number of different stages before and after the Financial Close, -FC is the moment where the agreement between the lenders and stakeholders occurs and the project achieves the finance - The stages previous to this milestone are grouped and called Pre-Financial Close task; those after this milestone are the Post-Financial Close activities.

As will be shown in this thesis, the bankability for those projects is not only addressed through the modelling of its energy yield followed by an on-site measurement campaign. It will be necessary to analyse more aspects. Financial Institutions require Independent Advisors to do the Independent Advisory previous to and after Financial Close. In the Pre-Financial Close stage, the Full Due Diligence process takes importance, mainly Legal & Tax Due Diligence, Technical Due Diligence (TDD) and Insurance Due Diligence (IDD). Our interest is focused on technical advisory and parts of those activities, in pre-financial close stage, are included in the called Technical Due Diligence (TDD) that will be managed in the Chapter 5.

The Technical Due Diligence (TDD) comprises all the technical aspects of a project, before financial close, from the production estimation to the contractual agreements and costs and financial model. Therefore, the objectives of the TDD are the following: understand and mitigate a variety of technical, legal and socio-environmental risks before you commit your valuable time and resources to the project, identify technical risks that could compromise your project's profitability, ensure that the technical feasibility of the project makes for a sound investment and ensure that all factors have been accounted for in the development process. The TDD is a multi-discipline analysis, in which risk assessments are made for all individual elements of the PV plant. It supports lenders and investors to ensure that projects are viable and contractually sound, focusing on identifying and controlling technical risks throughout the project lifecycle.

One of the key points in any project finance is to analyse the risk and uncertainties involved with the project before assessing how much collateral is required or trying to ascertain whether project financing is possible. This requires a thorough study of the individual factors and associated risks and via provision of mitigations to any identified risks in order to quantify and reduce, if possible, the project uncertainties. Specifically, the risks associated to the any utility-scale photovoltaic project can be the following in reference to:

- Technology
- Principal contractors and suppliers:
- Project design and solar resource,
- EPC experience, contracts (EPC and O&M)
- Warranties (materials, equipment, performance, etc)
- License, permits and authorizations
- Construction, start up and initial tests, operation and asset management and other:
- Environmental
- Monitoring system
- Security system, etc.

In this way, in order to handle the different risks and minimize them it is very useful to have services technical support. Then, those services will be done by an Independent Technical Advisor (ITA). The activities or tools that an independent technical advisor usually does include: the developers proposed design, installation, key technical components and balance of plant. Also they can provide assessment and advice on contractual elements, including the assessment of capital cost, operating costs and plant performance test evaluation as well as perform full energy yield assessment analysis using different models of the PV plant. In addition, they can have the role in to oversee the construction and performance test phase of the PV Plant as well as provide onsite support and specialist services from construction phase through to provisional acceptance certification.

The TDD is an intensive review and evaluation that can potentially be subject to bias of the individual reviewer or technical advisor. In that sense it is necessary to develop methods and / or process support tools that help reduce subjectivity and allow comparisons and objective assessments. In addition, it will be noted that in the Post-Financial stage, other activities need special attention and can be asked for the independent advisors, such as Construction Monitoring, Provisional Acceptance Certificate (PAC) and Final Acceptance Certificate (FAC) tests, Guarantee Period Monitoring and Operation & Maintenance Monitoring.

Ultimately the goal of independent technical advice is to determine first and then ensure the technical feasibility of the proposed project.

Moreover, although the photovoltaic technology based on crystalline silicon can be considered a mature technology, it is still a new technology with few years of experience, especially in large installations connected to the grid, hardly reaching ten years in a global context.

The review and analysis of operation of large PV plants is a work in progress that still needs study and work, mainly technological. You need to draw conclusions that allow to know better: the detection of faults and malfunctions, design optimization and upgrading of one of the devices involved in the installation.

These are specific tasks appropriate to technological development and innovation for technological research. In short, the PV technology based on Si is a field where a technologist still has much to do.

Then, according with the previous considerations the aim of this thesis work is: first, to thoroughly analyze and understand the technical processes and management of large PV projects, and then, to structure the different phases of the process; Second, and based on this study, we propose a way of doing things for the Independent Technical Advisory (ITA), with phases, task and actions clearly defined,-included TDD- so that the subjectivity of the process is reduced, allowing an objective and high quality ITA to reduce risks and ensure project results and project success. To do so, previously we have done a review of the state of the art on the Utility-Scale PV Projects and its fundamentals (chapter 2). Then, we have done a deep analysis of the developing process to implement large PV projects; and also of the management structure to run it (Chap 3). In this chapter we establish the main stage and managing task of a large PV project; in addition, we have structured them and time scheduled them, in order to survey and define the task, duties and responsibilities of the independent technical advisory. In chapter 4 we do a review of the financing mechanism, focusing on Project Finance as the main tool to finance large PV project. In this chapter we present the “Project Finance Constellation”; a very good way to understand, and graphically summarize, the entire performers involved in a Project Finance. It not only identifies them, but it describes the inter-relationship between them, missions, main task and duties of each one. In chapter 5 we present the main technical risk in a large PV project and the main procedure to evaluate, control and mitigate the risk: the independent technical advisory. Last but not least, we have made also the assessment of several experimental case studies to validate the previous procedures (chapter 6). Finally, in chapter 7 we present the main conclusions and the proposal for future lines and works arising out of this study.

Table the Contents

List of Figures

List of Tables

CHAPTER 1
INTRODUCTION

CHAPTER 1. Introduction

The use of the renewables energies in general, and the photovoltaic energy in particular, is characterized by having low operation and maintenance (O&M) cost. However, large investment is required. Then, their use and development is linked with a properly financed system that is able on one hand to face to the initial investment and on the other hand the debt payment with the benefits that are assumed by the photovoltaic energy with a very low O&M [**1**] [**2**].

Utility-scale PV projects have experienced tremendous growth in the world in the last years; in the US, China, South Africa, Chile, India and Japan, above all. The considerable budget of such projects requires special development and financing methods.

A successful photovoltaic project requires careful consideration of financing options. Financing stands or falls with the actual annual solar power yield fed into the grid. Usually, banks expect a return on project investment of 9 % or possibly higher. The strong market for large-scale PV plants that prevailed at times in Spain (2008), Germany (between 2010 and 2012) and Italy (2011) often created unrealistic expectations of the returns that solar power was able to yield. The Eurozone crisis and the withdrawal of state subsidies are therefore forcing photovoltaic to take a more realistic view of things – and enabling it to exploit its long-term advantages more successfully. Ever more investors are recognizing the fact that the technology has matured and the risk of default is low.

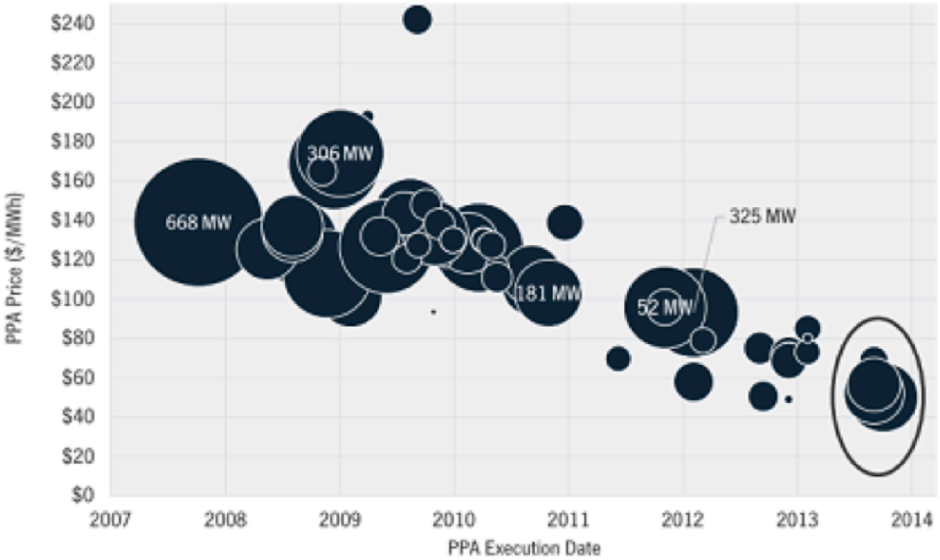


Figure 1: PPA Price ($/MWh) by PPA execution date in the US (Source: GTM Research [3])

The investment, and thus the prices it can achieve on the power market, is not linked to the uncertainties of the oil market. So for instance in the latest years the tendency of the price of the electricity coming from large PV plants is to fall, figure 1 [**3**], above all in the USA. And the sun supplies its energy for free, which gives to energy photovoltaic a fundamental advantage. Precisely last July 2015, Warren Buffett's Nevada utility has lined up what may be the cheapest electricity in the U.S., and it's from a PV farm [**4**]. Berkshire Hathaway Inc.'s NV Energy agreed to pay 3.87 cents a kilowatt-hour for power from a 100-megawatt project that First Solar Inc. is developing, according to a filing with regulators [**4**].

Outside of the US the cost is a little bit more expensive, although it must be noted that in the US it is usual to finance with tax equity investors that improve the project's profitability. So for instance, Dubai Electricity and Water Authority (DEWA) has signed a 25-year Power Purchase Agreement (PPA) and a Shareholder Agreement for the 200 MW expansion of the Mohammed bin Rashid Al Maktoum Solar Park. ACWA Power will finance, build and operate that photovoltaic plant starting in 2017. This plant also sets a worldwide milestone for utility-scale solar power generation with a landmark level tariff of 5.84 USD cents/kWh [**5**].

Different financing mechanisms can be implemented in those installations. The budget of MW size projects requires debt financing either by way of balance sheet/corporate guarantee or by project financing. As will be analysed later in this document, there are different financing mechanisms for utility-scale photovoltaic projects, but the most common is the *Project Finance*. It can be defined as the financing of long-term infrastructure, industrial projects or public services - in our case utility-scale photovoltaic projects - based upon a non-recourse or limited recourse financial structure where the project debt and equity used to finance the project are paid back from the cashflow generated by the project. The aim is to finance the PV plant without risks for the stakeholder. This financial mechanism was used in the last decades for the financing of large investments and is subtended as much of the capacity of the project to generate cash flows that can meet the repayment of loans as in the contracts between the diverse parties that ensures the profitability of the project [**6**] [**7**] [**8**]. The increase of the large investments in infrastructures and the tendency of the governments to reduce their levels of budget deficit, has been a fundamental fact in the development of the *Project Finance*. This finance tool has been of widespread use in the implementation in the telecommunication sector. However, nowadays that tool has taken large importance in the electric sector and in the energy generation. More specifically, large PV and wind turbines plants are usually financed by means of this modality because the very nature of this type of project is adapted properly to this philosophy of the *Project Finance*. In order to use this type of financing supported by the project itself, it is essential to thoroughly evaluate all technical aspects to ensure that the investment is based on the verified and reliable project data [**9**] [**10**].

Another way for financing can include tax equity. For instance, it was done in 2014 by Norwegian solar company Scatec Solar that closed the project financing for a 104 MW PV plant in Utah, US, and a further 60 MW plant in Honduras. It can increase the profitability of the project.

Therefore, a primary objective for any photovoltaic power plant is to ensure that the plant continuously and reliably operates, thereby generating the maximum economic and energy performance returns.

However, the lenders will require some elements to be included for a contract to be considered ‘bankable’: a fixed completion date, a fixed completion price, no or limited technology risk, output guarantees, liquidated damages for both delay and performance + security from the contractor and/or its parent, large caps on liability (ideally, there would be no caps on liability, however, given the nature of EPC contracting and the risks to the contractors involved there are almost always caps on liability) or restrictions on the ability of the contractor to claim extensions of time and additional costs.

Such projects must pass through a number of different stages before and after the Financial Close, -FC is the moment where the agreement between the lenders and stakeholders occurs and the project achieves the finance - The stages previous to this milestone are grouped and called Pre-Financial Close task; those after this milestone are the Post-Financial Close activities.

As will be shown in this thesis, the bankability for those projects is not only addressed through the modelling of its energy yield followed by an on-site measurement campaign [**11**] [**12**] [**13**]. It will be necessary to analyse more aspects. Financial Institutions require Independent Advisors to do the Independent Advisory previous to and after Financial Close. In the Pre-Financial Close stage the Full Due Diligence process takes importance, mainly Legal & Tax Due Diligence, Technical Due Diligence (TDD) and Insurance Due Diligence (IDD). Our interest is focused on technical advisory and parts of those activities, in pre-financial close stage, are included in the called Technical Due Diligence (TDD) that will be managed in the Chapter 5.

The Technical Due Diligence (TDD) comprises all the technical aspects of a project, before financial close, from the production estimation to the contractual agreements and costs and financial model. Therefore, the objectives of the TDD are the following: understand and mitigate a variety of technical, legal and socio-environmental risks before you commit your valuable time and resources to the project, identify technical risks that could compromise your project’s profitability, ensure that the technical feasibility of the project makes for a sound investment and ensure that all factors have been accounted for in the development process. The TDD is a multi-discipline analysis, in which risk assessments are made for all individual elements of the PV plant. It supports lenders and investors to ensure that projects are viable and contractually sound, focusing on identifying and controlling technical risks throughout the project lifecycle.

One of the key points in any project finance is to analyse the risk and uncertainties involved with the project before assessing how much collateral is required or trying to ascertain whether project financing is possible. This requires a thorough study of the individual factors and associated risks and via provision of mitigations to any identified risks in order to quantify and reduce, if possible, the project uncertainties. Specifically, the risks associated to the any utility-scale photovoltaic project can be the following in reference to:

- Technology
- Principal contractors and suppliers:
- Project design and solar resource,
- EPC experience, contracts (EPC and O&M)
- Warranties (materials, equipment, performance, etc…)
- License, permits and authorizations
- Construction, start up and initial tests, operation and asset management and other:
- Environmental
- Monitoring system
- Security system, etc.

In this way, in order to handle the different risks and minimize them it is very useful to have services technical support. Then, those services will be done by an Independent Technical Advisor (ITA). The activities or tools that an independent technical advisor usually does include: the developers proposed design, installation, key technical components and balance of plant. Also they can provide assessment and advice on contractual elements, including the assessment of capital cost, operating costs and plant performance test evaluation as well as perform full energy yield assessment analysis using different models of the PV plant. In addition, they can have the role in to oversee the construction and performance test phase of the PV Plant as well as provide onsite support and specialist services from construction phase through to provisional acceptance certification.

The TDD is an intensive review and evaluation that can potentially be subject to bias of the individual reviewer or technical advisor [**14**]. In that sense it is necessary to develop methods and / or process support tools that help reduce subjectivity and allow comparisons and objective assessments [**15**] [**16**]. In addition, it will be noted that in the Post-Financial stage, other activities need special attention and can be asked for the independent advisors, such as Construction Monitoring, Provisional Acceptance Certificate (PAC) and Final Acceptance Certificate (FAC) tests, Guarantee Period Monitoring and Operation & Maintenance Monitoring.

Ultimately the goal of independent technical advice is to determine first and then ensure the technical feasibility of the proposed project.

Moreover, although the photovoltaic technology based on crystalline silicon can be considered a mature technology, it is still a new technology with few years of experience, especially in large installations connected to the grid, hardly reaching ten years in a global context.

The review and analysis of operation of large PV plants is a work in progress that still needs study and work, mainly technological. You need to draw conclusions that allow to know better: the detection of faults and malfunctions, design optimization and upgrading of one of the devices involved in the installation.

These are specific tasks appropriate to technological development and innovation for technological research. In short, the PV technology based on Si is a field where a technologist still has much to do. At this time also with the massive installation of large PV plants in recent years, not only in Spain, where this process has stopped abruptly, but in other countries, where there has been more orderly and continues to grow steadily [**17**] [**18**].

Then, according with the previous considerations the aim of this thesis work is: first, to thoroughly analyze and understand the technical processes and management of large PV projects, and then, to structure the different phases of the process; Second, and based on this study, we propose a way of doing things for the Independent Technical Advisory (ITA), with phases, task and actions clearly defined,-included TDD- so that the subjectivity of the process is reduced, allowing an objective and high quality ITA to reduce risks and ensure project results and project success. To do so, previously we have done a review of the state of the art on the Utility-Scale PV Projects and its fundamentals (chapter 2). Then, we have done a deep analysis of the developing process to implement large PV projects; and also of the management structure to run it (Chap 3). In this chapter we establish the main stage and managing task of a large PV project; in addition, we have structured them and time scheduled them, in order to survey and define the task, duties and responsibilities of the independent technical advisory. In chapter 4 we do a review of the financing mechanism, focusing on Project Finance as the main tool to finance large PV project. In this chapter we present the "Project Finance Constellation"; a very good way to understand, and graphically summarize, the entire performers involved in a Project Finance. It not only identifies them, but it describes the inter-relationship between them, missions, main task and duties of each one. In chapter 5 we present the main technical risk in a large PV project and the main procedure to evaluate, control and mitigate the risk: the independent technical advisory. Last but not least, we have made also the assessment of several experimental case studies to validate the previous procedures (chapter 6). Finally, in chapter 7 we present the main conclusions and the proposal for future lines and works arising out of this study.

It is important to note that this work has been developed within the framework of the "CEAEMA" de la Universidad de Jaén, in collaboration with the Electronic Technology Department of the of the Universidad Carlos III de Madrid (UC3M) and with the company Astrom Technical Advisor (ATA) renewables. This environment encourages adequate scientific and technological support for the development of this thesis and to make the most of large databases and experience and knowledge of such established groups as the IDEA Group (Development Group for Solar Energy in the Universidad de Jaen), the Power Electronic

System Group (GSEP) of the UC3M [**19**] [**20**] [**21**] [**22**]; and the company ATA with a large experience in investment PV projects by mean of evaluation of TDD and O&M [**15**] [**23**] [**24**] allowing validation of the procedures and results thereof.

CHAPTER 2

UTILITY-SCALE PHOTOVOLTAIC PROJECTS: OVERVIEW & FUNDAMENTALS

CHAPTER 2. Utility-Scale Photovoltaic Projects. Overview & Fundamentals

2.1 Utility-scale Photovoltaic Projects

Large-scale PV power plants (also called utility-scale or megawatt-scale power plants) may be installed on large rooftops or on the ground, and may employ different PV technologies, conventional photovoltaic (PV), or concentrating photovoltaic (CPV). What distinguishes large-scale solar from distributed generation is the size of this type of project and the fact that the electricity that they produce is sold to wholesale utility buyers, not to end-use consumers [**25**]. Large-scale PV plants provide the benefit of fixed-priced electricity during long periods of time and even during peak demand periods when electricity from fossil fuels is more expensive.

Sometimes, Megawatt-scale energy storage can be added. Then, two main families of large-scale energy storage system (ESS) projects can be distinguished: the first is to aid renewable energy integration by smoothing, shaping and adjust time-shifting the intermittent and unpredictable output of photovoltaic plants to the grid requirements. The second is the grid storage in which containers or storage systems are deployed to support the grid stabilization by providing auxiliary functions, such as frequency regulation and voltage regulation, [**26**] [**27**] [**28**] [**29**].

According to the latest data from the Photovoltaic Power Systems Programme (PVPS) of the International Energy Agency IEA updated up to 2015 [**30**], at least 38.7 GW of PV systems have been installed and mostly connected to the grid in the world during the past year, Figure 1.

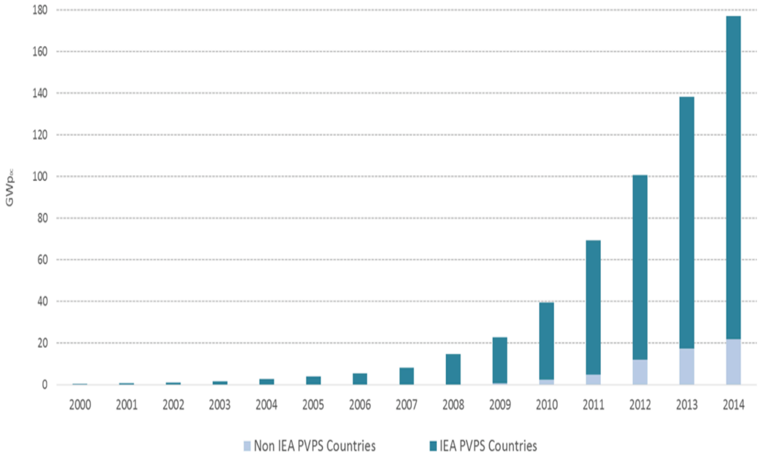


Figure 2.1: Evolution of PV capacity yearly (GW) (Source: International Energy Agency PVPS)

Likewise, large-scale photovoltaic projects have grown rapidly in number and size over the last few years. So, shown in Table 2.1 are the top PV plants installed in the world updated to 2015.

Table 2.1: Top PV plants installed in the world updated to 2015

Name	Country	Capacity (MW)
Gujarat Solar Park	India	590
Solar Star (I and II)	USA	579
Topaz Solar Farm	USA	550
Desert Sunlight	USA	550
Copper Mountain Solar Facility	USA	458

This increment of installation of PV plants is aided by the fall in the price of the PV components, and, most significantly, by the drop in the price of conventional crystalline silicon PV modules, that has decreased sharply, from 3.5 €/W to 0.5 €/W as shown in Figure 2, [1] [**31**] [2]. Due to this incredible drop in prices, the installed capacity of PV has increased more than tenfold in the last six years.

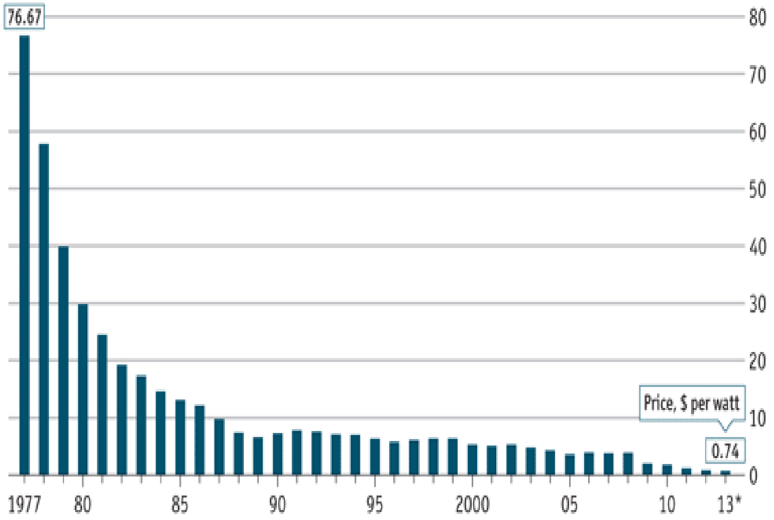
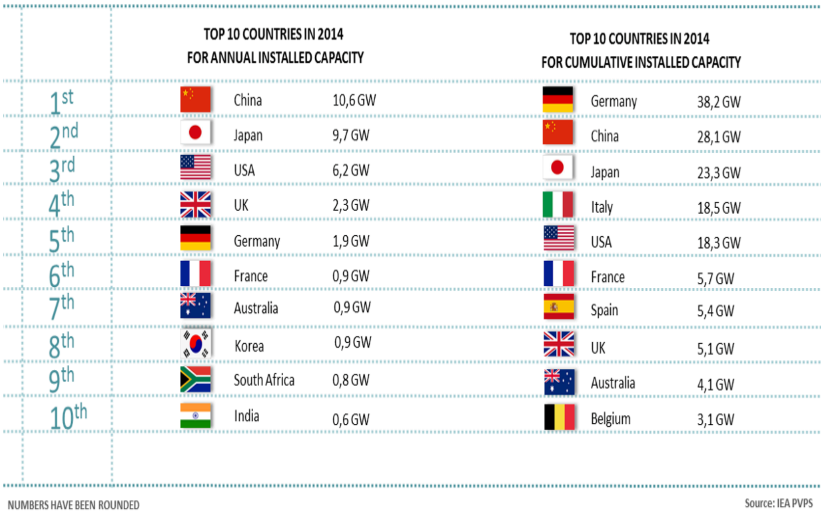


Figure 2.2: PV module price (1977-2013) (Source: Bloomberg New Energy Finance [7])

Major markets -such as the EU, USA, China and Japan- continue to ramp up installations and new markets, like India, South Africa, Chile and other emerging countries, make the promise of large-scale photovoltaic electricity production continue to be a bright spot of the PV market, Table 2 [**30**].

Table 2.2: Top 10 countries in 2014 for annual installed capacity and cumulative installed capacity [30]

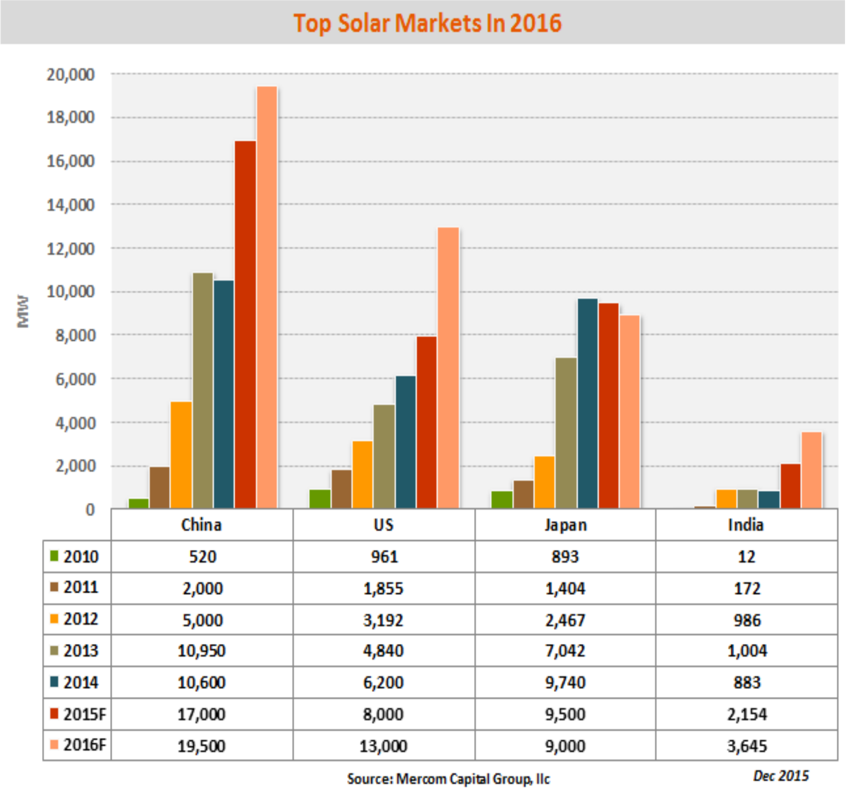


	TOP 10 COUNTRIES IN 2014 FOR ANNUAL INSTALLED CAPACITY		TOP 10 COUNTRIES IN 2014 FOR CUMULATIVE INSTALLED CAPACITY	
1st	China	10,6 GW	Germany	38,2 GW
2nd	Japan	9,7 GW	China	28,1 GW
3rd	USA	6,2 GW	Japan	23,3 GW
4th	UK	2,3 GW	Italy	18,5 GW
5th	Germany	1,9 GW	USA	18,3 GW
6th	France	0,9 GW	France	5,7 GW
7th	Australia	0,9 GW	Spain	5,4 GW
8th	Korea	0,9 GW	UK	5,1 GW
9th	South Africa	0,8 GW	Australia	4,1 GW
10th	India	0,6 GW	Belgium	3,1 GW

NUMBERS HAVE BEEN ROUNDED

Source: IEA PVPS

According to Mercom Capital Group LLC forecasting, in 2016 there will be another year of PV growth in the world with installations expected to reach 64.7 GW in 2016 up from 57.8 GW forecast for 2015 [**32**]. So, it is expected that the largest markets in 2016 will again be China, the United States and Japan; the United States is set to overtake Japan as the second largest photovoltaic market behind China, Figure 3. These three countries will account for about 65 percent of installations next year.



	China	US	Japan	India
2010	520	961	893	12
2011	2,000	1,855	1,404	172
2012	5,000	3,192	2,467	986
2013	10,950	4,840	7,042	1,004
2014	10,600	6,200	9,740	883
2015F	17,000	8,000	9,500	2,154
2016F	19,500	13,000	9,000	3,645

Source: Mercom Capital Group, llc

Dec 2015

Figure 2.3: Evolution of top PV markets (Source: Mercom Capital Group LLC, [32])

2.2. Energy yields and efficiencies

In this section we will deal with factors that characterize the performance of a PV plant, by means of which its energy production can be estimated. Such factors include efficiency, efficacy or the different losses that may reduce the productivity of a given ideal system. In addition, we will outline, through different examples, the software used for the design, simulation and estimation of figures of merit in PV plants.

2.2.1 Efficiency and productivity

Efficiency and efficacy are two figures of merit in various types of systems (not only in PV plants) which can help to describe the characteristics and quality of a system. Both efficiency and efficacy provide information on the quality of the system, being different and complementary factors. Efficacy, the ratio between the theoretical and the actual output of the system, provides information on the performance of the system, at least comparatively. Efficiency, the ratio between the output and the input of the system, provides information on the system from a technological rather than comparative perspective, and at the same time provides a quantitative estimate of the production of the system

In the PV sector, and more particularly in large-scale PV plants, two figures of merit related to the aforementioned concepts are generally used.

On the one hand, the PR (Performance Ratio) is a parameter that measures effectively the real behaviour of the system (produced energy) when compared with the hypothetical production of an ideal plant, with the same characteristics as the PV plant being studied but with its cells working at a temperature of 25º C (like at STC [Standard Test Condition]) and with no losses at all.

The PR describes the relationship between the actual and the theoretical energy outputs of the PV plant. It thus shows the proportion of the energy that is actually available for export to the grid after subtracting energy losses (e.g. due to thermal losses, collection losses, conduction losses, etc.) and after subtracting energy consumption for operation.

The PR indicates the overall effect of losses on the rated output due to array temperature, incomplete utilization of the irradiation and system component inefficiencies or failures [**33**].

It is defined analytically by the following formula:

$$PR = \frac{E_{AC}}{E_{th}} = \frac{E_{AC}}{\frac{P_{STC}\int G_i(t)dt}{G_{STD}}} = \frac{E_{AC}}{\frac{P_{STC}}{G_{STC}}H_i} \qquad \textbf{(2.1)}$$

Where,

E_{AC} is the actual energy produced by the PV system in a given period of time (typically one year),

P_{STC} is the nominal power of the plant under STC (also called peak power),

Gi(t) is the irradiance on the PV generator surface,

G_{STD} is the irradiance at the STC (1000 W/m^2),

H_i is the irradiation on the PV generator along the time considered for EAC and

E_{th} is the energy produced by the same PV system working under STC cell temperature and without losses.

It is clear that this parameter provides information on the behaviour of the system. The closer this parameter approaches one, the better the plant will operate. This is a generalized indicator, virtually universal, since it provides useful and comprehensive information on the behaviour of the system and is both easy to obtain and to understand: simply by knowing the energy exported to the grid, the PV generator irradiation during the same period and the nominal power of the plant. It also provides a measure of the global losses of the system (LG) which prevent the maximum theoretical value of the energy output from being reached. So,

$$LG = 1 - PR \tag{2.2}$$

However, this parameter has shortcomings that need to be taken into account. It is important not to focus only on its value but also to seek additional information from other quality parameters. As regards the losses of the PV system, for example, it does not differentiate between unavoidable losses and the losses that a well-engineered plant can prevent.

In this respect, we can distinguish other factors by including only some of the losses in the denominator of equation (2.1). If we only consider unavoidable losses, we would obtain the PI (Performance Index). This parameter does not provide precise information on the engineering of the plant nor on the compliance with the specifications of the equipment. For this reason, its use is less common and the information that it yields may be confusing due to the fact that it is difficult to determine the standard for what can be considered as “avoidable” or “unavoidable” losses.

Another characteristic of PR to be taken into account is the fact that it tends to “favor” low-productivity systems. This may sound paradoxical as regards the profitability of the system. In general, highly productive systems work under high radiation and temperature, which increases the generation losses. In other words, under Nordic weather (low radiation, low temperatures) PR values are higher than under high isolation (and consequently higher temperature) despite the fact that the former produces less energy per unit of nominal power.

This last aspect brings into play a third consideration about PR. For a hypothetical investor, this parameter does not provide information on the profitability of the system. That is to say, its value does not (directly) indicate anything about the production of the system. To obtain such values we must examine efficiency-based indicators. Perhaps, the most widely used in large-scale PV plants is FY (Final Yield Factor), which defines the energy produced during a given period of time (which usually stretches over a year) normalized to the nominal power.

$$FY = \frac{E_{AC}}{P_{STC}} \tag{2.3}$$

2.2.2 Losses in large-scale PV plants

The actual energy production of a PV power plant, EAC, is obtained from the expression:

$$E_{AC} = P_{STC}\frac{H_i}{G_{STC}}PR = E_{th} \cdot PR \tag{2.4}$$

In Equation 2.4, PR reflects the effects of losses in the system which reduce the theoretical energy production. Some of these losses are linked to the transformation of the solar input and the final amount of energy supplied to the network. A brief overview and evaluation of the main factors which account for the total losses in a PV power plant are included in the following paragraph.

Losses can be classified into four main groups, three of which are related to the functioning of the PV generator, the so called capture losses: collection losses, losses due to functioning under conditions other than STC and losses derived from dispersion and module specifications. The fourth group is associated with the PV BoS (Balance of System).

In the first group, collection losses (Lcoll), we include several factors that reduce the effective light that will be converted into electricity by the solar cells. These factors include shading due to obstacles in the path of sunlight impinging on the solar cells, reflection due to an off-normal axis incidence angle, module soiling losses and spectral losses due to the actual solar spectrum being other than 1.5 Air Mass spectrum (AM1.5).

Most of the time, cells are not working under STC (which are very unlikely outdoors) and, as a consequence, the efficiency of the module is usually lower than the nominal one under STC. The main factor that reduces efficiency is cell temperature, which is usually higher than 25 °C. Taking into account that cell efficiency has a temperature coefficient of about –0.5 %/K (Si-x) and that the temperature of the cell is usually twenty or more degrees over STC, the temperature loss can easily be above 10%. Another effect included in these losses is the low irradiance effect that reduces the open circuit voltage of the cell. These are the second group we called deviation from STC losses, LSTC.

Finally, as regards capture losses, we must take into account the current mismatch of the module in one string that limits the overall current in each string of the array. A string is a set of connected modules, all of which have the same current. Not all the modules can produce the same current under the same operating conditions (dispersion). As a result, the string current is limited by the module with the lowest value. Another factor to take into account in this block is the deviation from the manufacture's specifications (tolerance parameters). The most important is the module power. The actual power of any one module, due to the tolerance, can be different (lower) than the nominal one. These are all called specification losses (LSpec).

In PV power plants there are devices and components other than PV modules. These are known collectively as the BoS equipment, whose non-ideal operation causes additional losses. These include wiring, DC/AC inverter and LV/HV transformer losses. In DC and AC wiring there are ohmic losses due to the resistance of the cables. The DC/AC inverters usually include a MPPT (Maximum Power Point) tracker. This device produces some losses while searching for the MPP (Maximum Power Point) of the PV array that changes along with the environmental conditions. There are also additional losses due to the non-ideal efficiency of the inverter (DC/AC conversion process). Taken together these are all known as the BoS losses, LBoS.

There are various methods and algorithms to calculate some of these loss factors. However, some of these loss factors can only be estimated through empirical procedures based on experience. This falls beyond the scope of the present chapter and we recommend the simulation tools described below to determine, calculate or estimate these loss factors.

Every device reduces the efficiency of energy production by a factor of (1- Li), where the subscript "i" represents the different devices. So, the overall losses of a PV power plant (see figure 9) can be calculated as follows:

$$L_G = 1\text{-}(1\text{-}\ L_{coll})(1\text{-}\ L_{STC})\big(1\text{-}\ L_{Spec}\big)(1\text{-}\ L_{BoS}) \tag{2.5}$$

From equation (2.2), we can consider PR as a product of the different losses, i.e.

$$PR = (1\text{-}\ L_{coll})(1\text{-}\ L_{STC})\big(1\text{-}\ L_{Spec}\big)(1\text{-}\ L_{BoS}) \tag{2.6}$$

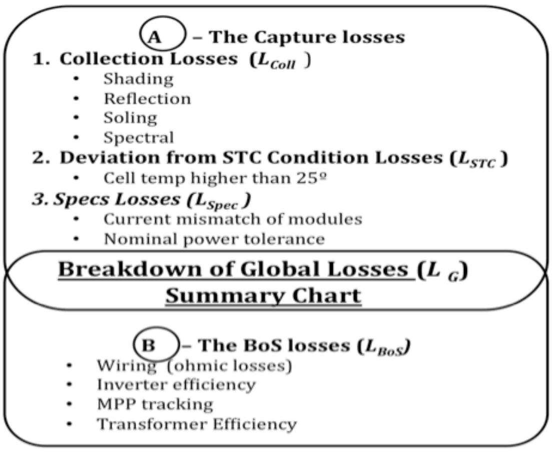


Figure 2.4: Overview of the overall losses in a large PV power plant

2.3 Economic Parameters: Grid Parity, Life-Cycle Cost and Levelized Cost of Electricity

Regarding the economic analysis of large-scale PV power plants there are several concepts that need to be defined: Grid Parity, LCC (Life-Cycle Cost) and LCOE (Levelized Cost of Electricity). They play the role of competitiveness and cost referees.

Grid Parity occurs when the cost of producing a unit of electricity by photovoltaics is the same as the average end-price for electricity to consumers. Grid parity should not be confused with generation-parity, as the latter concept includes the transport and distribution of the electricity which was generated off the grid.

The **Life-Cycle Cost** of the PV system, includes the present worth of all the expenses incurred throughout the life of the plant (N years) and will depend on the initial investment (PVIN, €) and the annual operation and maintenance (O&M) cost (PVAOM, €) associated with the selected PV technology [**34**] [**35**].

Unless the project is not financed, the initial investment will be affected by the annual interest rate for borrowing money during a period of time, and the O&M will extend throughout the lifetime of the plant, so the sum of these annual costs has to be added to the present worth of the initial investment in the PV system (PW[PVIN], €) and to the present worth of the operation and maintenance cost over N years (PW[PVOM (N)], €) associated with the PV technology, being the present worth the current worth of the future investment.

Here, like in any other investment, it is necessary to establish the present worth of the capital invested. Therefore we have taken into account the nominal discount rate, r (%) [**36**].

$$LCC(€) = PW[PV_{IN}] + PW[PW_{OM}(N)] \qquad (2.7)$$

The investment can be financed either with company capital (own capital, OC) (PW[PVOC], €) or external capital (PW[PVEC], €). The assumption has been made that there is an annual retribution, for own capital in form of a dividend (di) and the investment will be amortized at the end of the life-cycle of the system (N years). As a result, to calculate the present worth of the own capital, the following equation is used, considering the factor q = 1/(1+r):

$$PW[PV_{OC}] = PV_{OC}\left[d_i \cdot \frac{q\cdot(1-q^N)}{(1-q)} + q^N\right] \qquad (2.8)$$

The rest of the investment, PVEC = PVIN – PVOC, may be financed with an annual loan interest il (%) and loan term Nl (years), so its present worth is,

$$PW[PV_{EC}] = [(PV_{IN} - PV_{OC}) \cdot i_l \frac{(1+i_l)^{N_l}}{(1+i_l)^{N_l-1}} \cdot \frac{q\cdot(1-q^{N_l})}{(1-q)}) \qquad (2.9)$$

Finally, the present worth of investment cost can be expressed as:

$$PW[PV_{IN}] = PW[PV_{EC}] + PW[PV_{OC}] \qquad (2.10)$$

The annual operation and maintenance cost is assumed to be proportional to the initial investment. Additionally, an annual escalation rate (εPVAOM) of the operation and maintenance cost of the system has been defined, so PW[PVOM (N) may be re-written as:

$$PW[PV_{OM}\,(N)] = PV_{AOM} \cdot \frac{K_{PV} \cdot (1 - K_{PV}^{N})}{1 - K_{PV}} \qquad (2.11)$$

Where

$$K_{PV} = [(1 + \varepsilon_{PVAOM})/(1 + r)] \qquad (2.12)$$

The **LCOE** [also called **Levelised Electricity Cost** (LEC)], is defined as the cost of a unit of electricity (€·kWh-1) produced by a given system over a specified number of years, normally throughout its whole operational lifetime. This cost is expressed in current monetary units and it is levelised for all the years that the system is intended to be generating electricity [**37**]. In the LCOE analysis, the cost of transport and maintenance of the network is not considered, so that it is possible to use this number to obtain the value for grid parity. This parameter calculates the price of the electricity that the system generates by dividing the project's total cost into the energy produced during its complete operating life. The LCOE can be defined by the following expression [**38**] [**39**]:

$$LCOE(€ \cdot kWh^{-1}) = \frac{LCC}{\sum_{i=1}^{N} \frac{E_{PV} \cdot (1 - \varepsilon_{pl})^{i}}{(1+r)^{i}}} \qquad (2.13)$$

In the previous equation, EPV is the annual PV electricity yield (kWh·year-1), where an annual decrease of the power generated of εpl (%) has been assumed.

The parameter LCOE is a widely used term in the PV industry and it is often used as a marketing tool in discussions regarding large-scale projects. The economic feasibility of PV projects is increasingly being evaluated using that parameter in order to compare it to investment in other electricity generation technologies. LCOE can also be used for economic comparison between different PV energy system configurations [**40**]. In addition, LCOE is the widely accepted criterion to fairly compare the cost of energy generated by different power plants.

CHAPTER 3

TIMING STRUCTURE OF A LARGE PV PROJECTS

CHAPTER 3. TIMING STRUCTURE OF A LARGE PV PROJECTS

A utility-scale photovoltaic project is complex and involves many different parties including developers, landowners, utilities, grid operators, government agencies and financing parties. Their mains objectives are: to find a trade-off between risk management versus crisis management; to do a implementation of a long life power plant with high energy yield and availability; to obtain a proper and safe operation complying with the relevant requirements and low cost high return on investment, [**41**], [**42**] [**43**].

It is known that a utility-scale photovoltaic project must pass through a number of different stages grouped as pre-financial and post-financial close activities. As an example, Figure 3.1 shows the project time frame for a 20 MW utility-scale photovoltaic project.

In the following paragraphs the different activities will be shown for every stage and phase of the project.

3.1 Pre-Financial Close

In the Pre-Financial Close stage a series of phases can be defined, such as: pre-feasibility study, feasibility study, land analysis, PLA (Permits, Licenses & Authorizations) study and engineering for PLA and financing.

Pre-feasibility study – This is the first assessment of the potential project. Site identification and securing, land property or lease agreement must be analysed. It is a high-level review of the main aspects of the project such as the solar resource, grid connection and construction cost in order to decide if it the project is worth taking forward, (Yilmaz), (Photovoltaic System Design and Installation, From the pre-feasibility study to the commissioning, Sunenergy, 2011), (India: Preparing Utility Scale Concentrated Solar Power Demonstration Project), (Investing in Renewables: Risk Accounting and the Value of New Technology), (Wit A. d., 1988).

Feasibility study – If the outcome of the pre-feasibility study is positive, a detailed feasibility study can be carried out. This consists of a significantly more detailed assessment of all aspects of the project. The purpose of the feasibility study is to explore the project in enough detail for the interested parties and stakeholders to make a commitment to proceed with its development, (Mosey, 2010) (HANSEN) (al. R. R., 2014).

Appropriate Solar PV technology would be identified based on factors like space requirements and availability, available global radiation (GHI), climatic conditions- especially temperature and wind velocity, cost of technology (CAPEX, capital expenditures & OPEX, operational expenditure), risks associated with the technologies, need for trained manpower, level of commercial development and performance, availability of technology suppliers/performance guarantees etc. All of these factors play a critical role in the identification of a suitable technology. For the selected technology, equipment providers are identified and selected.

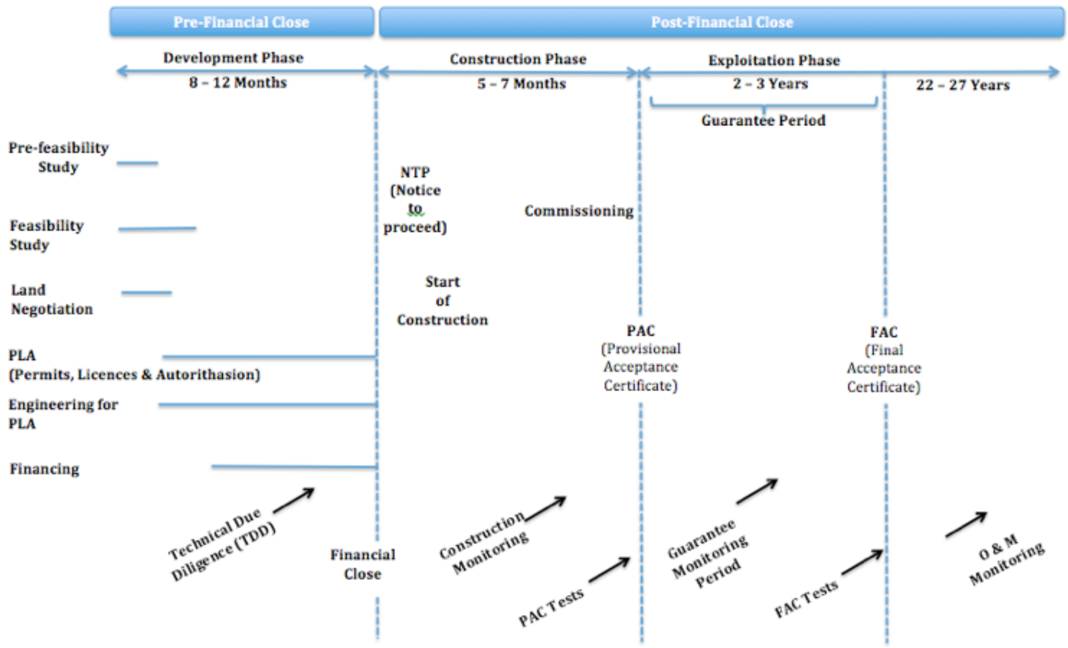


Figure 3.1: Project Time Frame for a 20 MW Utility-scale PV project [**43**]

Land Negotiation – the first task towards project development is the identification of a suitable site. The project developer needs to identify a site and check its availability. Once the feasibility of the land is checked, the developer closes the negotiation of the land contracts.

PLA (Permits, Licenses & Authorizations) analysis – this includes all necessary administrative authorisation activities - such as the application for building or environmental permits - that need to be completed before the construction of the PV installation may start. Requirements common to all Utility-scale photovoltaic installations to be sited in designated locations can be subdivided into three groups: regional administration, local administration and utility company permits.

- **Regional Administration**: these permits include, project approval, administration authorization and environmental formalization process and others.
- **Local Administration**: to this type of administration, the business activity license, building and construction permits will be asked for.
- **Utility company permits**: they include all actions necessary in order to obtain the license to produce electricity. These licenses may have different names, such as electricity generation license or exploitation authorization, but the more common are, the exact electrical access connection point, the PPA (Power Purchase Agreement), grid impact study and the connection contract, [**52**] [**53**].

Engineering for PLA – The key systems and structures will be designed in detail. A contractor will generally complete this activity. Besides choosing properly all components, the selection of the system direct current (DC) voltage (600, 1000 or 1500 Vdc) is very important to take into consideration too because it can influence on the total cost and also on the life of the PV plant, if it is not well designed [**54**]. PV plant topologies are classified into four basic groups: centralized, ac modular, string, and multistring. The type of PV inverters and their interconnection methods highly impact on features of PV power plants in terms of efficiency, investment cost, and reliability in energy generation, [**55**]- [**56**]. In addition, it has to be decided whether the PV generator is mounted at a fixed-tilt or on a tracking system.

Financing – This includes: memorandum, road show and Due Diligence (Legal, Technical and Insurance). The steps to be taken to acquire the necessary capital, equity or financing for the realisation of the PV installation. For financial projects the following steps are often seen: Development Phase, Selecting Lenders and Investors, Due Diligence, Credit Convention and Shareholder Agreement Financial Closing.

Selecting Lenders: the project is presented. A pool of banks and investors is selected. Investors negotiate the terms and conditions of the financing (gearing, DSCR, debt term, etc.), the term sheet.

Due Diligence: this is a project evaluation that identifies the risks and methods of mitigating them prior to investment. There are typically three main due diligence evaluations: Legal Due Diligence (LDD), Technical Due Diligence (TDD) and Insurance Due Diligence (IDD). TDD will be managed in more detail in the chapter VI in this document.

Credit Convention and Shareholders' Agreement: Time Contacts, Lenders, Investors, negotiate the terms and conditions of the debt-financing and negotiate the terms and conditions of the equity financing

3.2 Financial Close

Financial Close occurs when all the project and financing agreements have been signed and all the required conditions contained in them have been met. It enables funds (e.g. loans, equity, grants) to start flowing so that project implementation can actually start. This stage includes activities to secure funding for the PV projects which, in addition to having rights to the land, permits, authorizations and licenses, also meet the requirements entitling them to receive certain revenues. In addition, a relationship with the EPC (Engineering Procurement Construction) contractors/manufacturers is established. In this time, all main contracts are signed: credit line, EPC, O&M…

3.3. Post Financial Close

This phase is divided into two parts: Construction and Exploitation Phase.

3.3.1 Construction Phase

The construction phase starts with a NTP (Notice to Proceed) from the owner. Thus, the physical construction of the PV plant starts. During this phase diverse activities can be done such as: quality control of the components (in the manufacture throughout the production process and during the construction stage with periodical tests onsite) and a cost control. Also, in the procurement phase, a monitoring must be done with the sole purpose of avoiding risks of any delay in the delivery of the components.

A Provisional Acceptance Certificate (PAC) is done when the construction phase finishes. PAC is one of the most important milestones in Utility-scale PV projects. The PAC consists of a series of tests and checks to have a clear representation of status and output of the plant in order to match these results with the energy production estimations included in the project base case, that all incomes and expenses are reflected in the project, and ultimately, its profitability.

3.3.2 Exploitation Phase

In the Exploitation Phase two periods can be distinguished: Guarantee and Exploitation Period.

a) **Guarantee Period**: this is the period between the PAC and the FAC (Final Acceptance Certificate). It lasts between two or three years where a warranty bond exists. In this phase, at the same time, there are two activities: operation and final commissioning [**49**].

- **Operation**: Includes supervision of the operation and maintenance of the power plant, performance monitoring and cost control.
- **Final Commissioning**: this is the process by which the PV plant is checked and tested to verify if it functions according to its design objectives or specifications and if it is in accordance with the project base case

b) **Exploitation Period**: The O&M (Operation and Maintenance) contract can continue throughout the PV plant life with preventive and corrective maintenance, via dedicated O&M service over its twenty to thirty years of PV plant operational lifetime.

CHAPTER 4

FINANCING PHOTOVOLTAIC PROJECTS PROJECT FINANCE

CHAPTER 4. Financing Photovoltaic Projects. Project Finance

4.1 Main financing mechanisms for PV projects

A number of financing mechanisms are available for infrastructure projects in general [**57**], [**58**]. Among them, larger PV installations requiring special development and financing methods. Many of the policies supporting renewable energy comprise tax incentives. However, renewable energy projects and their developers generally do not have enough tax liability, also known as “tax appetite,” to utilize the credits to their full potential.

A number of financial structures have been developed to take advantage of the tax credits at their highest value. These structures generally require an equity investment from a firm with sufficient tax appetite to utilize the tax credits. This is referred to as a tax equity investment [**59**]. Innumerable variations on these structures can be applied depending on the risk appetites and reward expectations of the parties involved, including allocation of tax and cash benefits, buyout provisions during set periods along the project life, and default allocation of risk to parties.

There are different structures of financing photovoltaic projects. They vary in the type of participants, source of financing and allocation of benefits. In fact, there are different risk/reward trade-offs for each type of financing structure, and a developer should help the customer choose the most appropriate structure depending on the customer’s risk appetite, cash flow constraints (if any), and existing tax liabilities. Three major financing structures primarily used for large PV projects. Descriptions of each structure are as follows:

Corporate financing

In this case, one corporation develops the project and finances all costs. There are no other investors or lenders involved. The project may be set up as a subsidiary of the corporate parent. However, with 100 % ownership, the subsidiary would have to be consolidated into the parent's financial accounts. Naturally, the corporation reaps all the benefits of the project. The corporate parent must have sufficient capacity for tax credits and benefits to be of use. In the renewable energy sector, this structure is rare and only used by utility companies themselves.

For instance, Sungevity, Inc. (Oakland, CA, U.S.) on December 15th, 2015 announced that it has completed an equity and project financing transaction totalling USD 650 million to support the company's U.S. and international solar photovoltaic (PV) business. This marks the largest financing of a private company in the solar industry for 2015.

Leasing.

A leasing company owns the PV system and leases it to the site host (the lessee) over a period of years. During this lease term, the site host is responsible for operating and maintaining the system, and is entitled to use the power generated by the system to offset its purchase of power from the utility. In exchange for this use of the system, the lessee makes a series of recurring lease payments to the lessor (these payments must be made irrespective of how well the system performs).

This option allows solar-powered companies to benefit from solar energy in exchange for a monthly lease payment for the use of the system hardware. Typical commercial solar lease agreements range from 15-20 years at which point the lease can be renewed or the customer can choose to purchase the system for a residual value. For organizations that cannot fully capitalize on available tax incentives and want to avoid upfront capital investment, a lease may be the best option to facilitate your transition to solar power.

Project Finance

This allows the generation of reasonably predictable, profitable and sustainable cash flow, according to the characteristics of the project, in combination with the quality of your own assets, with possibilities for individual financing, without full resources on the part of the investors, and with high leverage, [**60**] [**61**] [**62**] [**63**]. Fig.4.1 shows the main requirements for project finance mechanism that can be used.

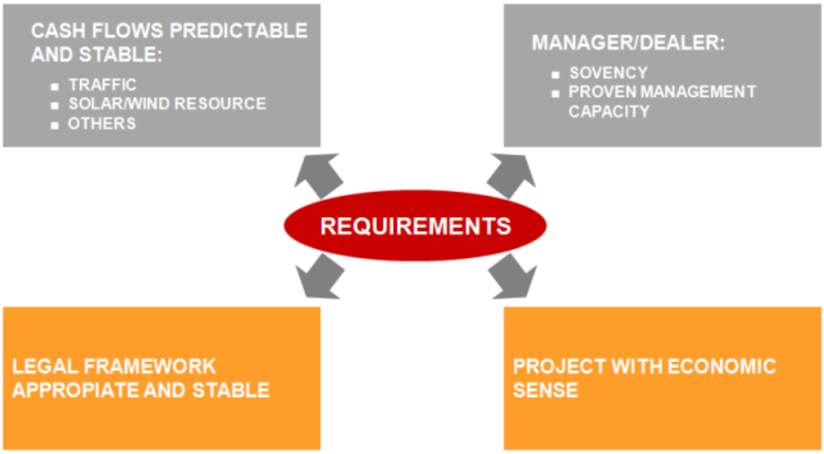


Figure 4.1: Project Finance Requirements

The Project Finance is the typical tool for financing very large projects in different sectors such as: Energy, Infrastructures, Water… (Fig. 4.2) [**64**] [**65**]. It will be managed in more detail in the next item.

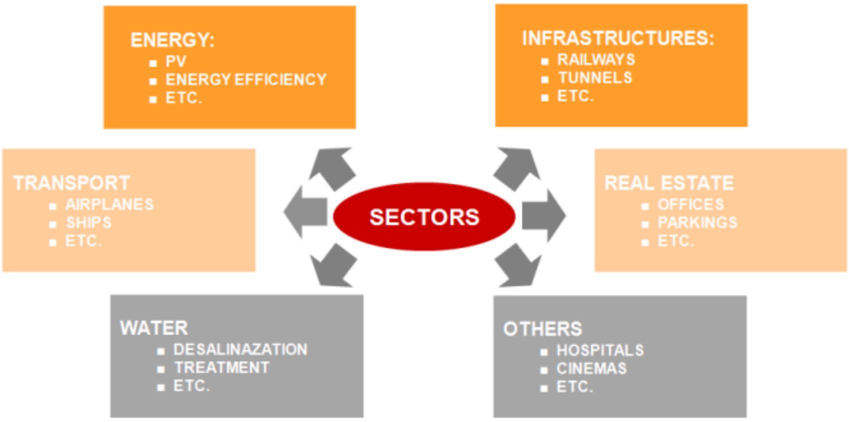


Figure 4.2: Project Finance: Tool for different sectors

A variation of project finance is the partnership flip, Figure 4.3.

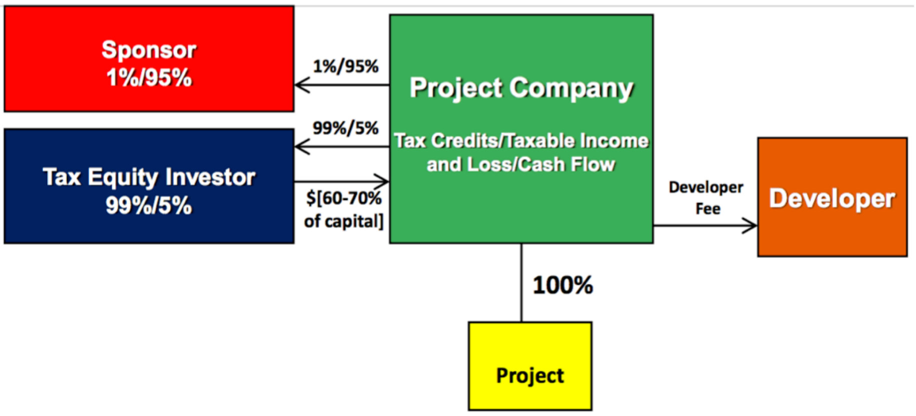


Figure 4.3: Partnership flip scheme.

For this case, during the period when tax benefits are available or until such later time as the Investor achieves a specified rate of return on its investment (the “flip date”, typically 6-7 years), a large majority (typically, 99 %) of taxable income, loss and credits are allocated to the Investor.

After the flip date, the allocations of profits, losses and distributions flips to, for example, 90 % or 95 % to the Developer and the rest to the Investor.

After flip date, the Developer frequently has an option to buy out the Investor's interest for fair market value determined by when the option is exercised. Option should not be continuous, but may be exercisable at predetermined times.

4.2 Project Finance scheme for Utility-Scale Photovoltaic Projects

Large-scale photovoltaic projects are characterized by the implementation of a long life power plant with high energy yield and availability, proper and safe operation complying with the relevant requirements, low cost, high returns on investment and debt financing. So, tasks such as the Technical Due Diligence (TDD) and third party verification of construction, progress & milestone completion are a key point for the project. The risk is influenced mainly by the uncertainty of the Technical Due Diligence. But the cost of financing is highly dependent on the risk [**66**] [**67**] [**68**] [**69**]. As has been seen in the previous item, a number of financing mechanisms are available for infrastructure projects: cash purchase, leasing and project finance. However, the latter, project finance is the most useful scheme where project debt and equity used to finance the project are paid back from the cash flow generated by the project. Although sometimes the project finance can be more complicated and expensive than alternative financing methods [**70**] [**71**] [**72**]. Project finance entails financial modelling, risk management, legal aspects and the creation of a financial structure. It is a way of structuring all aspects of the project.

The project finance was used to finance imports and exports already during the Roman Empire [**73**]. Project loans were also used to finance trading expeditions from Europe to Asia in the seventeenth and eighteenth centuries. The first large scale application of project finance was the development of oil fields in the North Sea in the 1970s. In recent years, project finance is applied for large-scale projects in infrastructure, natural resource and electric power which typically are capital-intensive and large-scale operations. So, it has had a growing importance over the last three decades.

An important feature of project finance is the organisational structure. The project company is a separate legal unit, independent from the sponsor company who initiated the project. The project company is sometimes known as a "*special purpose vehicle*" (SPV), established to perform one particular task, Figure 3. So, the Special Purpose Vehicle is a legal entity created to fulfil narrow, specific or temporary objectives. SPVs are typically used by companies to isolate the firm from financial risk. They are also commonly used to hide debt (inflating profits), hide ownership, and obscure relationships between different entities which are in fact related to each other [**74**].

In project finance, lenders and investors rely either exclusively or mainly on the cash flow generated by the project to repay their loans and earn a return on their investments. This is in contrast to corporate lending where lenders rely on the strength of the borrower's balance sheet for their loans.

The capital structure in a project financed venture typically involves a high debt level, often as much as 70 – 80 % of the total capital. The debt is in most cases provided by commercial banks, but the bond market is also available for projects.

Another important aspect of project finance is the wide-spread use of contracts. Then, project finance involves many participants depending on the type and the scale of a project (sponsor, lender, developer, utility, EPC (Engineering, Procurement, and Construction) contractor, Insurance company, management and O&M contractor; in addition, there will be the Financial Advisors, Technical Advisors, Legal Advisors, Debt Financiers and Equity Investors), and contracts that contribute to regulate relationships and define responsibilities.

The sponsors are the project owners with an equity stake in the project. It is possible for a single company or for a consortium to sponsor a project. Typical sponsors include foreign multinationals, local companies, contractors, operators, suppliers or other participants.

Contracts are used to govern the relations to other parties such as contractors, suppliers, sponsors, the government, customers and lenders. With numerous parties involved it is important to have contracts delegating responsibilities, distributing risk and defining the purpose of the project's cash flows. The use of contracts in project finance is significant in the risk management.

Providers of project financing can include commercial banks, is the more usual. However, there are other providers such as multinational corporation (the World Bank, the European Bank of Investment, Inter-American Development Bank ...), leasing companies, insurance companies, pension funds, governmental bond authorities, finance companies, export credits, international financing agencies, private lenders, and customers.

The developer and/or the future sponsor of the project forms a club deal of financial institutions in order to carry out the financial closure, [**75**]. The steps to bring the pool of banks and proceed to financing are summarized below (Figure 1):

- Document Preparation. A memorandum with the information of the project related to financial and technical aspects and also with a qualitative and quantitative risk analysis.
- Choose the Banks. The memorandum is shown to a large number of banks with different interest and objectives.
- Roadshow. The sponsor meets all these banks in order to show the memorandum.
- Select the Banks Interested. Once the banks have showed interest, the sponsor select a club deal with the final pool of banks

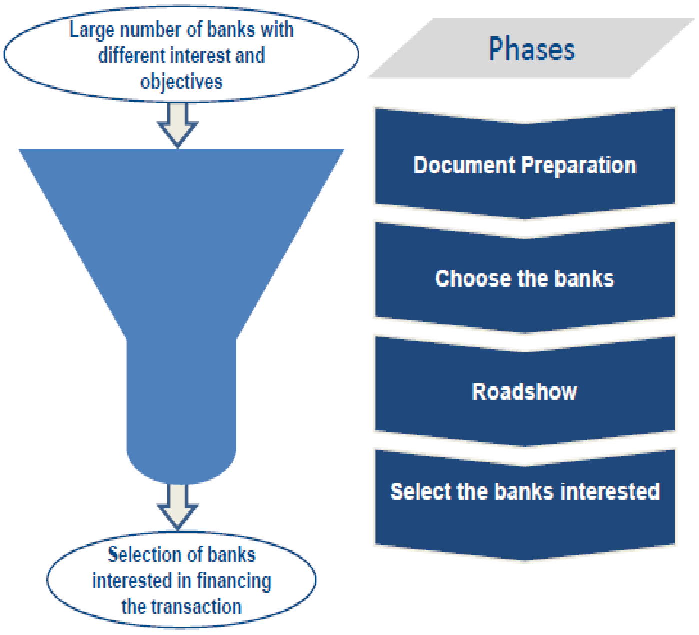


Figure 4.4: **Phases for selecting banks to do a club deal** [75]

The club deal of banks has different leaders for different activities until the financial closure is reached. The estimated timing to do a club deal and finalize the financial closure is shown in Figure 2.

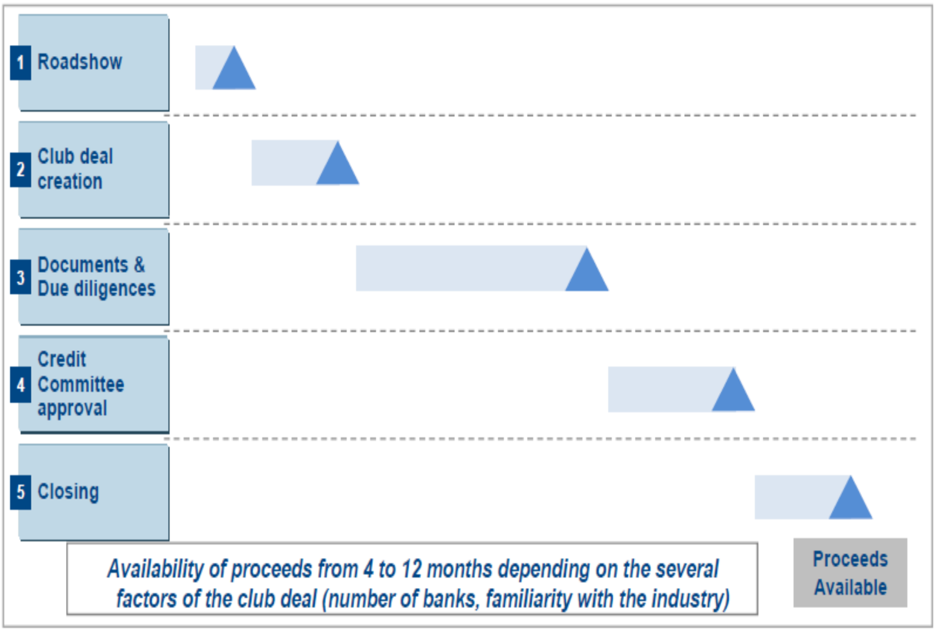


Figure 4.5: **Estimated timing to do a club deal and reach the financial closure** [75]

As an example of financing from multinational corporation, last Dec 14, 2015 the Inter-American Development Bank (IDB) approved a $57.7 million loan from its ordinary capital and $30 million from the Canadian Climate Fund for the Private Sector in the Americas, which is administered by the Bank, to finance the private sector in El Salvador in the construction, operation and maintenance of a photovoltaic solar energy plant and its related facilities.

The main sources of funds are equity and debt, in addition comes the possibility of lease finance and government support. The equity in the project company is provided by the sponsoring companies. The equity is held by one or a few sponsors and constitutes a smaller fraction of the capital structure, typically around 30 or 20 %.

The importance of the main contracts in project finance is considerable because they provide credit support. The construction contract consists of three general parts; engineering, procurement and construction. In the case of all three areas being covered in one contract, this is called an EPC contract. The EPC contract describes the scope of the project, including design, technical specifications, criteria for performance, a fixed schedule for progress and a fixed price with strong guarantees, penalizations and liabilities. In some cases, the contract also includes installation, in which the contract is called EPCI contract [**76**], although in the Photovoltaic sector is commonly called EPC contract.

The O&M contract contains requirements regarding budget limits, health and safety standards, operating standards, routine inspections, fast response to solve problems, minimum stock of spare parts, availability guarantees and emergency repairs.

There is another important contract in the project, the loan contract between the banks and sponsor (debt and equity). This contract is usually advised only by legal advisors.

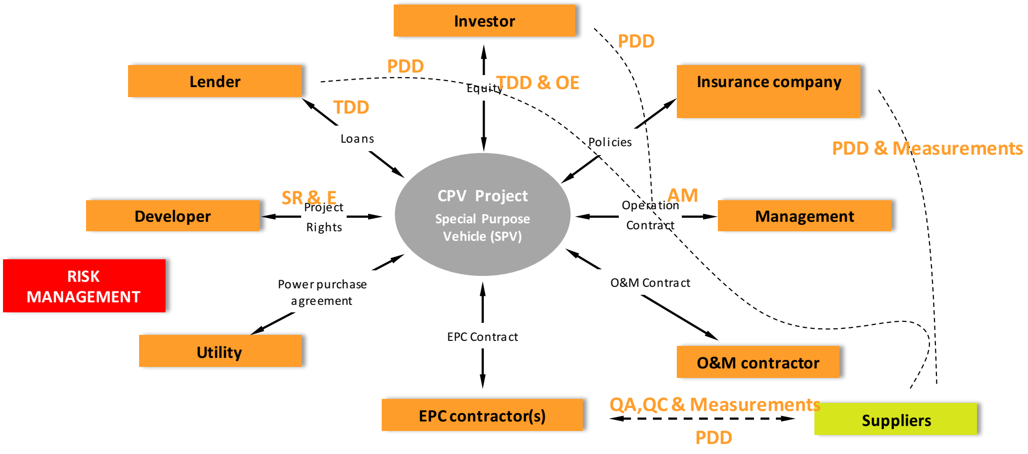


Figure 4.6: **Project Finance constellation or Project Finance scheme, including different rolls of Independent Technical Advisor** [**78**] [**75**]

The capital structure combined with the contracts contributes to distributing the risks involved in the project between all parties involved, not only the sponsors.

The typical project financing scheme or structure to build and operate the project is shown in Figure 3. In it, the key elements of the structure are presented in [**78**].

Shown in Figure 3 is the typical scheme of the project finance in large PV plants. It's the project finance constellation. As can be seen, a developer is responsible for getting the permits, licenses and authorizations. In parallel he gets debt and equity and structures the finance of the project, as a future sponsor. The sale of electricity is usually based on a PPA (Power Purchase Agreement) contract. There is an EPC contractor trying to cover risk with their suppliers. The operator of the plant usually will be the constructor, for at least the first 3 years after provisional acceptance certification. In the constellation can be seen the different tasks carried out by the independent technical advisor in order to manage the risks of the project at different levels.

- TDD: Technical Due Diligence
- PDD: Product Due Diligence
- SR & E: Solar resource analysis and energy estimation
- QA, QC & Measurements: Quality assurance, quality control and measurements
- OE: Owners engineering
- AM: Assets management

Although it is also worth mentioning that there are particular cases where there is different legislation with tax advantages. It is the case of the United States where the solar Investment Tax Credit (ITC) is one of the most important federal policy mechanisms to support the deployment of solar energy in the United States. This has created a proliferation of a specific case of the project finance where one of the actors is the Tax Equity Investor. For instance, the subsidiary of the Chinese solar firm has finalized recently a tax equity investment commitment and $180 million debt facility for development of a 75 MW Astoria 2 solar farm in California [**79**].

CHAPTER 5

EVALUATING, LIMITING AND MITIGATING TECHNICAL RISKS. THE INDEPENDENT TECHNICAL ADVISORY

CHAPTER 5. Evaluating, Limiting and Mitigating technical risks. The Independent Technical Advisory

This section focuses on identifying the risks in the Utility-Scale PV projects. The list of risks identified below is not an exhaustive list. They can be divided into two categories: technical and non-technical (economic, legal, political, social and time delay risks). Both of these categories are further subdivided into development stage risks and operational risks [**80**] [**81**]. They are associated with the steps of the project.

The technical risks are managed by the Independent Technical Advisory.

5. 1 Technical Risks

Technical risks are those that arise from the PV module, PV inverters, and other mechanical and electrical components, as well as system engineering, energy modelling and installation. The technical risks can be grouped into different perspectives. One classification can be done taking into consideration the phases of the project. So, they can be subdivided into development stage risks and operational risks.

Then, Table 5.1 shows the technical risks during the Pre-Financial Close phase in the PV project including various aspects of system design, resource estimation and validation, siting evaluations, and grid interconnection.

Table 5.1: Technical Risks during the Pre-Financial Close stage

Risk	Potential Damages or Losses
Resource Estimation	Resource-related production shortfalls/Debt service delinquency or default
Component Specifications	Manufacturer insolvency/Serial defects/Infant mortality
System Design	Component failures/Production shortfalls/Forced downtime
Site Characterization	Environmental and Archaeological constraints prohibitions/Infrastructure constraints/Transmission cost overruns
Transportation/installation	Equipment damage delays

There are four main risks to cover during the construction stage, unexpected events related to timing, quality, guarantees and cost overruns. These risks may be detailed further in the following:

- Delays in the delivery time of materials and components
- Delays to reach the milestones of the EPC contract
- No quality control of the main components (modules and inverters)
- Insolvency of manufacturers and/or constructor guarantees
- Cost overrun related to incomplete scope of work (variation orders)
- Etc.

The potential damages and losses related to these construction risks may be the following: delay in the project and insolvency of guarantors with the consequent application of clauses of penalties, including termination; cost overrun with the consequent reduction of project profitability and with the consequent leverage loan reduction, etc.

The principal risk in the operational phase of a project is the uncertainty of energy production. If actual project performance does not meet the budgeted generation estimates, the project will generate less revenue from power sales, and the sponsor may experience difficulty in servicing its debts or earning its investors their returns. Production shortfalls can result from plant operation contingencies, such as component failures (serial and otherwise), latent defects, forced outages, module degradation, and resource variability.

Then, the technical risks during the project operation and potential damages or losses arising from those risks can be the following: serial failures, latent defects, high rates of degradation, forced outages, planned and unplanned maintenance downtime and costs, manufacturer insolvency and resource inadequacy.

Another perspective to analyse the risks can be to subdivide into those associated with the plant location and with the technology.

Risks associated with the plant location of the PV project can be distinguished by the following: the technological adequacy to climate change, estimation of flood risks, estimation of effective solar radiation hours, earthworks and geotechnical problems in the terrain [**82**].

On the other hand, regarding risks associated with the technology, the following technical risks can be found: development of new photovoltaic solar power systems, selection of the PV modules, selection of PV inverters, selection of solar tracker, connection into the grid and possibility of alternative power generation systems.

5.2 The Independent Technical Advisory (ITA) as a Tool to Evaluate & Control Technical Risk

Taking into consideration that Project Finance has been chosen as the financing option, the target is to satisfy the Financial Institutions that a project is feasible and that the risks (for each actor of the Utility-scale PV project -Lender, Developer, Insurance Company, Investor, EPC, O&M contractor…- is faced in some step of the project) are acceptable and covered. However, this requires a broad analysis of technical, commercial, regulatory, environmental and financial factors to verify that the proposed system can deliver the assumptions in the business model. Then, the project evaluations identify the risks and methods of mitigating them prior to investment and financing.

5.2.1 ITA in the Pre-Financial Close Stage. The Technical Due Diligence (TDD)

In this stage, the independent technical advisory carries out the following activities:

A) Studies of the solar resource, at the specific site where the PV project (in the pre-feasibility and feasibility stage) will be installed. Selection of proper irradiation data source and known uncertainty is a critical issue. Solar-resource uncertainty and inherent seasonal variability represent a performance and revenue risk for a project that is tied primarily to the quality of the data available and the commercial risks dictated by the contractual arrangements governing the sale of energy from the project. In this chapter, methods for allocating performance and revenue risk related to the solar resource are mentioned [**83**], [**84**].

B) Energy yield prediction assessment. This is important at all stages of the project lifecycle, particularly in the preliminary stages of the development and for project financing. The aim of analysing the prospective energy yield is to predict the average annual energy output for the lifetime of the proposed power plant, typically 25-30 years. Energy production is estimated using modelling tools and the following inputs must be taken into consideration: Irradiation data to be expected on site based on the best available sources, site inclination, project design (e.g. inclination and positioning of the modules, partial shading, etc…), Actual characteristics of the plant key components (including temperature behaviour of the modules, part load characteristics of inverters and transformers), [**85**], [**86**], [**87**], [**88**].

Severe climatic conditions of high temperature and high humidity (for instance in tropical countries), have negative impacts on performance and reliability of PV systems. Since high temperature causes a reduction in output power of PV modules, the temperature effects are one of main concerns when forecasting energy production or analyzing losses of the PV systems, [**89**], [**90**], [**91**], [**92**], [**93**], [**94**], [**95**], [**96**], [**97**], [**98**].

The reports used for investment consideration can include an estimated project lifetime and annual production table with data at some confidence levels of percentiles (P). Most usual levels are P50, P75, P90, P95 and P99. Those confidence levels provide a range of expected average production outputs for the project. In addition, table matrices quantifying average net production values on monthly and diurnal time scales are often provided too.

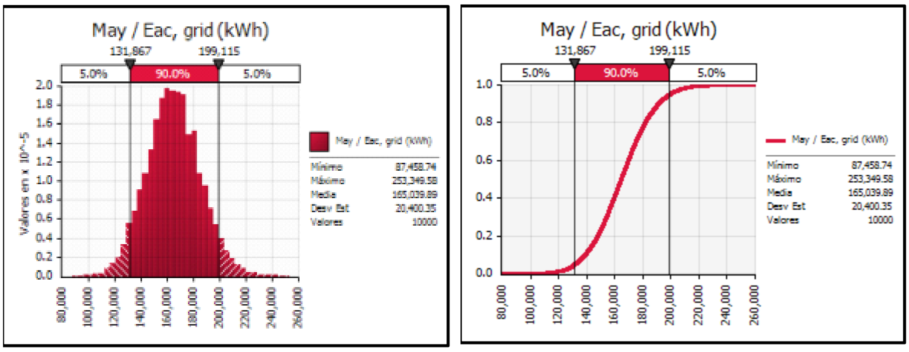


Figure 5.1: Percentiles calculations using Monte Carlo method [**99**]

C) On-site screening of the land where the PV project is going to be installed, in order to check the adequacy of the land. Some of the constraints typically reviewed include: Local climate available area and land use, accessibility, terrain and topography, geotechnical, hydrology, grid connection, water availability… [**100**].

D) Contractual agreement of the land review where the PV project is going to be installed.

E) Assistance for project sizing and optimisation of design (dc voltage optimization, configuration to reduce shadowing losses, etc), in the development phase, and engineering for processing the requests. Suitable technologies can then be recommended which are optimised for the site location. Preliminary review of the ratio of nominal dc power vs peak dc power and also review of layout options should be undertaken early in the PV plant development phase to ensure the selected equipment is suitable for the site. Then, it is necessary to get the following information: the layout in the land area available (the layout configuration and electrical PV plant topology may also affect equipment selection); an appropriate buffer zone around the plant to account for shading/other activities and overall size appropriate for the grid connection [**101**], [**102**], [**103**].

F) Evaluation of the technical components: PV modules, mounting structure (elaboration of cost and time efficient adequate mounting structure and identification of geological requirements) and inverter (Elaboration of adequate inverter technology based on availability of maintenance and cost- efficiency and identification of costs and service availability).

G) Determine acceptability of contractual arrangements (EPC, O&M, grid connection, power purchase and/or FiT regulations): Looking for interface points and areas where there could be risks, examining construction timelines and ensuring that the critical path is clearly identified and mitigated in the contracts and assessing the warranty and guarantee positions within the contracts – protection for the lenders.

H) Assistance to the sponsor (they can be the first developers or the fund that has bought the permissions from the developers) in order to understand the Project and presenting to the possible future banks that will form the club deal, develop technical aspects of finance documents

I) Assess the key assumptions in the business plan, always from the technical point of view

J) Technical Due Diligence (TDD). This is integrated into the Due Diligence phase of evaluation of the project and takes place along with the Legal Due Diligence (LDD) and Insurance Due Diligence (IDD). For instance, it is a multi-discipline analysis, in which risk assessments are made for all individual elements of the PV plant. It comprises all the technical aspects of a Project, from the production estimation to the contractual agreements and costs.

Typical areas assessed during the TDD are: natural resource, losses and yield estimation; analysis of technologies track record; fit for purpose and technological evaluation of equipment and plant design; equipment supplier evaluations: references, previous experience and delivery periods; contract evaluation (EPC, O&M, PPA, etc.); evaluation of authorizations, licenses, permits; environmental evaluation and technical evaluation of the base case: price, expenses, revenue, maintenance reserve account (MRA) [**104**], [**105**], [**106**], [**107**]. All of these are integrated in the Finance Project [**108**], [**109**], [**110**], [**111**], [**112**].

Once the banks have been chosen, they mandate advisors. Then, the technical advisors carry out the TDD so that Financial Close is reached, including reports from other advisors. In this phase, the Independent Technical Advisory also assists the sponsors and the Banks to negotiate the agreements of the EPC and the O&M, respectively (sometimes the EPC and the Operator are the same).

L) Assessing that the model assumptions are complete and appropriate is also a part of the process. Besides, technical input data for the financial model: CAPEX Capital Expenditure & OPEX Operations and Maintenance costs [**113**].

The Independent Technical Advisor (TA) makes a sustained study of the Technical Due Diligence for all financial institutions. Often, when the Independent Technical Advisor has already done a lot of work for the Developer/Sponsor (during development phase), depending on the scheme of the Project and particularly if the Sponsor is not the EPC contractor simultaneously, the Financial Institutions has no difficulty in supporting the same activities to be done by the Independent Technical Advisor. It is understood that there is no conflict of interest because the subjects that the TA reviews are common with the interests of the Financing Institutions and the Sponsor.

Furthermore, the Sponsor figure is not always the same as the Developer because the latter sometimes sells the permissions of the Project to another one (Sponsor).

5.2.2 ITA in Post-Financial Close Stage. Construction, Commissioning, Verification & Certification

In this stage, the independent technical advice can provide to lenders some services throughout the project life cycle until the loan is repaid. The scope of the post-financial close services encompasses the construction and operational phases of the project and will typically involve: attendance at design reviews, certification of milestones, quarterly or monthly reporting on progress to the Lenders, approval of technical changes, performance monitoring of operational systems and commercial performance of the borrower’s business.

Then, additional Independent Technical Advisory services often offer construction monitoring, testing and completion and monitoring during operation.

During the Construction Phase

The customer is provided with independent verification that the works have been completed in accordance with specified requirements, (compliance with contract / specifications). It is the process for monitoring and recording the existence, condition and timing of significant operations on a construction site.

The involvement of the consultants is important during the construction phase to ensure that: the design is being correctly interpreted, the construction techniques are appropriate and do not reduce the effectiveness of the design and the work is completed generally in accordance with the plans and specifications.

In addition, another task can be done: compliance with project schedule, review of the EPC contractor‘s / owner‘s progress report, site and workshop inspections and preparation of monthly or quarterly progress reports and progress certificates [**114**], [**115**].

When the construction finishes the plant is connected and ready for Commissioning.

Commissioning

Commissioning is the process that encompasses functional safety checks, connecting the PV plant to the grid and putting in into operation [**116**]. The tests that are done by the Independent Technical Advisory are normally split into three groups: visual, pre-connection and post-connection acceptance test.

- **Visual acceptance tests**. These tests take place before any systems are energised and consist of a detailed visual inspection of all significant aspects of the plant.

- **Pre-connection acceptance tests**. These include an open circuit voltage test and short circuit current test. These tests must take place before grid connection.

- **Post-connection acceptance test**. Once the plant is connected to the grid, a DC current test should be carried out. Thereafter, the performance ratio of the plant is measured and compared with the value stated in the contract. An availability test, usually over a period of 5 days, should also be carried out.

After the Commissioning there is a **PAC (Provisional Acceptance Certification).** In order to verify that the EPC contractor has achieved provisional acceptance, a variety of services can be offered including: Document review, Visual acceptance, Technical acceptance, Witnessing the commissioning, Plant Testing and issue of take-over certificates and Performance Evaluation from analysis of data from the functional testing period.

The target is to ensure that there is no deviation from the contractual technical specifications of the main components (PV modules, PV inverters, supporting structures and electrical infrastructure). Availability and performance testing are also conducted on completion of all the mechanical and electrical works. The results of all tests are reviewed to ensure that a plant is performing at the expected level.

Testing verification

Performance evaluation is an important part of provisional acceptance. Normally, an assessment of the plant is done in order to check the performance ratio and availability to validate compliance with the guarantees in the EPC contract. The activities that can often be developed are the following: attendance and monitoring of the performance and reliability tests and review of performance test results in view of liquidated damages requests.

In addition, Non-Destructive Testing can be included, such as: Visual Inspection, Radiography, Ultrasonic, Magnetic Particle, Penetrant Testing and PMI (Positive Material Identification).

During the Exploitation Phase

In this phase there are some activities related with the two periods: Guarantee and Non-Guarantee period.

During the Guarantee Period

The data of the PR (Performance Ratio) for every year is reviewed as well as the possible incidences of the solar resource and the O&M. This period finishes with a Final Acceptance Certificate (FAC).

Final Acceptance Certification

Final acceptance certification is the final stage in the financial development of a solar PV plant and it is important to ensure the EPC contractor has completed works to a high standard and that the plant is performing as expected. This verification can be provided through a number of options including: site visit noting any defects and reviewing condition of the plant assets; review of O&M contractor reports; review of PR for every year; review of plant operational data confirming actual versus expected output and review of scheduled and unscheduled maintenance activities.

During the Non-Guarantee Period

This stage consists of:

- Forcing the O&M contractor to perform **Preventative Maintenance** (entails routine inspection and servicing of equipment to prevent breakdowns and unnecessary production) and **Corrective or Reactive Maintenance** (addresses equipment break-downs after their occurrence and, as such, is instituted to mitigate unplanned downtime losses).

- Conducting **periodic site inspections** to ensure that the PV plant is being maintained at an acceptable level such that the asset value is not adversely affected by the maintenance program and operating practices of the O&M contractor.
- The preparation of semi or annual operating status reports including: operating performance (availability, power performance, energy yield), maintenance and extraordinary events and O&M budget verification.

- **Checking the performance guarantees** as agreed in the EPC and O&M contracts (performance ratio, availability); independent calculation and comparison of actual values against guaranteed values
- Monthly and annual O&M reports provided by the O&M contractor
- The maintenance activities conducted by the O&M contractor and opinion on whether they are being carried out in accordance with the contract
- Monthly and yearly energy production of the PV plant. Analysis of the possible degradation [**117**].
- Monthly and yearly solar irradiation
- Operation and maintenance costs during the year of operation (OPEX)
- Checking the adequacy of the project O&M budget including Maintenance Reserve Account (MRA)
- Advising the owner to provide a budget of Maintenance Reserve Account (including PV Inverter Replacement Reserve)
- Revenues against plant performance [**118**]

In addition, the Independent Technical Advisory can perform other tasks such as

- Technical assets management,
- Refinancing
- Operator Changes

PV plant certification

The purpose of PV plant certification is to evaluate whether type-certified PV equipment and particular support structure/foundation(s) designs conform with the external conditions, applicable construction and electrical codes and other requirements relevant to a specific site [**119**]. The certification body shall evaluate whether the solar conditions, other environmental conditions, electrical network conditions and soil properties at the site conform with those defined in the design documentation for the PV plant type and foundation(s). The evaluation includes safety and quality. Certification of PV plants can consist of the following aspects: site conditions evaluation, design evaluation, equipment evaluation, site-specific design evaluation, application specific design evaluation, installation surveillance commissioning, final evaluation and certificate operation and maintenance surveillance.

CHAPTER 6

VALIDATION: EXAMPLES

Chapter 6: Validation. Examples

6.1 Methodology for Solar Resource Analysis

The methodology for solar resources analysis is based on ATA´s model that consists of evaluating the Time Meteorological Year (TMY) follow their experience and the best practices in the market. Both satellite and terrestrial databases that are available for a specific site and weights them according to different parameters such as source type (ground or satellite), precision, accuracy, years of data, distance to the site and type of irradiation sensors (for the terrestrial stations) are studied.

When taking ground station data for the resource study, the calibration of the sensors, the accuracy of the sensors, the maintenance plans and the absence of missing data are the most important parameters that are taken into account. If there are no long time series measured onsite, spatial interpolation of ground measured data is possible, but when the distance to the site of the different ground stations is more than 50km, then satellite derived solar radiation has been proven to be a good alternative to those ground measurements.

The accuracy of the solar yield will depend on the area of the world where the project is located, the availability of the different satellite data sources at this location, etc. but normally, even if just satellite databases are used, the accuracy of the solar resource will be close to the range of 3 % to 6 % of variability. For PV solar energy, the quality of these satellite data sources is enough to take it into account for the yield studies without the necessity of having onsite measurements of global horizontal irradiation, diffuse irradiations and beam irradiation campaigns.

The databases more commonly used are:

- SOLARGIS (http://solargis.info/). SolarGis is the most used climate database in PV sector that provides solar radiation and temperature data that is derived from satellite images. The periods of data, the resolution and the satellite that is used depend on the region of the world. Solargis is also in the process of expanding coverage to all areas of the world. The current coverage can be seen in the Figure 6.1.

Figure 6.1: Satellite coverage based on the region of the world (Source: Solargis)

The different satellites have the following temporal resolution and periods of available data.

Meteosat Second Generation (MSG) satellites: in PRIME region (covering most of Europe, Africa, Middle East) from 04/2004 up to present with a temporal resolution 15 minutes.

Meteosat First Generation (MFG) satellites: in PRIME region from 01/1994 to 12/2005 and in IODC region with Meteosat 5 (covering Western Australia up to longitude 125°E, South-East Asia: Malaysia, Indonesia, Philippines, and Central Asia: Iran, Afghanistan, Pakistan, Turkmenistan, Tajikistan, Uzbekistan, Kyrgyzstan and most of Kazakhstan) from 01/1999 up to present. The temporal resolution is 30 minutes.

GOES (Geostationary Operational Environmental Satellite) satellites: in GOES-EAST region (covering basically North America, Central America, South America and Pacific Islands like Hawaii) from 01/1999 up to present and temporal resolution is between 30 minutes and 3 hours.

The spatial resolution is 4 x 5 km at mid-latitudes and decreases to approximately 3 x 3 km at lower or higher latitudes. One of the most important innovations that has been implemented in the Solargis program is the use of daily values for aerosol and water vapour data from 2003 onwards. Earlier data relies on monthly averages. One of the established limitations to accurate irradiance measurements from satellite images is the modelling performed to estimate the level of aerosol and water vapour present. Finally, any terrain effects are automatically included in the irradiance estimates that are made by Solargis. The air temperature data included in Solargis is derived at 2 meters and is calculated from NOAA (National Oceanic and Atmospheric Administration) and NCEP (Natural Centre for Environmental Prediction) data sources. The data is based on the period between January 1994 and the present. The spatial resolution of the final output database is 1 km.

Solargis is one of the most recent products that have been commercialized (2010) and the simulation methods implement the latest knowledge and best-practices in solar radiation and PV modelling. The recent (February 2011) IEA SHC (Solar Heating and Cooling Programme) Task 36 data inter-comparison activity, has independently confirmed that SolarGIS is one of the better performing satellite solar radiation database presently available on the market.

- PV GIS (http://re.jrc.ec.europa.eu/pvgis/apps4/pvest.php#). Photovoltaic Geographical Information System (PVGIS) provides a map-based inventory of solar energy resource and assessment of the electricity generation from photovoltaic systems in Europe, Africa, and South-West Asia. It is a part of the SOLAREC action that contributes to the implementation of renewable energy in the European Union as a sustainable and long-term energy supply by undertaking new S&T developments in fields where harmonization is required and requested by customers.

- METEONORM (http://www.meteonorm.com). The METEONORM 7 database contains data from more than 6,200 cities, 8,300 weather stations and 1,200 DRY (Design Reference Years). If the nearest site is more than 20 km away, a mixture of ground and satellite information is used. Satellite data is used for interpolation in remote areas. In instances when no reliable ground irradiance measurement is available, satellite information is also used. Once the simulation has been performed, Meteonorm 7 indicates the reference data that were used. It should also be noted that the option to model the horizon effects was chosen, so that any natural barriers have been factored into the resulting irradiance data.

- NASA (http://eosweb.larc.nasa.gov/sse/). The North American Space Agency (NASA) developed a geographic information system capable of providing extrapolated irradiance data for a given site and based upon a grid that is 50 km by 50 km. The data is summarized in a monthly format and for a horizontal surface. Due to the size of the projection grid used in SIG, 50x50 km^2, NASA's system has reduced accuracy, because it cannot take into account local effects, such as topography or altitude within the established grid. The data of NASA cover the period: 1983-2005.

- NREL-SWERA (http://en.openei.org/apps/SWERA/). Solar and Wind Energy Resource Assessment (SWERA) is a web site that is designed to provide easy access to solar and wind resource data for around the world. It essentially gathers various sources of information and depending on the location of the project different sources of information will be available.

- Other Databases. For instance, UNIVERSITY OF CHILE (http://ernc.dgf.uchile.cl/Explorador/Solar2/). The system used to get global radiation of much of the territory of Chile has been conducted by the Department of Geophysics of the University of Chile requested by the Ministry of Energy and GIZ, (*Deusche Gesellschaft für Internationale Zusammenarbeit GmbH*), a company which provides services worldwide in the field of international cooperation for sustainable development.

The maps provided by the system have been generated from atmospheric modelling and satellite data for the years between 2003 and 2012, with a spatial resolution of 1 km.

The methodology used to generate the database of solar radiation is based on the use of a radiative transfer model combined with information inferred from the GOES EAST satellite and local observations.

In addition to the numerical values of Global Horizontal Radiation provided by the system, this gives us a map with information on Global Horizontal Radiation in a colour scale.

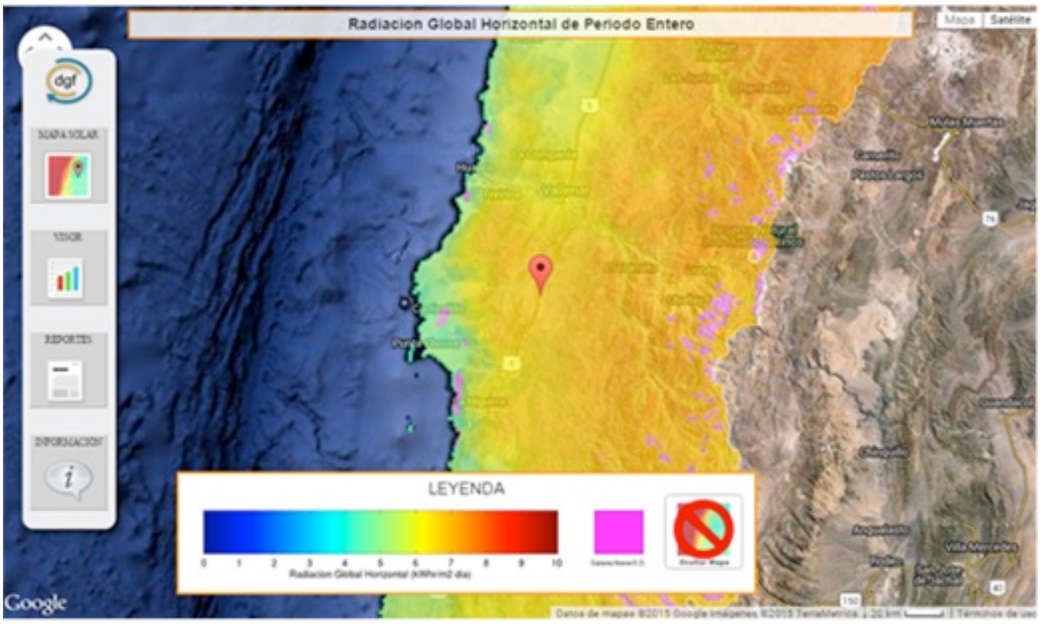


Figure 6.2: Irradiance Map of Project Location in Chile (Source: Department of Geophysics of the University of Chile)

All the databases used in this solar resource methodology are well known and have enough meteorological data quality to be taken into account. All the databases that have been included to do this kind of analysis are considered as reliable and valid for this solar resource studies, as documented in several scientific papers.

Table 6.1: Example of a real PV project of 3,4 MW in Chile. Horizontal Irradiance from different sources

Month	SolarGIs (kWh/m^2)	University of Chile (kWh/m^2)	Meteonorm (kWh/m^2)	NASA (kWh/m^2)	NREL (kWh/m^2)
January	260	260	223	215	244
February	213	214	186	172	199
March	196	200	168	160	173
April	140	143	117	128	135
May	103	105	88	101	97
June	85	87	72	86	84
July	98	98	84	94	90
August	121	124	109	119	115
September	154	158	140	154	149
October	209	214	190	189	197
November	237	236	207	200	221
December	264	265	232	220	257
Annual	**2,079**	**2,103**	**1,816**	**1,839**	**1,961**

At the end, there are several data bases that usually provide the average daily irradiation on horizontal surfaces by means of satellite or meteorological stations near the place under study. First we get the average value of this sources and then, using the Liu y Jordan [4], the Collares-Pereira [5], the Page correlations, [6], the Whillier [7] and the Pérez [8] procedures we can obtain the hourly irradiation data on an tilted surface.

6.2 Methodology for Annual Energy Production Estimation

The energy production estimation methodology bases its results in the solar irradiation received on the photovoltaic modules on an hourly basis, the electrical configuration of the PV plant, the main equipment technical data and other inputs, such as, the ambient temperature hourly values. There are a number of losses associated with the conversion of the solar resource to energy supplied to the grid. A detailed description and evaluation of each of the factors which make up the total loss of the Project are included in the following paragraph. The result of the model is the energy produced by the photovoltaic plant and supplied to the grid on an hourly basis.

The first loss to be taken into account is the shadowing loss. This loss is calculated by modelling the plant in the PVSYST software and a result for every hour of the year is obtained. Then, this value is deducted from the total irradiation received (calculated in the previous paragraph) to obtain the effective irradiation received on the module surface:

$$H_{effective} = H_{solar} - H_{shadowing} \tag{6.1}$$

Where:

- H_{solar} is the global irradiance incidence on the photovoltaic module surface
- $H_{shadowing}$ is the global irradiance that is lost due to the shading on the photovoltaic module surface
- $H_{effective}$ is the global irradiance incidence on the photovoltaic module surface deducting the shadowing losses

Considering the formula (6.1), the shadowing loss ($L_{shadowing}$) may be calculated as follows:

$$L_{shadowing} = \frac{H_{shadowing}}{H_{solar}} \tag{6.2}$$

Taking the effective irradiation value ($H_{effective}$) on an hourly basis, the power at the maximum power point of the photovoltaic generator (considering an ideal load) (P_{max}) is provided by the following equation, which makes use of the nominal power value (P^{*}) under the Standard Test Conditions (STC) given by the module manufacture in the modules flash-lists reports:

$$P_{max} = P^{*}\ x\ \frac{H_{effective}}{G^{*}} \tag{6.3}$$

Where G* is the global irradiance under STC, it means G*=1000 W/m^2

Taking also into consideration the ambient temperature on an hourly basis, the power at the maximum power point of the photovoltaic generator at a certain temperature (considering an ideal load) (P_{temp}), is obtained. This can be done using the following equations:

$$P_{temp} = P_{max}\ x\ [1 - \ \delta\ x\ (T_c - \ T_c^*)] \tag{6.4}$$

$$T_c = T_a + \frac{NOCT - 20}{800}\ x\ G_{effective} \tag{6.5}$$

Where:

- P_{max} is the average hourly power corrected at the maximum power point of the photovoltaic generator under the specific conditions of the site in kW
- G^* is the irradiation under STC (1,000 Wh/m²)
- T_c is the cell temperature in ºC
- T_c^* is the cell temperature under STC (25 ºC)
- T_a is the ambient temperature in ºC
- $NOCT$ is the nominal operating cell temperature in ºC
- δ is the temperature coefficient of power in %/ºC
- $G_{effective} = \frac{H_{effective}}{1h}$

The temperature losses (L_{temp}) at any time may be calculated using the results of the formula (6.4):

$$L_{temp} = \frac{P_{temp}}{P_{max}} = \ 1 - \ \delta\ x\ (T_c - \ T_c^*) \tag{6.6}$$

There are some other losses to be taken into account regarding the photovoltaic modules:

- Losses due to not reaching the Nominal Power of the modules (L_P)
- The Mismatch losses (L_M)
- The Dust and Soiling losses (L_{DS})
- The angular and Spectral losses (L_{AS})

All of them factorized constitute the modules losses, L_{mod}:

$$[(1-L_P)x\,(1-L_M)x\,(1-L_{DS})x\,(1-L_{AS})] \tag{6.7}$$

There are also additional losses because of the DC wiring ($L_{OH,DC}$). As the rest of the losses, it is calculated on an hourly basis. The formula to determine this loss is the following:

$$L_{OH,DC} = 2\,x\,\frac{I_{DC}\,x\,L_{cable}\,x\,\rho_T}{S_{cable}\,x\,V_{DC}} \tag{6.8}$$

Where:

- I_{DC} is the average hourly current that drives the DC cable in A
- L_{cable} is the length of the DC cable in meters
- ρ_T is the resistivity of the DC cable in Ωmm^2/m at a certain temperature T
- S_{cable} is the section of the DC cable in mm^2
- V_{DC} is the voltage of the DC cable in V

Taking into account all these losses, the resulting power would be:

$$P(\,DC) = P\_max\ \ x\ \ (1-L\_temp\,)\ x\,(1-L\_mod\,)\ x\,(1-L\_(OH,DC)\,) \tag{6.9}$$

Where:

- P_{DC} Is the resulting average hourly power including all the losses regarding the shading, the modules and the cables. Physically is the inverter input power

The next component which introduces losses in the power generated is the inverter. Two types of losses have to be considered in the inverter: the maximum power point tracker (MPPT) losses and the DC/AC conversion losses.

The MPPT losses (L_{MPPT}), can be calculated directly from the MPPT efficiency curve of the inverter (η_{MPPT}):

$$L_{MPPT} = 1 - \eta_{MPPT} \tag{6.10}$$

The corresponding output power value due to the MPPT losses ($P_{DC,MPPT}$) can be calculated as follows:

$$P_{DC,MPPT} = P_{DC}\ x\ \eta_{MPPT} = P_{DC}\ x\ (1 - L_{MPPT}) \tag{6.11}$$

The available AC power at the inverter output (P_{inv}) can be calculated deducting the inverter efficiency losses (L_{inv}) by using the inverter AC/DC output efficiency curve (η_{inv}):

$$L_{inv} = 1 - \eta_{inv} \tag{6.12}$$

$$P_{inv} = P_{DC,MPPT}\ x\ \eta_{inv} = P_{DC,MPPT}\ x\ (1 - L_{inv}) \tag{6.13}$$

The next loss to be calculated is the low voltage AC wiring loss ($L_{OH,AC-LV}$), which will be applied to the level of power obtained from the previous calculation to obtain the power ($P_{OH,AC-LV}$) to the transformer or to the connection to the grid, in case the connection is defined in a low voltage point:

$$L_{OH,AC-LV} = \sqrt{3}\ x\ \frac{I_{OH,AC-LV}\ x\ L_{cable}\ x\ \rho_T}{S_{cable}\ x\ V_{OH,AC-LV}} \tag{6.14}$$

Where:

- $I_{OH,AC-LV}$ is the average hourly current that drives the LV AC cable
- L_{cable} is the length of the LV AC cable
- ρ_T is the resistivity of the LV AC cable
- S_{cable} is the section of the LV AC cable
- $V_{OH,AC-LV}$ is the voltage of the LV AC cable

$$P_{OH,AC-LV} = P_{inv}\ x\ (1 - L_{OH,AC-LV}) \tag{6.15}$$

Finally, in the case that the connection to the grid point is located in the medium voltage system, the MV/LV transformer losses ($L_{trafos-MV/LV}$) should be taken into account. These losses are calculated as follows:

$$L_{trafos-MV/LV} = \frac{P_0 + \left(\frac{P_{OH,AC-LV}}{P_{n,trafos-MVLV}}\right)^2 x\ P_{sc}}{P_{OH,AC-LV}} \tag{6.16}$$

Where:

- P_0 is the transformer open circuit power
- $P_{n,trafos-MVLV}$ is the transformer nominal power
- P_{sc} is the transformer short circuit power

And then, the total power at the transformer output is calculated using the following formula:

$$P_{trafos} = P_{OH,AC-LV}\ x\ (1 - L_{trafos-MV/LV}) \qquad (6.17)$$

Although the configuration could be more complex depending on where the grid connection point is located (it could include an evacuation line after the transformers and sub-station transformers), the calculations of the additional losses would be done with the previous formulae (6.14) and (6.16).

An estimate of the energy produced by the system at the grid connection point ($E_{AC,grid}$) can be evaluated by carrying out the previously mentioned calculations for each irradiation and ambient temperature hourly values, obtaining the grid connection point power delivered ($P_{AC,grid}$) and integrating the whole year.

$$E_{AC,grid} = \sum_{year} P_{AC,grid} \qquad (6.18)$$

These calculations provide an accurate data of the energy delivered by the PV plant and consequently adequate information on the profitability and other economic figures of the project.

6.3 Results

As an example of a solar resource analysis and energy production estimation methodology used during a Technical Due Diligence (TDD), a real PV project of 182 MW has been analysed in detail. The Project was installed in Moree, Australia. It will be shown in detail in Annex I.

The methodology shown in this example comprises the following steps:

- Introduction
- Site
- Solar Resource Analysis
- Energy Yield Estimations
  - Description of Losses
  - Production and Variability Calculations
  - Degradation and Availability Analysis
  - Long Term Expectations

In addition, as an example of a solar resource analysis and energy production estimation versus real data as a part of Technical Due Diligence (TDD), thirty real utility-scale PV projects have been analysed as a representative sample that represent more than 200 MW installed. The projects were installed in Bulgaria, France, Italy, Peru, Portugal, Spain and South Africa.

Shown in Figure 6.3 is the real and the estimated radiation (kWh/m^2) for the thirty installations analysed, for every installation. As can be observed the difference between the real value and the estimated is very close.

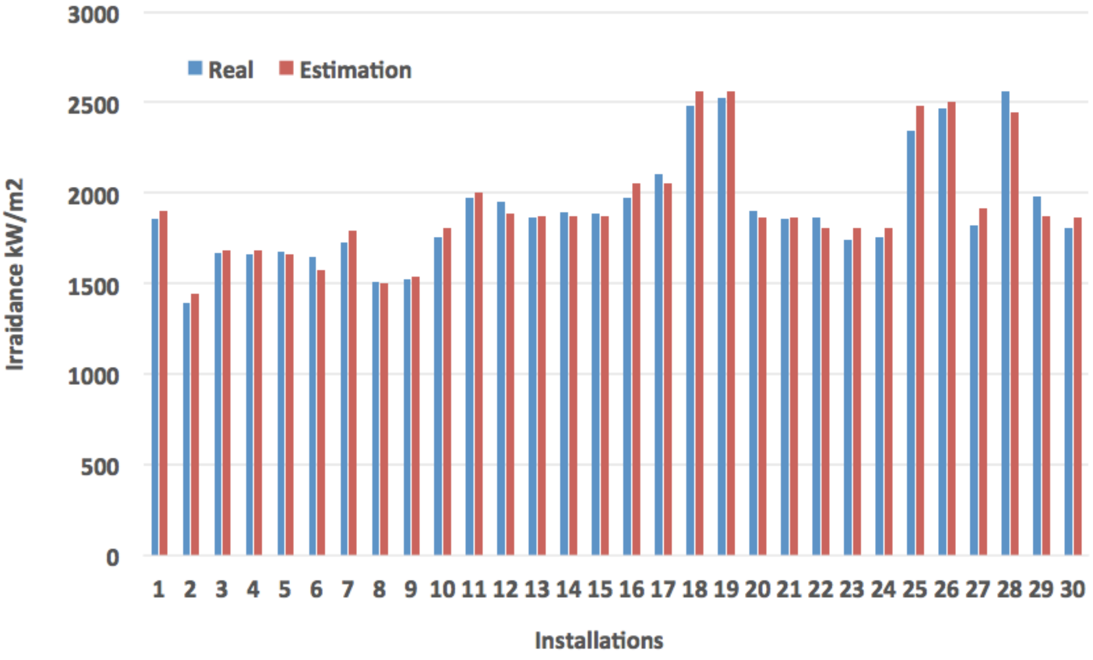


Figure 6.3: Radiation (kWh/m^2) for the twenty-six installations analysed

For estimating the relationships among both variables, in our case the real and estimation radiation, a regression analysis will be done. In this way, the coefficient of determination, R^2, has been useful because it gives the proportion of the variance (fluctuation) of one variable (estimated radiation) from the other variable (real radiation). It is a measure that allows us to determine how certain one can be in making predictions from a certain model/graph. The coefficient of determination is the ratio of the explained variation to the total variation. It is a measure of how well the regression line represents the data. If the regression line passes exactly through every point on the scatter plot, it would be able to explain all of the variation. The further the line is away from the points, the less it is able to explain.

Anyway, shown in Figure 6.4 is the straight line that depicts the linear trend in the data coming from the projects shown in Figure 6.3, where the coefficient of determination, R^2, is 0.97584. It is a proof of how both data are very similar.

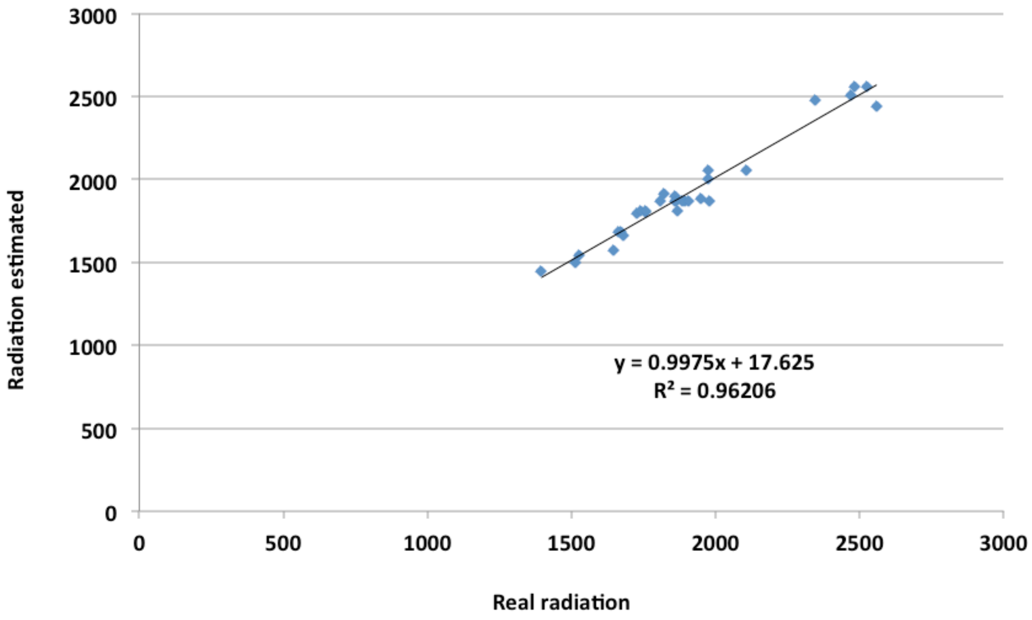


Figure 6.4: Irradiation estimated vs real irradiation for projects shown in Figure 6.3

Also, for the same projects analysed previously, Figures 6.3 and 6.4, a comparison is depicted about the production of the plants (MWh) between the real and the estimation, Figure 6.5.

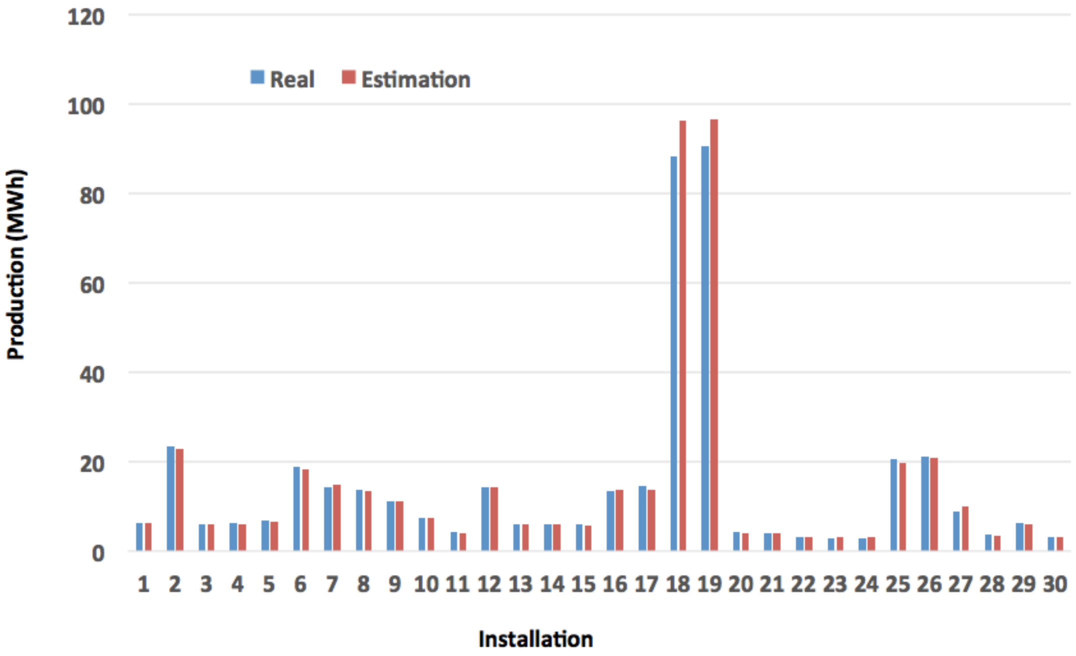


Figure 6.5: Real and estimation production (MWh) for the projects analysed in Figures 6.3 and 6.4

Shown in Figure 6.6 is the linear trend for the real and estimated production in MWh. In this case, the coefficient of determination, R^2, is 0.99892, where it is seen that the estimation done is very precise.

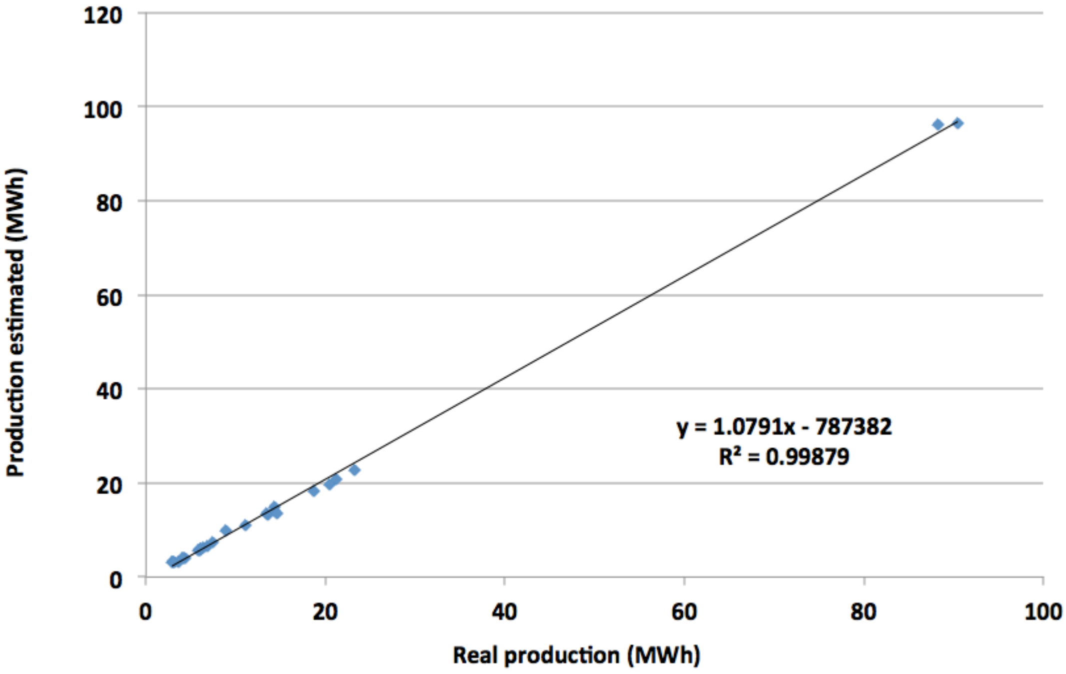


Figure 6.6: Production estimated vs real production

And depicted in Figure 6.14 is the linear trend for the real and estimated ratio between the production and power installed. Also in this case the correlation coefficient is high.

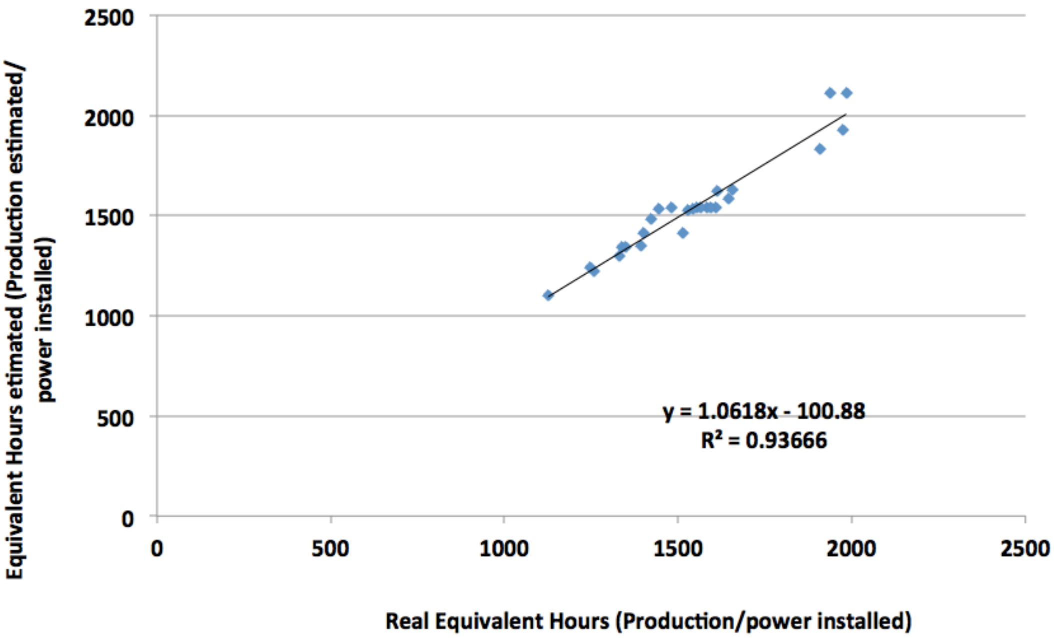


Figure 6.7: Equivalent Hours estimated vs real Equivalent hours

In this part of this chapter data will be shown more in detail about five of the thirty previous installations analysed.

The projects selected for this comparison are shown in the Table 6.2.

Table 6.2: Projects analysed in detail

Installation	Country	Nominal power installed (kW)	Type of structure
A	Spain	5.98	PV modules on Fixed Structure
B	Spain	1.84	PV modules on 2 Axes Tracker
C	Italy	9,19	PV modules on Fixed Structure
D	Italy	3,70	PV modules on Fixed Structure
E	Italy	1,99	PV modules on Fixed Structure

For the Spanish projects two years of data were available data, while for Italian projects one year of data were analysed. Also, the data used are mainly the production measured at the energy meters installed in the PV Plants and the irradiance received at the collector plane of the PV modules.

Concerning energy values, the production data are measured in Low Voltage. And, with respect to irradiance values, for all installations a CTE irradiance sensor has been used while for installation E is provided with pyranometer. On the information received from the project's owners, the irradiance sensors used for the PR (Performance Ratio) calculation are being checked and cleaned between two weeks and one month depending of the status of the same sensors, except for installation E where the cleaning is scheduled each three months (anyway the accumulation of dust on pyranometers is generally quite lower that in case of CTE sensors). It is important to consider that all PR estimations from TDD include 99 % annual availability.

Shown in Table 6.3 is the monthly comparison (in the deviation %) between the estimation done in the TDD in the real data obtained. Although in some months the deviation can be large, 24.02 %, the average deviation is only 3.06 %.

6.3.1 Installation A

Data from January 2011 to December 2012.

Table 6.3: Monthly radiation (kWh/m^2), comparison between estimated (TDD) and real data, for the installation A

Radiance "in plane"					
Period	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	85,0	69,7	72,0	-18,06%	-15,30%
February	119,0	122,1	139,4	2,60%	17,17%
March	163,0	135,5	185,9	-16,88%	14,05%
April	174,0	182,8	123,8	5,06%	-28,85%
May	188,0	205,8	206,3	9,49%	9,75%
June	207,0	215,7	200,0	4,19%	-3,36%
July	217,0	234,0	234,2	7,84%	7,91%
August	208,0	211,2	224,9	1,56%	8,14%
September	177,0	197,5	178,2	11,58%	0,69%
October	129,0	168,4	143,6	30,57%	11,32%
November	85,0	78,5	85,0	-7,60%	-0,05%
December	70,0	92,9	45,5	32,68%	-35,06%
Annual	**1822,0**	**1914,2**	**1838,9**	**5,06%**	**0,93%**

Table 6.4: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project A

PR (TDD Vs REAL)					
Period	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	87,17%	92,48%	91,92%	6,09%	5,45%
February	85,34%	90,37%	91,06%	5,90%	6,71%
March	83,03%	88,55%	88,17%	6,65%	6,19%
April	82,02%	91,08%	87,17%	11,04%	6,27%
May	81,22%	77,49%	85,49%	-4,60%	5,25%
June	78,10%	91,21%	84,88%	16,78%	8,68%
July	77,00%	84,84%	84,30%	10,19%	9,49%
August	77,18%	85,31%	83,89%	10,53%	8,69%
September	79,14%	84,31%	84,74%	6,53%	7,07%
October	82,20%	88,39%	79,52%	7,53%	-3,26%
November	84,99%	88,63%	89,41%	4,28%	5,20%
December	88,23%	92,49%	90,03%	4,83%	2,05%
Annual	**81,00%**	**87,09%**	**85,89%**	**7,52%**	**6,04%**

Table 6.5: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project A

PR (UPDATED PR CALCULATION Vs REAL)						
Period	**Updated Estimation 1st year**	**REAL 1st year**	**Updated Estimation 2nd year**	**REAL 2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	87,7%	92,48%	88,09%	91,9%	5,47%	4,35%
February	86,7%	90,37%	86,32%	91,1%	4,24%	5,49%
March	84,8%	88,55%	84,01%	88,2%	4,43%	4,95%
April	83,5%	91,08%	85,88%	87,2%	9,03%	1,50%
May	81,8%	77,49%	82,03%	85,5%	-5,32%	4,22%
June	79,7%	91,21%	80,29%	84,9%	14,50%	5,71%
July	78,6%	84,84%	78,54%	84,3%	7,99%	7,34%
August	78,9%	85,31%	78,59%	83,9%	8,13%	6,75%
September	80,4%	84,31%	80,71%	84,7%	4,82%	5,00%
October	82,9%	88,39%	83,08%	79,5%	6,66%	-4,28%
November	87,5%	88,63%	87,48%	89,4%	1,32%	2,21%
December	87,7%	92,49%	88,02%	90,0%	5,52%	2,28%
Annual	**82,2%**	**87,09%**	**82,34%**	**85,89%**	**5,92%**	**4,32%**

6.3.2 Installation B

Data from January 2010 to December 2011.

Table 6.6: Monthly radiation (kWh/m^2), comparison between estimated (TDD) and real data, for the installation B

Radiation "in plane"					
Period	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	142,06	96,3	109,0	-32,21%	-23,27%
February	162,28	44,4	170,9	-72,64%	5,31%
March	233,44	187,8	169,9	-19,55%	-27,22%
April	242,86	241,2	233,3	-0,68%	-3,93%
May	278,42	287,1	265,9	3,12%	-4,50%
June	309,87	276,2	303,5	-10,86%	-2,05%
July	312,02	340,6	336,1	9,16%	7,72%
August	280,40	303,6	303,3	8,27%	8,17%
September	219,38	243,8	270,1	11,13%	23,12%
October	177,92	200,0	219,7	12,41%	23,48%
November	124,99	125,2	109,4	0,17%	-12,47%
December	75,31	97,7	123,7	29,73%	64,25%
Annual	**2558,94**	**2443,9**	**2614,8**	**-4,50%**	**2,18%**

Table 6.7: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for a project B

PR (TDD Vs REAL)					
Period	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	82,9%	88,38%	87,34%	6,60%	5,35%
February	81,5%	84,16%	85,04%	3,28%	4,36%
March	79,8%	81,09%	84,28%	1,63%	5,63%
April	79,1%	79,35%	79,82%	0,27%	0,86%
May	78,1%	79,51%	79,43%	1,84%	1,74%
June	76,0%	76,60%	75,36%	0,79%	-0,85%
July	74,4%	72,90%	76,21%	-2,03%	2,42%
August	74,5%	73,24%	72,32%	-1,64%	-2,88%
September	77,6%	76,50%	73,23%	-1,45%	-5,66%
October	79,6%	82,12%	75,51%	3,10%	-5,20%
November	81,5%	85,13%	80,21%	4,43%	-1,60%
December	83,5%	85,62%	81,62%	2,49%	-2,30%
Annual	**78,1%**	**78,47%**	**77,93%**	**0,44%**	**-0,25%**

Table 6.8: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project B

PR (UPDATED PR CALCULATION Vs REAL)						
Period	**Updated Estimation 1st year**	**REAL 1st year**	**Updated Estimation 2nd year**	**REAL 2nd year**	**Deviation 1st year**	**Deviation 2nd year**
January	84,1%	88,38%	84,5%	87,34%	5,07%	3,33%
February	83,5%	84,16%	83,0%	85,04%	0,82%	2,48%
March	81,4%	81,09%	81,9%	84,28%	-0,39%	2,86%
April	80,5%	79,35%	80,2%	79,82%	-1,43%	-0,44%
May	79,0%	79,51%	78,7%	79,43%	0,64%	0,99%
June	77,5%	76,60%	77,4%	75,36%	-1,20%	-2,58%
July	75,6%	72,90%	75,7%	76,21%	-3,58%	0,63%
August	75,9%	73,24%	76,0%	72,32%	-3,56%	-4,89%
September	77,9%	76,50%	77,9%	73,23%	-1,75%	-5,94%
October	80,2%	82,12%	80,3%	75,51%	2,36%	-5,99%
November	83,3%	85,13%	83,5%	80,21%	2,23%	-3,95%
December	83,8%	85,62%	83,9%	81,62%	2,20%	-2,67%
Annual	**79,0%**	**78,47%**	**79,2%**	**77,93%**	**-0,67%**	**-1,61%**

6.3.3 Installation C

Data from July 2011 to June 2012.

Table 6.9: Monthly radiation (kWh/m^2), comparison between estimated (TDD) and real data, for the installation C

Radiance "in plane"			
Period	**TDD**	**1st year**	**Deviation 1st year**
July	223,00	214,6	-3,78 %
August	203,00	209,8	3,37 %
September	170,00	173,9	2,32 %
October	135,00	144,4	6,99 %
November	92,00	97,1	5,58 %
December	75,00	93,0	24,04 %
January	84,00	99,9	18,98 %
February	105,00	90,0	-14,29 %
March	153,00	165,7	8,32 %
April	175,00	164,3	-6,09 %
May	204,00	206,8	1,38 %
June	211,00	226,3	7,23 %
Annual	**1830,00**	**1886,0**	**3,06 %**

Table 6.10: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for a project C

PR (TDD Vs REAL)			
Period	**TDD**	**1^{st} year**	**Deviation 1^{st} year**
July	77,3%	81,6%	5,54 %
August	78,0%	85,9%	10,16 %
September	80,4%	88,8%	10,42 %
October	82,5%	90,4%	9,63 %
November	85,7%	90,9%	6,04 %
December	87,9%	84,4%	-3,96 %
January	87,5%	88,6%	1,27 %
February	86,7%	88,7%	2,30 %
March	84,8%	93,2%	9,88 %
April	83,8%	88,9%	6,09 %
May	81,1%	84,2%	3,79 %
June	78,8%	84,1%	6,74 %
Annual	**81,8%**	**87,0%**	**6,39 %**

Table 6.11: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project C

PR (UPDATED PR CALCULATION Vs REAL)			
Period	**Updated Estimation 1st year**	**REAL 1st year**	**Deviation 1st year**
July	90,6%	81,6%	-9,95 %
August	90,5%	85,9%	-5,03 %
September	87,0%	88,8%	2,05 %
October	85,4%	90,4%	5,89 %
November	85,0%	90,9%	6,94 %
December	79,6%	84,4%	6,03 %
January	78,6%	88,6%	12,68 %
February	78,5%	88,7%	12,98 %
March	80,8%	93,2%	15,31 %
April	85,8%	88,9%	3,59 %
May	88,3%	84,2%	-4,69 %
June	89,3%	84,1%	-5,76 %
Annual	**83,7%**	**87,0%**	**3,89 %**

6.3.4 Installation D

Data from July 2011 to June 2012.

Table 6.12: Monthly radiation (kWh/m^2), comparison between estimated (TDD) and real data, for the installation D

Irradiance "in plane"			
Period	**TDD**	**1st year**	**Deviation 1st year**
July	220,00	216,3	-1,7%
August	209,00	206,9	-1,0%
September	179,00	174,4	-2,6%
October	156,00	129,5	-17,0%
November	120,00	83,1	-30,7%
December	97,00	94,0	-3,1%
January	107,00	101,6	-5,0%
February	125,00	116,0	-7,2%
March	168,00	158,9	-5,4%
April	183,00	176,0	-3,8%
May	209,00	204,4	-2,2%
June	207,00	211,7	2,3%
Annual	**1980,00**	**1872,8**	**-5,41%**

Table 6.13: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project D

PR (TDD Vs REAL)			
Period	**TDD**	**1st year**	**Deviation 1st year**
July	78,5%	72,9%	-7,16%
August	78,7%	82,0%	4,28%
September	80,4%	87,4%	8,70%
October	82,0%	86,7%	5,80%
November	84,7%	90,4%	6,76%
December	86,7%	94,0%	8,36%
January	86,8%	93,5%	7,76%
February	86,2%	91,0%	5,63%
March	84,7%	94,6%	11,69%
April	83,6%	82,7%	-1,04%
May	81,3%	84,2%	3,47%
June	80,0%	83,3%	4,11%
Annual	**82,1%**	**85,5%**	**4,06%**

Table 6.14: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project D

PR (UPDATED PR CALCULATION Vs REAL)			
Period	**Updated Estimation 1st year**	**REAL 1st year**	**Deviation 1st year**
July	89,8%	72,9%	-18,80%
August	88,9%	82,0%	-7,76%
September	87,6%	87,4%	-0,15%
October	85,3%	86,7%	1,60%
November	83,6%	90,4%	8,06%
December	79,9%	94,0%	17,66%
January	79,4%	93,5%	17,86%
February	79,6%	91,0%	14,35%
March	81,9%	94,6%	15,48%
April	88,5%	82,7%	-6,50%
May	88,4%	84,2%	-4,82%
June	89,0%	83,3%	-6,43%
Annual	**84,1%**	**85,5%**	**1,64%**

6.3.5 Installation E

Data from April 2011 to March 2012.

Table 6.15: Monthly radiation (kWh/m^2), comparison between estimated (TDD) and real data, for the installation E

Irradiance "in plane"			
Period	**TDD**	**1st year**	**Deviation 1st year**
April	172,00	177,9	3,43%
May	201,00	183,9	-8,51%
June	209,00	214,5	2,64%
July	221,00	223,9	1,31%
August	203,00	228,6	12,62%
September	169,00	164,9	-2,44%
October	142,00	139,4	-1,80%
November	89,00	112,4	26,29%
December	75,00	75,3	0,38%
January	82,00	105,5	28,71%
February	101,00	82,5	-18,29%
March	144,00	158,4	9,97%
Annual	**1808,00**	**1867,3**	**3,28%**

Table 6.16: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project E

PR (TDD Vs REAL)			
Period	**TDD**	**1st year**	**Deviation 1st year**
April	85,5%	86,7%	1,41%
May	82,8%	87,1%	5,17%
June	81,1%	80,6%	-0,52%
July	79,7%	83,3%	4,52%
August	79,9%	85,3%	6,71%
September	82,1%	86,6%	5,41%
October	83,6%	90,1%	7,75%
November	87,4%	93,6%	7,20%
December	89,0%	95,5%	7,36%
January	88,9%	94,5%	6,27%
February	88,7%	92,8%	4,63%
March	86,3%	92,3%	6,98%
Annual	**83,5%**	**87,7%**	**4,96%**

Table 6.17: Monthly PR (performance ratio) comparison between estimated (TDD) and real data for the project E

PR (UPDATED PR CALCULATION Vs REAL)			
Period	**Updated Estimation 1st year**	**REAL 1st year**	**Deviation 1st year**
April	88,5%	86,7%	-2,06%
May	89,7%	87,1%	-2,94%
June	87,0%	80,6%	-7,34%
July	86,2%	83,3%	-3,33%
August	85,0%	85,3%	0,34%
September	80,9%	86,6%	6,99%
October	81,4%	90,1%	10,76%
November	80,9%	93,6%	15,68%
December	83,3%	95,5%	14,71%
January	87,3%	94,5%	8,27%
February	86,4%	92,8%	7,36%
March	88,9%	92,3%	3,80%
Annual	**84,6%**	**87,7%**	**3,68%**

6.4 Conclusion

Shown in Tables 6.18, 6.19 and 6.20 are the summarize of the data analysed previously.

Table 6.18: Summarize of the radiation (kWh/m^2) in plane measured and estimated

Radiance "in plane"					
Project	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
A	1822,0	1914,2	1838,9	5,1%	0,9%
B	2558,9	2443,9	2614,8	-4,5%	2,2%
C	1830,0	1886,0	-	3,1%	-
D	1980,0	1872,8	-	-5,4%	-
E	1808,0	1867,3	-	3,3%	-

So, in Table 6.18, it is possible to see that the difference from estimations and the real values are in a range of ±5.4 %, and the average deviation is 0.3 % for the first year and 1.6 % for the second year. Therefore, the real values and the estimation done is considered perfectly valid.

Concerning the comparative of real performance versus the estimated, the following table shows the annual results for the five projects.

Table 6.19: Summarize of PR (Performance Ratio) measured and estimated for two years of data available

PR (TDD Vs REAL)					
Project	**TDD**	**1st year**	**2nd year**	**Deviation 1st year**	**Deviation 2nd year**
A	81,0%	87,1%	85,89%	7,5%	6,0%
B	78,1%	78,5%	77,9%	0,4%	-0,2%
C	81,8%	87,0%	-	6,4%	-
D	82,1%	85,5%	-	4,1%	-
E	83,5%	87,7%	-	5,0%	-

As can observed in Table 6.19, the estimations done are quite conservative and between 4,1 % and 7.5 % under the real performance for the system employing PV modules on fixed structure (25º-30º inclination). Concerning installation B, the only one with 2 axis tracking, the estimation is very close to the real production values.

In the following and final table, the comparison with the updated estimation has been included for the five projects.

Table 6.20: Summarize of PR (Performance Ratio) measured and estimated for two years of data available

PR (UPDATED PR CALCULATION Vs REAL)						
Project	**Updated Estimation 1st year**	**REAL 1st year**	**Updated Estimation 2nd year**	**REAL 2nd year**	**Deviation 1st year**	**Deviation 2nd year**
A	82,2%	87,1%	82,3%	85,9%	5,9%	4,3%
B	79,0%	78,5%	79,2%	77,9%	-0,7%	-1,6%
C	83,7%	87,0%	-	-	3,9%	-
D	84,1%	85,5%	-	-	1,6%	-
E	84,6%	87,7%	-	-	3,7%	-

In Table 6.20, it is possible to observe that the difference using the new Production Estimate Model implemented from 2012 is closer to the real value with respect the real values. From 1,6 to 3,9 % for the Italian projects with fixed structure, 5,9 % for the Spanish project with the same kind of supporting structure.

It is possible to conclude that with the new model the estimation is a 2 % closer for the PV plants employing fixed supporting structure and there is no important difference (only 0.5 %) for the 2 Axes Tracker PV plant. Therefore, it can be concluded, for typical projects with PV modules on fixed structure, that the estimations are still conservative with respect the reality with an approximately 2-3 % of underestimation.

CHAPTER 7

CONCLUSIONS AND FUTURE WORK

CHAPTER 7. Conclusions and Future Work

7.1 Conclusions

The price of electricity coming from PV is falling to reach a competitive level with those from conventional electricity, not only at consume level but also at generation level. So, large-scale PV power plants are growing across the world. The budget of these utility-scale projects requires specifics financing tools. These tools, based upon de cash-flow generated by the project to attend the debt, make necessary an intensive and high quality technical advice to assure the reliability of the project.

On the other hand, even though PV systems based on Si technology is considered to have a high level of development and maturity, nevertheless, there is no enough experience on operation and performances of such large PV plants. All this demands a very high quality and objective Independent Technical Advisory (ITA) with procedure and task well defined.

These have been the scope and frame of this work and, summarizing, the main conclusions and contributions are:

1. It has been done a review of the fundamentals and present status of the large PV power plants. It has been referenced an electricity price coming from PV as low as 3.87 cents (dollars) per kilowatt-hour of energy in 2015 and close to 3 cents (dollars) per kilowatt-hour of energy in 2016. This shows the emerging growth of large PV systems is only in its early days.
2. It has been done a thoroughly analyze to understand the technical processes and management of large PV projects, and then, we have done a deep analysis of the developing process to implement large PV projects, and also of the management structure to run it. So, we have structured the different phases of the process and time scheduling them, regarding the ITA works; in order to survey and define the task, duties and responsibilities of the independent technical advisory. We have implemented all of this in a simple graphic (Fig 3.1).
3. It has been analyzed, the structure, actors, phases, task and interrelationship of a typical model of Project Finance. It is explained and summarized by the “Project Finance Constellation”; a very good way to understand, and graphically summarize, the entire performers involves in a Project Finance. Not only identifies them, but it described the inter-relationship between them, missions, main task and duties of each ones.
4. It has been done a risk analysis of the big PV power plants and the most important conclusion is that the main procedure to evaluate, control and

mitigate the risk is the use of high quality and independent technical advisory (ITA).

5. Taken into account all of the previous analyses, knowledge and contributions, it is proposed a way of doing things for the Independent Technical Advisory (ITA), with phases, task, actions and liability clearly defined,-included TDD- so that the subjectivity of the process is reduced, allowing an objective and high quality ITA, to reduce risks and ensure project results and project success.
6. Last but not least, it has also been made the assessment of several experimental case of study to validate the previous procedures included in the TDD like Solar Resource Analysis and Annual Energy Estimation and it is concluded that the reality versus estimations are good correlated and we can trust in the theoretical model used in ITA in order to mitigate the technical risks associated to the project.

7.2 Future Work

The future lines and works arising out of this study can be the following:

1. To standardize the inspections in PV plants in operation in order to assign a technical rating similar to the credit rating managed by rating agencies such as Poor's Publishing Company or Fitch Publishing Company. It could help a lot in operations such as Project Finance Bond, an alternative source of financing infrastructure projects.
2. Optimization of the estimations and estimations calculation of the solar resource and production with Big Data databases and/or iterations of real data versus estimations
3. Optimization in the estimation of the component life and the PV plants life by means of the simulations tools based on rate real failures vs estimated
4. Optimization of the diagnostic techniques of the PV plants with fails by means of statistical analyses.

REFERENCES

[1] S. J Pickle, Financing investments in renewable energy: the impacts of policy design, Renewable and Sustainable Energy Reviews, Volume 2, Issue 4, 1 December 1998, Pages 361-386, ISSN 1364-0321 R. H Wiser, , 1998.

[2] E. Menichetti. Strategic choices for renewable energy investment: Conceptual framework and opportunities for further research R. Wüstenhagen, *Energy Policy*, vol. Volume 40, pp. Pages 1-10, January 2012.

[3] *GTM Research, 2014*.

[4] *Buffett Scores Cheapest Electricity Rate With Nevada Solar Farms, Bloomberg Business*., July 7, 2015.

[5] *DEWA and ACWA Power consortium sign solar park PPA by Utilities ME Staff on Mar 26, 2015*.

[6] M. Dailami and D. Leipziger, "“Infrastructure project finance and capital flows: A new perspective”," *World Development*, vol. Volume: 26, no. Issue: 7, pp. Pages: 1283-1298, 1998.

[7] S.L. “A practical guide to transactional project finance - basic concepts, risk identification, and contractual considerations”, Business Lawyer, Vol.: 45, Issue: 1, nov 1989, pp: 181-232 Hoffman, , 1989.

[8] C.R. Beidleman, D. Fletcher, and D. “On allocating risk - the essence of project finance”, Sloan Management Review, vol.: 31, iss.: 3, 1990,pp.: 47-55 Vesbosky, , 1990.

[9] G. Pollio., "Project finance and international energy development," *ENERGY POLICY*, vol. 26, no. 9, pp. 687-697, 1998.

[10] K. “Renewable energy investment and the clean development mechanism”, Energy Policy, Vol.: 40, Jan. 2012, pp.: 81-89, ISSN 0301-4215 Zavodov, , 2012.

[11] *J. Leloux, et al A bankable method of assessing the performance of a CPV plant*.: Applied Energy, 2014, vol. 118.

[12] J. Morgenson, *Defining Bankability for Utility-scale PV*.: Power Engineering, 2011, vol. 115.

[13] B. Marshall, *Management, Assessing Bankability in Utility-Scale PV The Key Role of the Inverter in Project Risk, SMA America, 2011*.

[14] A. Masini and E. “The impact of behavioral factors in the renewable energy investment decision making process: Conceptual framework and empirical findings”, Energy Policy, Vol.: 40, Jan. 2012, pp.: 28-38, ISSN 0301-4215 Menichetti, , 2012.

[15] P., et all., Solar energy: comparative analysis of solar technologies for electricity production. Proceedings of 3rd World Conference on Photovoltaic Energy Conversion, pp. 2482 - 2485 Valera, , vol. 3, 2003.

[16] C., Entrepreneurial Financing and Costly Due Diligence. Financial Review, 44: 137–149. doi: 10.1111/j.1540-6288.2008.00213.x Yung, , 2009.

[17] M.J."Renewable energy policy and landscape management in Andalusia, Spain: The facts" , Energy Policy, Volume 38, Issue 11, November 2010, Pages 6900-6909, ISSN 0301-4215 Prados, , 2010.

[18] S. Ruiz Romero, A. Colmenar Santos, and M. A. “EU plans for renewable energy. An application to the Spanish case”, Renewable Energy, Vol.: 43, July 2012, pp.: 322-330, ISSN 0960-1481 Castro Gil, , 2012.

[19] M. et al. "Univer Project. A grid connected photovoltaic system of 200 kW at Jaén University. Overview and performace analysis". Solar Energy Materials and Solar Cells, Volume 91, Issue 8, 4 May 2007, Pages 670–683 Drif, , 2007.

[20] J.C. Hernández, P.G. Vidal, and G., Almonacid, "Photovoltaic in grid-connected building. Sizing and economics analysis. ," *Renewable Energy*, vol. 15, no. 1-4, pp. 562-565, 1998.

[21] J. et al., "A bankable method of assessing the performance of a CPV plant". Applied Energy 118, pp. 1.11 Leloux, , 2014.

[22] V Salas and E. Olías, "Overview of the state of technique for PV inverters used in low voltage," *Renewable and Sustainable Energy Reviews 15 (2011) 1250–1257. 2011. 2011.*, vol. 15, pp. 1250–1257, 2011.

[23] Technical aspects of project finance in solar energy projects – methodology to improve the technical due diligences. 28th European PV solar Energy Conf. Paris. Valera P. et al., , 2013.

[24] et al. P. Valera, "Review of independent technical advisory in utility-scale PV projects," Jaén (Spain), PhD Thesis 2014.

[25] T. James, and M. Woodhouse A. Goodrich, *Residential, commercial, utility-scale photovoltaic (PV) system prices in the united states: Current drivers and cost-reduction opportunities,” Nat. Renew. Energy Lab. (NREL), Golden, CO, USA, Tech. Rep. DE-AC36-08GO28308, Feb. 2012*.

[26] Masakazu Ito et al, *A comparative study on cost and life-cycle analysis for 100 MW very large-scale PV (VLS-PV) systems in deserts using m-Si, a-Si,*

CdTe, and CIS modules, Progress in Photovoltaics: Research and Applications, Volume 16, Issue 1, pages 17–30, January 2008.

[27] *Megawatt scale Li-ion batteries shape up for real-world PV grid integration projects, Electrical Review, 11 June 2013*.

[28] Xiaohui Yan et al., *Techno-economic and social analysis of energy storage for commercial buildings, Energy Conversion and Management, Volume 78, February 2014, Pages 125-136*.

[29] A. Kleit and J. Cho A. Shcherbakova, *The value of energy storage in South Korea's electricity market: A Hotelling approach, Applied Energy, Volume 125, 15 July 2014, Pages 93-102*.

[30] *A Snapshot of Global PV Markets 2014, Report IEA PVPS T1:2015*.

[31] *Bloomberg new energy finance, 2014*.

[32] "Solar 2016 Funding and M&A Report Bundle," Mercon Solar , 2015.

[33] "Grid connected photovoltaic systems - Minimum requirements for system documentation, commissioning tests and inspection," International Electrotechnical Commission, Switzerland, 2009. IEC 62446,.

[34] M. Pathak and J. Pearce, "A review of solar photovoltaic levelized cost of electricity," Renewable & Sustainable Energy Reviews, vol. 15 , no. 9, pp. pp.4470-4482, 2011. K. Branker,.

[35] J. Blunden, E. Smeloff and P. Aschenbrenner., "Minimizing utility-scale PV power plant LCOE through the use of high capacity factor configurations," in Proc. 34th IEEE PVSC, 2009. M. Campbell,.

[36] J. Pierce, M. Faber and G. Broome, "Project Finance Primer for Renewable Energy and Clean Tech Projects," Wilson Sonsini Goodrid & Rosati, 2010. C. Groobey,.

[37] ""Infrastructure project finance and capital flows: A new perspective"," World Development, vol. Volume: 26, no. Issue: 7, pp. Pages: 1283-1298, 1998. M. Dailami and D. Leipziger,.

[38] "Project finance and international energy development," ENERGY POLICY, vol. 26, no. 9, pp. 687-697, 1998 G. Pollio.,.

[39] "Bankability: The Ticket for Successful Solar Energy Project Business.," Global Photovoltaic Business & Resources, 2011. W. Lange,.

[40] "Defining bankability for utility-scale PV," Power Engineering, 2011 J. Morgenson,.

[41] Anton de Wit, "Measurement of project success," *International Journal of Project Management, Volume 6, Issue 3, August 1988, Pages 164–170*.

[42] C. Kreycik, L. Bird, P. Schwabe, and K. Cory M. Mendelsohn, "The Impact of Financial Structure on the Cost of Solar Energy, NREL, 2012".

[43] P. Valera, "Managing the Risk – Technical Due Diligence, 2014".

[44] Pelin, M. Hakan Hocaoglu, and Alp Er S. Konukman. Yilmaz, *"A pre-feasibility case study on integrated resource planning including renewables." Energy Policy 36.3 (2008): 1223-1232.*

[45] "Photovoltaic System Design and Installation, From the pre-feasibility study to the commissioning, Sunenergy, 2011".

[46] MENA Report (Sep 27, 2013). India: Preparing Utility Scale Concentrated Solar Power Demonstration Project,.

[47] Shimon Awerbuch, Ph.D., Energy Economics and Finance, 2000 Investing in Renewables: Risk Accounting and the Value of New Technology,.

[48] A. de Wit, "Measurement of project success, International Journal of Project Management," vol. 6, no. 3, pp. 164–170, August 1988.

[49] L. Lisell and G. Mosey, "Feasibility Study of Economics and Performance of Solar Photovoltaics in Nitro, West Virginia," *Technical Report NREL/ TP-6A2-48594*, August 2010.

[50] Ulrich et al. Prospects for investment in large-scale, grid-connected solar power in Africa. UNEP Risø Centre, Technical University of Denmark, 2014. HANSEN,.

[51] R. R. HERNANDEZ et al., "Environmental impacts of utility-scale solar energy," *Renewable and Sustainable Energy Reviews*, vol. 29, pp. 766-779., 2014.

[52] Mackay MILLER and Sadie. Overview of Variable Renewable Energy Regulatory Issues. Contract, 2014. COX,.

[53] Michael GORTON and Scott D. Solar Power Installations: Navigating Environmental and Regulatory Issues to Reduce Risk. 2011. DEATHERAGE,.

[54] P. Valera, "Managing the Risk – Technical Due Diligence," in *Workshop: Towards to new standard in the large-scale PV power plants: 1500 V*, vol. February, Madrid, 2016.

[55] The Drivers of the Levelized Cost of Electricity for Utility-Scale Photovoltaics, 2008 Matt Cambell,.

[56] M. Camberll et al, "Minimizing utility-scale PV power plant LCOE through the use of high capacity factor configurations, 34th IEEE Photovoltaic Specialists

Conference (PVSC), Page(s): 000421 – 000426, 2009".

[57] Sophia, and Emily Poole Chong, *Financing Infrastructure: A Spectrum of Country Approaches*, September ed.: RBA Bulletin, 2013.

[58] Emily, Carl Toohey, and Peter Harris Poole, *Public Infrastructure: A framework for decision-making*, Paper for Reserve Bank 2014 Conference Financial flows and infrastructure financing, Ed., 2014.

[59] Michael, and Claire Kreycik Mendelsohn, *Federal and state structures to support financing utility-scale solar projects and the business models designed to utilize them* , 303rd ed., 2012.

[60] John Pierce, Michael Faber, and Greg Broome Chris Groobey, "Project Finance Primer for Renewable Energy and Clean Tech Projects," *Wilson Sonsini Goodrid & Rosati*, 2010.

[61] Ragna Schmidt-Haup, "PV Project Finance In India: Working The System," *EQ INTERNATIONAL*, June 2013.

[62] Michael Mendelsohn, Bethany Speer and Roger Hill Travis Lowder, "Continuing Developments in PV Risk Management: Strategies, Solutions, and Implications," *National Renewable Energy Laboratory and Sandia National Laboratories*, February 2013.

[63] 2011, "The Guide to Guidance How to Prepare, Procure and Deliver PPP Projects," *European PPP Expertise Center. European Investment Bank*, 2011.

[64] Roger Black, "PPPs and the water sector Plugging the infrastructure hole," *Deloitte Corporate Finance Infrastructure & Project Finance*, 2009.

[65] Matt LeDucq, "Mitigating Risk in Utility-scale Photovoltaic Projects," *Electric Light and Power*, pp. 48-49, Sept/Oct 2011.

[66] Andy Goldman, , PV, Projects Financing Photovoltaic, Ed.: Renewable Green Energy Power, 11th March, 2012.

[67] Matt. LeDucq, *Mitigating Risk in Utility-scale Photovoltaic Projects*.: Electric Light and Power, Sep/Oct 2011.

[68] Travis, et al. Lowder, *Continuing Developments in PV Risk Management: Strategies, Solutions, and Implications*, Contract 303, Ed., 2013.

[69] B. Esty, *Returns on project-financed investments: evolution and managerial implications Journal of Applied Corporate Finance*., 2002, vol. 15.

[70] Ryan H., and Steven J. Pickle Wiser, *Financing investments in renewable energy: the impacts of policy design*, Renewable and Sustainable Energy

Reviews, Ed., 1998, vol. 2.

[71] Chris, and Colin F. Duffield Clifton, *Improved PFI/PPP service outcomes through the integration of Alliance principles."* , International Journal of Project Management, Ed., 2006, vol. 24.

[72] K. Branker and J.M. Pearce, *Financial return for government support of large-scale thin-film solar photovoltaic manufacturing in Canada Energy Policy*, Energy Policy, Ed., August 2010, vol. 38.

[73] S. Gatti, *Project finance in theory and practice: designing, structuring, and financing private and public projects*.: Academic Press , 2013.

[74] B. C. Esty, *The economic motivations for using project finance*.: Harvard Business School, 2003, vol. 28.

[75] P. et al Valera, *State of the Technique of the Methods Implemented in Independent Technical Advisory Services, Including the Technical Due Diligences (TDD), Related with the Project Finance in Photovoltaic Energy Projects, PVSEC*, 29th European Photovoltaic Solar Energy Conference and Exhibition, Ed., 2014.

[76] M. Khan et al., *41 Financing large projects: Using project finance techniques and practices*., 2003.

[77] D. Goldman et. al, *Financing projects that use clean-energy technologies: an overview of barriers and opportunities*.: National Renewable Energy Laboratory, 2005.

[78] *The Guide to Guidance: How to Prepare, Procure And Deliver PPP projects*.: European Investment Bank (EIB), 2011.

[79] Ian Clover, *Canadian Solar's Recurrent Energy closes financing for 75 MW PV project, Financial & Legal Affairs, Global PV markets, Industry & Suppliers*, PV Magazine Photovoltaic Markets & Technology, Ed., 2016, vol. 5th January.

[80] Travis Lowder et. al, "Continuing Developments in PV Risk Management: Strategies, Solutions, and Implications," NREL, 2013.

[81] H.T. Nguyen and J.M. Pearce, "Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System," *Solar Energy*, vol. 84, no. 5, pp. 831-843, May 2010.

[82] D. Turney and V. Fthenakis, "Environmental impacts from the installation and operation of large-scale solar power plants," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 6, pp. 3261-3270, 2011.

[83] Scott Kuszmaul et al., "Lanai High Density Irradiance Sensor Network for Characterizing Solar Resource Variability of MW-Scale PV System," in *35th*

Photovoltaic Specialist Conference, vol. 21June , 2010.

[84] Marie Schnitzer, "Evaluating solar energy plants to support investment decisions," , vol. October, 2009.

[85] Ibrahim Reda, *Method to Calculate Uncertainties in Measuring Shortwave Solar Irradiance Using Thermopile and Semiconductor Solar Radiometers*.: NREL, 2011.

[86] H.T. Nguyen and J.M. Pearce, "Estimating potential photovoltaic yield with r.sun and the open source Geographical Resources Analysis Support System," *Solar Energy*, vol. 84, no. 5, pp. 831-843, May 2010.

[87] D. Thevenard et al., "Estimating the uncertainty in long-term photovoltaic yield predictions," *Solar Energy*, no. 91, pp. 432-445, May 2013.

[88] G. Makrides et al., "Energy yield prediction errors and uncertainties of different photovoltaic models," *Progress in Photovoltaics: Research and Applications*, vol. 4, no. 21, pp. 500-516, June 2013.

[89] K. Chumpolrat et. al., "Effect of Ambient Temperature on Performance of Grid-Connected Inverter Installed in Thailand," *Hindawi Publishing Corporation International Journal of Photoenergy*, 2014.

[90] A. Woyte, R. Belmans, P. J. M. Heskes, and P. M. Rooij S. Islam, "Investigating performance, reliability and safety parameters of photovoltaic module inverter: test results and compliances with the standards," *Renewable Energy*, vol. 31, no. 8, pp. 1157–1181, 2006.

[91] B.Burgerand and R.Rüther, "Inverter sizing of grid-connected photovoltaic systems in the light of local solar resource distribution characteristics and temperature," *Solar Energy*, vol. 80, no. 1, pp. 32-45, 2006.

[92] M. Eltawil and Z. Zhao, "Grid-connected photovoltaic power systems: technical and potential problems—a review," *Renewable and Sustainable Energy Reviews*, vol. 14, no. 1, pp. 112-129, 2010.

[93] H. Takahashi, K. Ichida, T. Minemoto, and H. Takakura Y. Nakada, "Influence of clearness index and air mass on sunlight and outdoor performance of photovoltaic modules," *Current Applied Physics*, vol. 10, no. 2, pp. S261–S264, 2010.

[94] S. Nagae, and H. Takakura T. Minemoto, "Impact of spectral irradiance distribution and temperature on the outdoor per- formance of amorphous Si photovoltaic modules," *Solar Energy Materials and Solar Cells*, vol. 91, no. 10, pp. 919–923, 2007.

[95] A. Limmanee and K. Chumpolrat, "Changes in spectral irradi- ance and their effects on PV module performance," in *Proceeding of the 6th Conference on*

Energy Network of Thailand (ENETT '10), 2010.

[96] G. Kleiss, and K. Reiche R. Rüther, "Spectral effects on amorphous silicon solar module fill factors," *Solar Energy Materials and Solar Cells*, vol. 71, no. 2, pp. 375–385, 2002.

[97] T. Hatayama, Y. Uraoka, T. Fuyuki, R. Hagihara, and M. Watanabe K. Nishioka, "Field-test analysis of PV system output characteristics focusing on module temperature," *Solar Energy Materials and Solar Cells*, vol. 74, no. 3, pp. 665–671, 2003.

[98] S. Mekhilef, "Effect of dust, humidity and air velocity on efficiency of photovoltaic cell," *Renewable & sustainable energy reviews*, 2012.

[99] Guido, Pierluigi Caramia, and Pietro Varilone Carpinelli, "Multi-linear Monte Carlo simulation method for probabilistic load flow of distribution systems with wind and photovoltaic generation systems," *Renewable Energy*, vol. 76, pp. 283-295, 2015.

[100] R.R. Hernandez, "Environmental impacts of utility-scale solar energy," *Renewable and Sustainable Energy Reviews*, vol. 29, pp. 766–779, June 2014.

[101] A. Giannitrapani et al., "Exploiting weather forecasts for sizing photovoltaic energy bids, IEEE PES ISGT Europe 2013, pp. 1 – 5, 2013,".

[102] Bhubaneswari et al. Parida, "A review of solar photovoltaic technologies," *Renewable and Sustainable Energy Reviews*, vol. 15, no. 3, pp. 1625 – 1636, 2011.

[103] Ye et al. Yang, "Sizing Strategy of Distributed Battery Storage System With High Penetration of Photovoltaic for Voltage Regulation and Peak Load Shaving," *IEEE Transactions on Smart Grid*, vol. 5, no. 2, pp. 982 - 991, 2014.

[104] P. Valera et al., "Technical Aspects of Project Finance in Solar Energy Projects – Methodology to Improve the Technical due Diligences,".

[105] Martifer Renewables, 2009 Investment and financing of renewable energy projects,.

[106] Mark Jeffery, *Return on Investment Analysis for E-business Projects, Northwestern University*.

[107] U. Varadaran et al., *The Impacts of Policy on the Financing Of Renewable Projects: A Case Study Analysis, Climate Policy Initiative, 2011*.

[108] International Finance Corporation, World Bank Group, 2012 Utility Scale Solar Power Plants A Guide For developers and investors,.

[109] Bouaziz Ait-Driss, *Essential Due-Diligence Steps For Utility-Scale Photovoltaic*

Projects, Solar Industry, 2012.

[110] Benjamin A. Compton, "Technical Certification of PV Power Plants: The Key to Bankability for Commercial and Utility-Scale Solar," in *International Solar Energy Technology Conference*, vol. October, 27, Santa Clara, California, 2011.

[111] F. Belfiore et al., "Risk and opportunities in the operation of large solar plants," in *Solar POWER-GEN 2013*, San Diego, CA, USA, 2013.

[112] Utility Scale Solar Photovoltaic Development Kristen Rodriguez and Hala Ballouz,.

[113] Solar Photovoltaics, Ed., *Competing in the Energy Sector. On the road to Competitiveness.*: EPIA, 2011.

[114] Richard Doyle, *Construction monitoring and risk management, Wind and PV, 2013*.

[115] Guidance to Support the Application of Reasonable Inquiry, 2013 Verification during construction,.

[116] "IEC 62446-1:2016 Photovoltaic (PV) systems - Requirements for testing, documentation and maintenance - Part 1: Grid connected systems - Documentation, commissioning tests and inspection,".

[117] D. C. Jordan and S. R. Kurtz, "Photovoltaic Degradation Rates—an Analytical Review," *Progress in Photovoltaics: Research and Applications*, vol. 21, no. 1, pp. 12-29, January 2013.

[118] L. M. Moore et al., "Five years of operating experience at a large, utility-scale photovoltaic generating plant," *Progress in Photovoltaics: Research and Applications*, vol. 16, no. 3, pp. 249–259, May 2008.

[119] Installation and Operations according to the, IECRE-PV Certified Equipment Scheme PVROP (2015): Rules of Procedure for the Certification of Photovoltaic Power Plant Equipment,.

PUBLICATIONS RELATED TO THE PHD THESIS

Publications related to the PhD Thesis

P. Valera, V. Salas and G. Almonacid, Overview of the Independent Technical Advisory: Mitigation of Technical Risks for Utility-Scale Photovoltaic Power Plants Projects, Renewable & Sustainable Energy Reviews, Elsevier, 2016, under reviewing.

F. Baena, J. Terrados, P. Gómez-Bueno, G. Almonacid, P. Gómez Vidal, **P. Valera**, L. Almonacid, Output Duration Curve. An Useful Tool for PV Analysis and Grid Integration, 31st European Photovoltaic Solar Energy Conference and Exhibition, 2015

P. Valera et al., State of the Technique of the Methods Implemented in Independent Technical Advisory Services, Including the Technical Due Diligences (TDD), Related with the Project Finance in Photovoltaic Energy Projects, 29th European Photovoltaic Solar Energy Conference and Exhibition, Amsterdam, 2014

P. Valera, Technical Aspects of Project Finance in Solar Energy Projects – Methodology to Improve the Technical due Diligences, 28th European Photovoltaic Solar Energy Conference and Exhibition, 2013

P.J. Pérez-Higueras, E. Muñoz-Cerón, G. Almonacid, P.G. Gómez Vidal, P. Banda, I. Luque-Heredia, **P. Valera**, M. Cabrerizo, A Spanish CPV Regulatory Framework: Proposal of a Feed-In Tariff, 25th European Photovoltaic Solar Energy Conference and Exhibition / 5th World Conference on Photovoltaic Energy Conversion, 6-10 September 2010, Valencia, Spain, 2010

ANNEX I

Annex I

182 MW PV Project. Real example of methodology

The methodology shown in this example comprises the following steps:

- Introduction
- Site
- Solar Resource Analysis
- Energy Yield Estimations
    - Description of Losses
    - Production and Variability Calculations
    - Degradation and Availability Analysis
    - Long Term Expectations

Introduction

This Project is a 182 MW PV Plant connected to the grid on one axis tracking system with backtracking. The cell technology is based on mono and poly crystalline silicon with 280 W modules and with standard 226 dc/ac inverters of 720 kVA each one. There are 113 transformers of 1,6 MVA each one grouped in 8 mid voltage rings connected 22/132 kV to the substation.

Site

The location is precisely at latitude 29° 34' 20.97" S, longitude 149° 51' 16.67" E at an elevation of 214 m. A red marker indicates the site in the figures below, Figure A.1.

Figure A.1: Moree (Australia) site location

The proposed site in Moree (Australia) is located approximately 10 km South of the town of Moree, Figure A.2.

Figure A.2: Moree close-up of site location

Solar Resource Analysis

Available Data

Data for the site was available from four sources, detailed in the Table A.1 and Figure A.3. As they show, the data sources vary in type, location, sampling rate, and time period. Considering that all sources are located within 10 km, the distance to the proposed site is considered negligible. It is also noteworthy that both BOMd (daily data) and BOMh (hourly data) come from the Bureau of Meteorology (BOM) in Australia (http://www.bom.gov.au/). The BOMd is daily irradiation data available to the public for free, while BOMh is hourly data available for purchase.

Table A.1: Data sources

Source	Type	Location	Sampling rate	Time period
BOMd	Satellite	Moree Airport	Daily	1990 – present
BOMh	Satellite	Site	Hourly	1998 – 31/03/2011
GPL048	Ground station	Site	Minute	26/07/2010 – 21/08/2011
GPL049	Ground station	Site	Minute	03/06/2011 – 21/08/2011

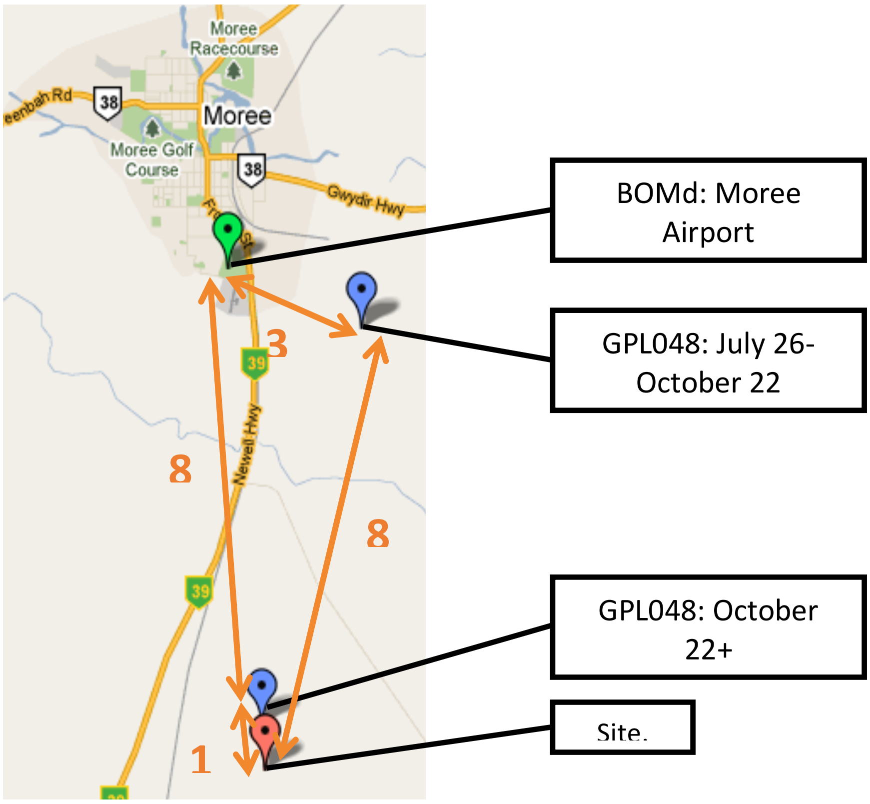


Figure A.3: Data source locations

The Bureau of Meteorology is Australia's national weather, climate and water agency

Its expertise and services assist Australians in dealing with the harsh realities of their natural environment, including drought, floods, fires, storms, tsunami and tropical cyclones.

Hourly BOM satellite data (BOMh) was obtained by Greenpower Labs from the Australian Bureau of Meteorology. These are data for the exact location of the proposed site, and is provided hourly for a period of 1998-31/03/2011.

Daily satellite data (BOMd) from the Australian Bureau of Meteorology (BOM) was obtained through the free web service on the BOM website (http://www.bom.gov.au/climate/data/). The site location used was 053115 Moree Aero, which is roughly 8 km north of the proposed site. Daily solar irradiation during a period of 1990-present is provided.

According to data sheets provided by the BOM, “satellite-derived solar global horizontal irradiance estimates are based on images from the Geostationary Meteorological Satellite GMS-5, Geostationary Operational Environmental Satellite (GOES-9) and MTSAT-1R satellites, which are provided with permission of the Japan Meteorological Agency (JMA) and the United States National Oceanic & Atmospheric Administration (NOAA).

The Bureau of Meteorology’s computer radiation model uses hourly visible images from geostationary meteorological satellites to estimate hourly instantaneous solar global horizontal irradiance (GHI) at ground level. Each GHI value is converted to a direct normal irradiance (DNI) value by applying a conversion algorithm which depends on the GHI values and the sun position.

At each location in each satellite acquired image, the brightnesses are averaged over each grid cell and used to estimate GHI at the ground. Essentially, the GHI at the ground can be calculated from the GHI at the top of the earth’s atmosphere, the amount absorbed in the atmosphere (dependant on the amount of water vapor present), the amount reflected from the surface (surface albedo) and the amount reflected from clouds (cloud albedo). These GHI values were produced by reprocessing archived raw satellite data using software that was extensively rewritten in 2006, but based on the two-band physical model (Weymouth and Le Marshall, 2001) that has been the basis of the Bureau of Meteorology’s satellite solar radiation system since 2000. The GHI values are not corrected for any bias with respect to ground-based radiation observations. Thumbnail images of all GHI grids were inspected and anomalous grids, due to satellite images that were noisy or otherwise anomalous, were rejected.

GHI is converted to DNI via the diffuse fraction estimated by applying a modified form of the Ridley et al. (2010) model. The model estimates the diffuse fraction (ratio of diffuse irradiance to GHI) from the instantaneous clearness index (ratio of GHI to extraterrestrial irradiance), daily mean clearness index, solar elevation, apparent solar time, and a measure of temporal variability that is the root mean squared difference between the clearness index for the current hour and those for one hour before and after. This variability parameter is used instead of the ‘persistence’ parameter adopted by Ridley et al. because it gave lower uncertainties (median absolute percentage error of 16%, compared with 20 % obtained by Ridley et al. for southern hemisphere stations). The model coefficients were established by fitting the model to observations of GHI and DNI from the Bureau’s surface radiation network, which were 1-minute observations taken at 1-hour intervals to simulate the satellite sampling.

The accuracy of the satellite-based GHI values is estimated by comparison with 1-minute averaged GHI measurements from Bureau of Meteorology surface-based instruments. The mean bias difference (average of the satellite - surface difference), calculated on an annual basis across all surface sites, is +11 to +40 W/m^2 and typically around +20 W/m^2. This is +4 % of the mean irradiance of around 480 W/m^2. The root mean square difference, calculated on a similar basis, is around 130 W/m^2, which is 27 % of the mean irradiance.

The accuracy of the satellite-based DNI values is estimated by comparison with 1-minute averaged DNI measurements from Bureau of Meteorology surface-based instruments. The mean bias difference (average of the satellite - surface difference), calculated on an annual basis across all surface sites, is -7 to +50 W/m^2 and typically around +30 W/m^2. This is +5 % of the mean irradiance of around 540 W/m^2. The root mean square difference, calculated on a similar basis, is around 150 W/m^2, which is 30 % of the mean irradiance.

The source of uncertainties associated with calculation of GHI includes uncertainties in:

- Anisotropy of cloud-top reflectance
- Water vapour in the atmosphere
- Satellite calibration
- GHI-to-DNI conversion model

It should be noted that a particular GHI or DNI value may not be representative of a 1-hour period, due to variations in the solar zenith angle during the hour, and most significantly because of variations in atmospheric conditions such as cloudiness.

GPL048 Weather Station

The device used to measure irradiance on site is an EKO Pyranometer MS-802. This type of pyranometer is considered “secondary standard” under the International Standard Organization and World Meteorological Organization standard ISO 9060:1990(E). Secondary standard is the highest quality level available, with a measurement uncertainty of 2 %. The calibration certificate of the GPL048 was checked.

It was installed on 26/07/2011, and was moved on 22/10/2011 to its current position at the proposed site. Through conversations with the owner of the PV plant, it is understood that the device was being properly maintained starting on 23/03/2011. The device provides irradiance measures by the minute.

GPL049 Weather Station

Equal in characteristics as GPL048, a second EKO Pyranometer MS-802 was installed in order to verify and calibrate the readings of the GPL048. It began taking readings by the minute on 04/06/2011. The calibration certificate of the GPL049 was also checked.

Data Analysis

Standard procedure for calculating long-term historical analysis of solar data is as follows:

1. Place high quality ground measuring device on the proposed site for a minimum of one year
2. Correlate the ground measurements with satellite data of the same period
3. Correct the long-term satellite data using the obtained correlation
4. Calculate average months to obtain the typical meteorological year
5. Due to uncertainties associated with the location and maintenance of GPL048, the GPL049 was used to calibrate the longer-term data of the GPL048. The time period available is 04/06/2011-21/08/2011. As the figure below shows, there is an excellent correlation between the two data sets with an R2 of 0.9927.

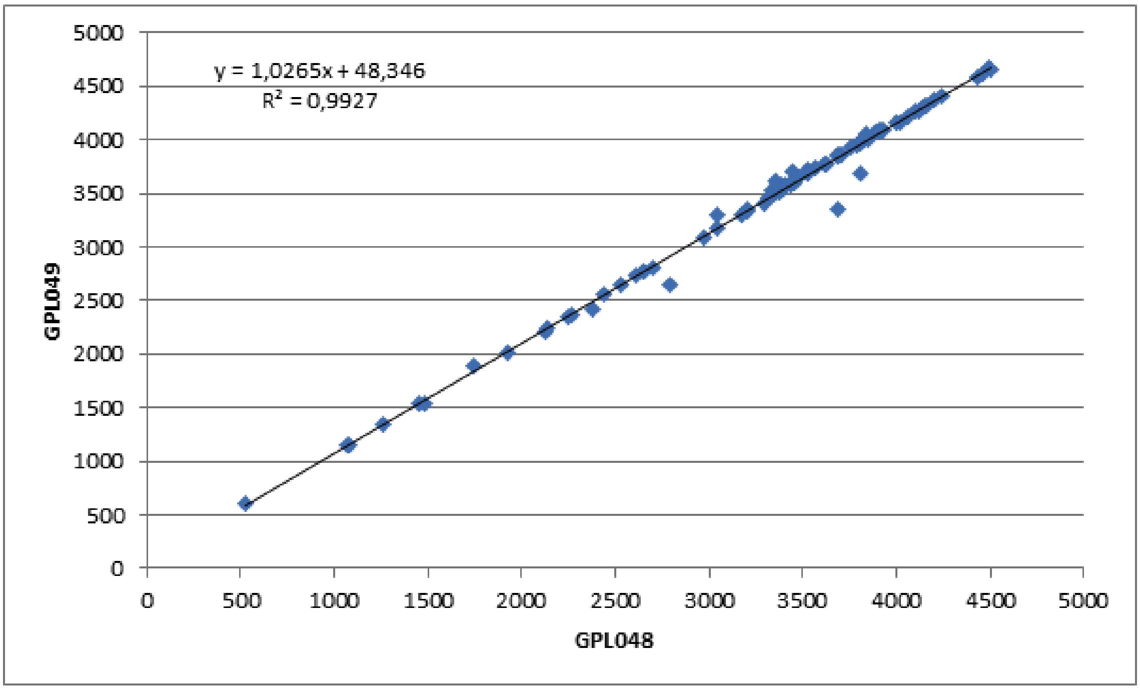


Figure A.4: GPL049 vs GPL048

Using the obtained correlation, the daily values of GPL048 were altered to make a data set called GPL048.

GPL048’ = 1.0265.GPL048 + 48.346

At this point, there were two choices of long-term satellite data: BOMd and BOMh. BOMd was chosen for two reasons:

1. Data for BOMh was only available until 31/03/2011, providing little overlapping with the period of proper maintenance for GPL048 beginning on 23/03/2011
2. The correlation of BOMh with GPL048’ for the period available of 26/07/2010-31/03/2011 (excluding 22/10/2010 due to moving of the ground station) resulted in an R2 of 0.8451, as the figure below shows, Figure A.5.

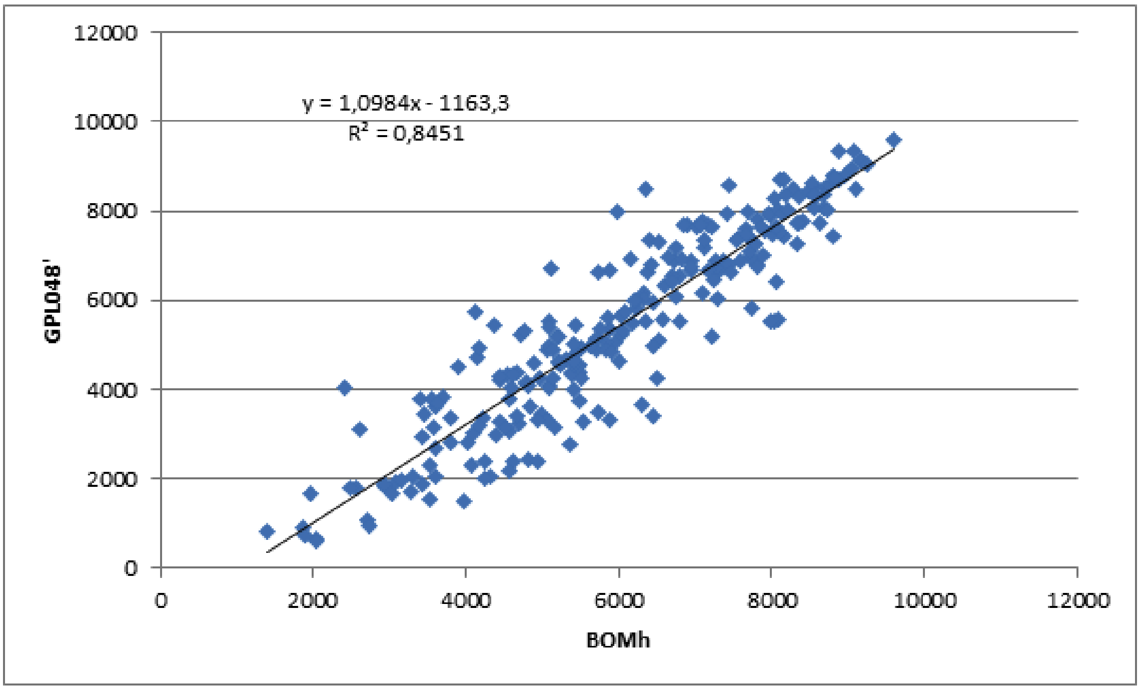


Figure A.5: GPL048' vs BOMh

The data set of GPL048’ was then correlated with BOMd during the time frame of proper maintenance of GPL048, 23/03/2011-21/08/2011, excluding the dates of 20/07/2011 and 04/08/2011 due to invalid values on the part of BOMd. The Figure A.6 demonstrates this correlation, with an R2 of 0.9166.

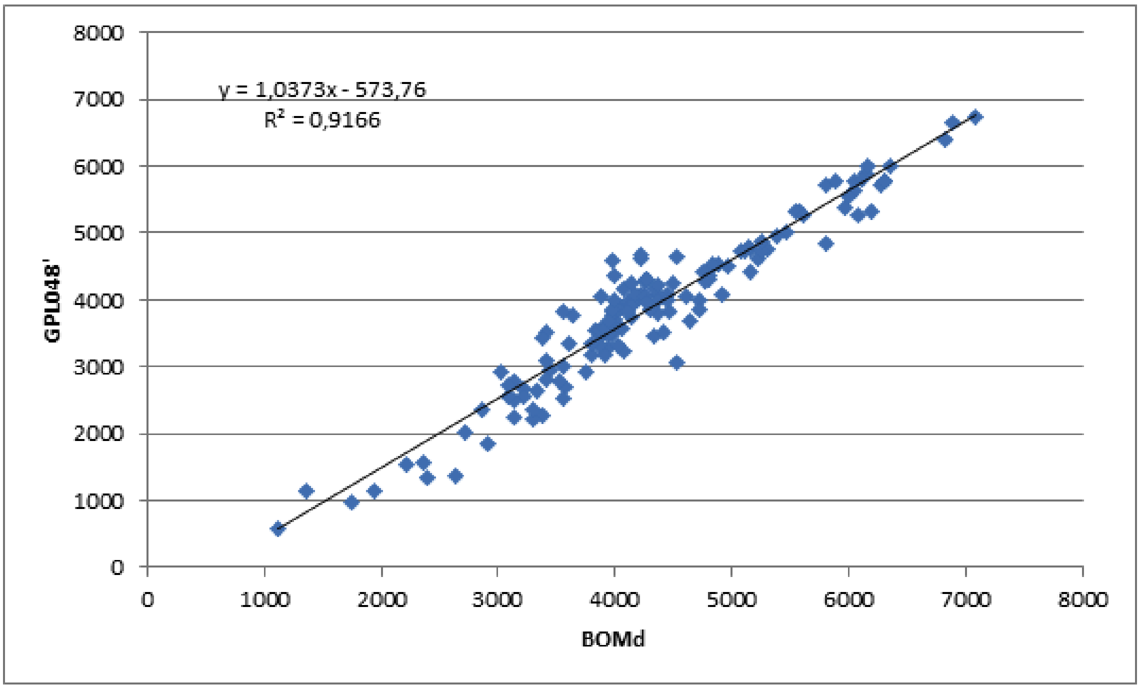


Figure A.6: GPL048' vs BOMd

An R2 of 0.9166 is considered acceptable, taking into account the sources of both data sets (one terrestrial and one satellite) as well as the lower correlation with the BOMh data. As was done with GPL048, BOMd daily values were altered using the correlation obtained in Figure 8.

BOMd'=1.0373.BOMd - 573.76

Using this new correlation, monthly values were obtained for the years 1990-2011. In order to accept only reliable months with recent data, years prior to 2001 were discarded. In addition, months that contained a daily value of less than or equal to 0 Wh/m2 were discarded. An average of the available months was taken, and then representative months from the actual data were selected to be as close to possible to that yearly average. The resulting valid months are shown in the table below:

Table A.2: Valid months

GHI (kWh/m2)	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
2001		195.26	172.07	137.29	111.13	88.74						
2002	238.71	167.42			111.65	90.78	113.52	126.80		210.48	215.92	242.14
2003		150.62	178.95				101.24	114.41	174.26		225.43	232.92
2004	217.68	195.66	171.49	136.13		92.94	97.64	132.13		193.13	217.25	239.72
2005	227.68	200.64	185.41	149.01			100.78	135.85		176.65		
2006	217.22	185.31	160.74				93.18	130.86	164.43	207.74	220.70	200.39
2007	223.13	194.10	185.38	141.00	112.63	75.31	103.95	123.86	175.49	198.87	185.75	206.44
2008	199.38	180.02			122.77				155.21	208.66	193.88	227.74
2009	228.26			140.37	115.19	92.42		129.19	160.02	207.39		221.31
2010	247.45	180.19	181.35	146.94	117.52	101.82	87.15	120.46		171.92	188.89	203.36
2011	235.63	200.87	170.20	151.09	116.51	95.97	101.13					

Using the valid months, the most probabilistic monthly value is obtained by calculating the distribution that best fits the valid months by using the statistical software @Risk. The sum of the different months results in an annual distribution function. This distribution of the annual solar resource obtained from the analysis can be found in the Figure A.7.

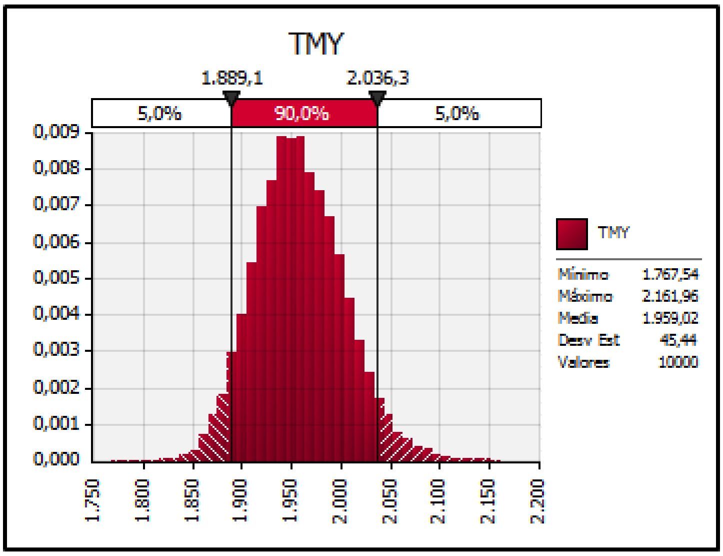


Figure A.7: TMY Distribution Analysis at @Risk

In order to convert the obtained TMY to an hourly set of data, the month-year most similar to the TMY value is chosen that also has a corresponding month from the available BOMh data (to be explained below). Then, a correction factor is applied to the hourly values to obtain the same monthly result. The TMY, closest available value and year, as well as the correction factor are shown in the following table.

Table A.3: Monthly TMY

Month	TMY GHI (kWh/m^2)	Closest value (kWh/m^2)	Closest value year	Correction factor
1	227	228	2009	0.995
2	187	185	2006	1.009
3	176	172	2001	1.024
4	143	141	2007	1.017
5	116	115	2009	1.010
6	92	92	2009	0.995
7	100	101	2005	0.994
8	127	129	2009	0.984
9	166	164	2006	1.007
10	198	199	2007	0.995
11	204	194	2008	1.051
12	222	221	2009	1.004
Total	**1959**			

As BOMd does not provide information about direct normal irradiance (DNI) and diffuse horizontal irradiance (DIF), BOMh is used to provide this breakdown. BOMh provides hourly values of GHI, DNI, and DIF; therefore, the following procedure is used:

1. For each day, convert the hourly BOMh values from absolute irradiance to relative percentages for the amount of irradiance during that hour for that particular day. For example, if hour 10 had 100 Wh/m^2 during a day with a total irradiation of 1000 Wh/m^2, hour 10 would have a relative value of 10 %.

2. In a similar fashion, absolute values of DNI and DIF are converted to values relative to the hourly absolute GHI value. For example, if hour 10 had 100 Wh/m^2 GHI, with absolute DNI of 90 Wh/m^2, the relative value of DNI would be 0.9.

3. As the diffuse fraction is 23.9 %, which is lower than the market standard, the technical advisor applied a correction factor of 10 % in order to make a more conservative estimate.

It is important to note that BOMh was selected over Meteonorm due to an explanation provided by BP Solar (one of the owners of the Project): “the Meteonorm method gives a ~22 % mean bias error for a validation in Alice Springs (the third largest town in the Northern Territory, Australia, located in the geographic centre of Australia) and the BOM method (Ridley et. al 2010) has median bias errors between 2 % to 14.4 % for 2 Australian sites.”

By creating these relative values, the daily BOMd’ values are broken down hourly into GHI, DNI, and DIF. The resulting complete TMY table is seen in Table A.4.

Table A.4: TMY breakdown into GHI, DNI, and DHI

Month	GHI (kWh/m^2)	DNI (kWh/m^2)	DIF (kWh/m^2)
1	227	247	55
2	187	221	39
3	176	197	52
4	143	217	24
5	116	189	23
6	92	152	25
7	100	178	21
8	127	193	27
9	166	239	26
10	198	232	43
11	204	211	63
12	222	223	72
Total	**1959**	**2499**	**468**

To calculate the gain due to the one axis tracker design, PVSyst software was used with the following data inputs:

- GHI and DIF from the table above
- Tilt: 19 degrees
- Movement range: -45 – 45 degrees
- Backtracking
- Pitch: 11 m
- Collector width: 3 m

Using this, PVSyst calculated the resulting global inclined radiation that is received by the tracker system. The results are shown in the Table A.5.

Table A.5: Results from PVSyst software analysis

Month	GHI (kWh/m2)	Global Inclined (kWh/m2)	Gain
1	227.2	276.6	21.7%
2	187.0	242.1	29.5%
3	176.3	243.6	38.2%
4	143.4	227.2	58.4%
5	116.4	197.1	69.3%
6	92.0	164.0	78.3%
7	100.2	163.0	62.7%
8	127.2	206.3	62.2%
9	165.6	250.8	51.4%
10	197.8	264.0	33.5%
11	203.8	246.4	20.9%
12	222.2	257.7	16.0%
Total	**1,959.0**	**2,738.9**	**39.8%**

As the table shows, the resulting overall gain is 39.8 %. This value was recommended by the Technical Advisor as a conservative figure. The gain could be higher if a lower diffuse fraction value is confirmed, but this point should be verified by installing a pyrheliometer on site to measure diffuse radiation.