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Development, maintenance and application of the United Nations Framework Classification for Resources:
Renewable energy resources

Draft Specifications for the application of the United Nations Framework Classification for Resources to Solar Energy

Prepared by the Solar Energy Sub-group of the Renewable Energy Working Group of the Expert Group on Resource Classification

Summary

This is a preliminary draft of the Specifications for the application of the United Nations Framework Classification for Resources to Solar Energy (Solar Specifications) which will evolve following comments from the Expert Group on Resource Classification. The document has been reviewed by the Technical Advisory Group of the Expert Group which noted that while it is enthusiastic about the progress made, further work and discussion is required on how to ensure integration with the United Nations Framework Classification for Resources (UNFC). In particular, issues to be resolved include: clearer consistency with the E and F categories of UNFC; and terminology consistent with UNFC, e.g. avoiding the term "reserves" since this can cause confusion. To help the Expert Group in its review of the draft Solar Specifications, footnotes have been added to indicate issues raised by the Technical Advisory Group.

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Preface

Over the last decade, the renewable energy industry has rapidly grown in scale and matured into an ever more important part of the current and future energy mix. The growing importance of renewable energy resources, including solar, has raised the need for a standardised reporting of energy resources estimates for projects and at national and international levels.

Work on an international framework classification for reserves and resources started in 1994, with the United Nations International Framework Classification for Reserves/Resources published in 1997. Following this, and in recognition of the need for comparable energy and other data, the Ad Hoc Group of Experts on Harmonization of Fossil Energy and Mineral Resources Terminology was established in November 2001, and later became the Expert Group on Resource Classification. As part of its work, the Expert Group revised the United Nations Framework Classification for Resources (UNFC), which was approved by the United Nations Economic Commission for Europe (ECE) Committee on Sustainable Energy at its Eighteenth Session. The Expert Group is currently responsible for the promotion and further development of UNFC, including the application of UNFC to renewable energy.

As a result of industry and ECE interest in renewable energy resource classifications, the Task Force on Application of UNFC to Renewable Energy Resources was established in June 2013, under the. Phase 1 of the Task Force's work was the production of generic Renewables Specifications for the application of the UNFC to renewable energy. The Task Force is now in Phase 2 of its work, and has five working groups, preparing specifications for the application of the UNFC to geothermal, bioenergy, hydro, wind and solar energy resources.

The Solar Working Group was established by the Task Force in July 2016, as per the ECE Expert Group on Resource Classification Work Plan for 2016–2017. In July and August 2016, there was a call for volunteers interested in joining a Working Group to draft the solar specifications for the UNFC, and the Solar Working Group began its work in August 2016. The Solar Working Group was charged with preparing these Solar Specifications with the aim of improving the consistency and interpretation of reported solar energy reserves and resources estimates while at the same time facilitating comparisons with other energy sources. In April 2017, the Solar Working Group and Renewables Tasks Force had their names changed to the Solar Subgroup (SSG) and Renewables Working Group (RWG) respectively.

While working on the Solar Specifications, the SSG noted that the Specifications not only support the estimation and classification of solar energy reserves and resources but also help identify the steps that solar projects and sites need to go through before solar energy can be utilised. This starts with the identification of potential solar energy resources and a series of stages towards realising commercial reserves at project sites where energy is either sold to market or used directly. The Solar Specifications are designed to support the classification of solar energy data in a way that follows a solar energy project cycle while at the same time allowing comparison with other energy sources.

Acknowledgements

The development of this first draft of the Solar Specifications was undertaken by the Solar Subgroup consisting of volunteers led by Jeremy Webb with Adrian Whiteman, Anteneh Dagnachew, Axel Gunaltun, Boris Lopicich, Carina Paton, Chris Freear, David Renne, Fred Morse, Jenny Chase, Kamel Ben Naceur, Lado Kurdgelashvili, Lauren Weir, Linus Mofor, Long Seng To, Manajit Sengupta, Monica Oliphant, Vivek Mittal and Yacob Mulugetta. Valuable inputs have also been received from Frank Denelle, the Chair of the Renewable Working Group, Gioia Falcone the Geothermal Subgroup lead, James Primrose the Bioenergy Subgroup lead, Tom Lefeber the Wind Subgroup Lead, Alistair Jones the Chair of the Technical Advisory Group, David MacDonald, Chair of the Expert Group on Resource Classification, as well as Charlotte Griffiths and Harikrishnan Tulsidas from the ECE secretariat. Work on development of the Solar Specifications was assisted by BP, which hosted a Solar Working Group Virtual Workshop. In addition, drafts received special feedback from Divyam Nagpal and important references from David Gernaat.

Contents

I. Introduction

1. The Solar Specifications provide a framework for assessing quantities of useful energy that a project, geographic area or country could utilise from the sun. This includes all types of solar energy, e.g. heat, light, electricity generated, and other solar energy. The Solar Specifications include a classification for reporting this energy, in relation to: confidence of useful energy estimates[1]; project maturity (i.e. how close the project is to being realised); and the degree of favourability around economic, social, environmental, legal and commercial conditions for a project to go ahead. Until now there has been no internationally accepted classification or framework for reporting solar energy in this way. As such, the Solar Specifications address an important gap. Potential applications of the Solar Specifications include business information systems and asset (i.e. reserve and resource) management by companies, national energy assessments by governments and international energy studies. Furthermore, there is an opportunity for the Solar Specifications to be used for public reporting or as a template for solar project reporting when seeking investors or project finance. Intended users for the Solar Specifications include governments, businesses and others interested in solar energy.

2. Central to the classification of solar energy estimates is a 2-dimensional table where the confidence of useful energy estimates is classified along the horizontal axis, and the socio-economic viability and project feasibility (i.e. maturity) are classified along the vertical axis. In short, the table differentiates economic solar energy reserves and resources. *Solar reserves* consist of the anticipated useful energy for commercially operational, pre-operational and designed solar projects. *Solar resources* consist of anticipated useful energy for sites, under various levels of investigation, where solar energy could be utilised cost effectively. In addition to this, the Solar Specifications also presents the 3-dimensional United Nations Framework Classification for Resources (UNFC), and highlights how solar energy estimates classified using the Solar Specifications can be compared, using UNFC, with other renewable and non-renewable energy resources. As such, UNFC provides a powerful framework for understanding and managing energy reserves and resources.

3. It should be noted that this is not the first-time solar energy, or other renewable energy resources, have been classified using frameworks that allow comparison between all energy sources. In 1989, the United States Department of Energy (DOE) undertook an assessment of renewable and non-renewable energy sources. This included the classification of economic “reserves”, “accessible resources” and the “total resource base” (see Annex 1). The exercise was prompted by the observation that “Data on estimated resources and reserves levels for major energy sources… are developed using a carefully delineated set of definitions and assumptions. However, U.S. resource and reserve estimates are not necessarily undertaken in a coordinated and parallel fashion across the full range of energy sources... Energy sources also do not have consistent reporting timeframes or equal levels of ongoing activities to update and refine previous estimates. Additionally, there has been little or no attempt to assemble and present energy resources information in a single, comprehensive data set…” (page 3, DOE 1989). Further efforts to establish renewable energy definitions were published by NREL (Maxwell and Renné, 1994). In this report the authors attempted to contrast depletable reserves (typically fossil and nuclear fuels) as depicted under the classic McKelvey Diagram (USGS 1976) with renewable reserves that are not depletable (e.g. solar and wind energy, and other renewable resources). The classification of renewable energy reserves and resources remains restricted to ad hoc classification exercises and the issues of

[1] “Useful energy” corresponds to the concept of “recoverable” energy. As such, the energy classified using the Solar Specifications is “…limited to those quantities that are potentially recoverable on the basis of existing technology or technology currently under development, and are associated with actual or possible future... ...projects" (page 22, UNFC 2009).

energy classification and comparison identified by the earlier U.S. DOE and NREL studies are relevant today.

4. With the growing importance of solar energy, government and intergovernmental organisations have been providing more guidance on issues of solar energy projects including potential resources, technologies, risk management and financial arrangements. This includes the establishment of the International Renewable Energy Agency (including assessments of national solar potentials) as well as work already underway at the International Energy Agency (e.g. Future Scenarios for Renewables and the World Energy Outlooks), the World Bank (e.g. Global Solar Atlas), the European Commission (e.g. Solar Bankability) and work continuing in countries from around the world (e.g. the United States National Renewable Energy Laboratory or PBL Netherland's Environment Agency). As noted by DOE in 1989, there are a range of delineations, definitions and assumptions that can be used to frame or classify solar energy and related projects. The World Energy Council (1994), for example, delineated renewable energy into "theoretical potential", "geographic potential", "technical potential" and "economic potential" (see Annex 2). The Solar Specifications draws upon existing work by these organizations, and takes the "economic potential" as applied to solar (Köberle et al 2015) further delineates it into solar energy reserves and resources. This includes the identification of solar energy project milestones that form the boundary between reserves and resources categories and subcategories.

5. Central to the Solar Specifications is the Solar Reserves and Resources Classification (Section II). The Solar Reserves and Resources Classification is framed around the steps required to take solar energy resources (i.e. possible projects or sites) and convert them into solar energy reserves (e.g. operational projects). It is anticipated that resource assessments using the Solar Specifications will become an important source of information for investors, project developers and energy-related authorities and government. It helps facilitate the monitoring of solar energy portfolios, investment opportunities and in doing so, supports decision making. In addition, the Solar Specifications provides terms, concepts and definitions important for classification of solar energy. It is expected that a competent person could take the Solar Specifications and work out how to apply the concepts and definitions to classify solar projects based on the data and information they have.

6. It should be noted that the classification of reserves and resources, which is the main focus of this document, is one step within a wider information cycle. Steps leading up to the classification of solar reserves and resources consist of: 1. Collecting data on projects or possible project sites; and, 2. Calculating the useful solar energy from each project or possible project site. These energy estimates are then: 3. Classified. After classifying projects, there are a series of other steps consisting of: 4. Compiling useful energy estimates in the same Solar Reserves and Resources Classification categories; 5. Controlling for data quality; and, 6. Reporting of information to decision makers. Data classified using the Solar Reserves and Resources Classification can serve as an input to energy system investment decisions either by business leaders, government agencies or others. Importantly, the implementation of these decisions then leads to changes, some of which will affect solar reserves and resources and their classification in subsequent assessments.

7. It should also be noted that the Solar Specifications does not provide step-by-step guidance on how to classify solar energy reserves and resources as there are too many business models, technologies and applications for this to be possible in a single document. Instead the Solar Specifications focuses on concepts and definitions in its first draft, leaving issues of sources, methods and rules of application for after the Specifications have been tested. It is anticipated that further guidance and case studies will be prepared once the Solar Specifications have been tested.

8. The Solar Specifications is an important reference for classifying solar reserves and resources. However, if conceptual questions arise, the Solar Specifications should be used in

conjunction with UNFC incorporating Specifications for its Application along with the Specifications for the Application of UNFC to Renewable Energy Resources (i.e. Renewables Specifications, ECE 2016a). Other useful references include the Geothermal Specifications (ECE 2016b) and Bioenergy Specifications (ECE 2017a).

II. Solar Reserves and Resources Classification[2]

9. The Solar Reserves and Resources Classification (Table 1) is designed to organise useful energy estimates into categories relevant for assessing and monitoring solar energy projects. As such, the categories are marked by key milestones along a solar energy project and investment life cycle. The classification can also be applied to smaller scale projects although the milestones may be less formal when applied at the scale of a household for example.

10. The Solar Reserves and Resources Classification has two dimensions[3]: the first being the confidence of useful energy estimates along the horizontal axis; and, the second being the socio-economic viability and project feasibility along the vertical axis[4]. Confidence of useful energy estimates is broken down into three categories consisting of: P90, i.e. there should be at least a 90 per cent probability that the quantities actually recovered will equal or exceed the low estimate; P50, i.e. there should be at least a 50 per cent probability that the quantities actually recovered will equal or exceed the best estimate; and, P10, i.e. there should be at least a 10% probability that the quantities actually recovered will equal or exceed the high estimate. Alternatively, instead of using P90, P50 and P10, useful energy estimates can be classified along the horizontal axis in terms of high, medium and low confidence (see page 14 and 15 of ECE 16a).

11. In cases where utility scale solar energy projects are generating electricity that is being sold into the grid, useful energy estimates can be sub-divided and recorded against expected prices. This is important where the price paid for electricity varies according to demand over the course of a day, week, or seasons, as this has a bearing on the amount of electricity expected to be generated and the overall viability and economics of a project. In other cases, ancillary services may be provided to an electricity grid, and a premium price may be expected for such services. In some cases, electricity generation is curtailed due to a lack of network storage, capacity or oversupply by generators. The classification also has space for capacity figures to be recorded alongside useful energy estimates (i.e. installed capacity or anticipated capacity for projects yet to start or complete construction).

12. Socio-economic viability and project feasibility are divided at the highest level between *reserves and resources*. *Reserves* include: reserves that are operational, i.e. at sites with technology to utilise the energy; reserves that are pre-operational i.e. at sites that are approved for development and have finance including sites under construction or waiting to

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[2] Technical Advisory Group has suggested revisions to this section. Issue related to the use of the term "reserves" and the definition of "resources" will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

[3] This is similar to the non-renewable energy classification schemes that have previously been bridged to the UNFC, including the Petroleum Resources Management System (PRMS 2007) and CRIRSCO (ECE 2015).

[4] The vertical axis consisting of socio-economic viability and project feasibility amalgamates the E and F axes from the UNFC with a model for utility scale solar projects from Springer (2013) that is also used in other NREL publications. See Section **Error! Reference source not found.** "**Error! Reference source not found.**" for more on the UNFC E and F axes and see **Error! Reference source not found.** for more on the model for utility scale solar projects.

start construction; and, reserves that are designed i.e. at sites which have designed projects and entitlements have been secured, but finance is still required. An important milestone for reserves is the commercial operation date, which for new projects is the date after which all testing and commissioning have been completed, and solar energy is being utilised (e.g. electricity generated, or heat being used). Designed reserves are divided from pre-operational reserves by the financial close milestone, "when all the project and financing agreements have been signed and all the required conditions contained in them have been met" (EIB 2015). *Reserves and resources* are divided by the *entitlements* milestone, which is where necessary legal permits and other project rights have been secured.

Table 1

Solar energy categories and sub-categories including definitions as well as milestones (in light blue) between categories and subcategories[5].

Solar energy categories and sub-categories		*Definitions*	*Confidence of useful energy estimate*		
			P90	*P50*	*P10*
			Units of energy	*Units of energy*	*Units of energy*
- - Commercial operation end date - -					
Reserves	Operational	Useful energy, over the remaining project lifespan, at sites with technology to utilise solar energy. The utilisation of useful solar energy is currently taking place and is economic on the basis of current market conditions and realistic assumptions of future market conditions.			
	- - Commercial operation date - -				
	Pre-operational	Useful energy, over the project lifespan, at sites that are approved for development and are under construction or are waiting to be constructed.			
	- - Financial close - -				
	Designed	Useful energy, over the project lifespan, at sites where a project has been designed and entitlements secured but finance is still required.			

[5] Expert Group reviewers should compare categories and subcategories in **Error! Reference source not found.** (above) with the categories and subcategories from Figure 3 in UNFC (2009).

- - Entitlements- -					
Resources	Under development	Useful energy at sites where projects are being designed.			
	Pre-development	Useful energy at sites that are being investigated but are yet to be justified for development.			
	- - Decision to investigate - -				
	Potentially accessible	Useful energy at sites that could potentially be developed, but for whatever reason are not currently being investigated for development.			
	Inaccessible	Useful energy that technically could be utilised at reasonable cost (i.e. economically), but for whatever reason, is not available for use. Reasons could include: a lack of market access, regulations, a lack of infrastructure, or a lack of users to utilise the energy.			
- - Technically possible and cost effective to use - -					

Note: Assessment period (years): e.g. project lifetime or the set period for a national assessment

Note: A modified version of the Solar Reserves and Resources Classification Table are available in Annex 3.

13. Resources are divided into four categories consisting of: under development; pre-development; potentially accessible; and inaccessible. A solar resource under development consists of the useful energy from a site where a project is being designed. A resource that is pre-development consists of the anticipated useful energy at site that is being investigated but is yet to be justified for development. It should be noted that the decision to investigate a resource is an important milestone. Note: For more detailed solar reserves and resources definitions see Section III.C. Solar reserves and resources. Also see Section III.D Solar reserves and resources estimates.

14. The two remaining categories of solar resource, potentially accessible and inaccessible, consist of potentially useful energy that has not yet been investigated. Inaccessible solar resources consist of the technically useful energy that, for whatever reason, is considered not useable even though it would be available at reasonable cost (i.e. would be economic). Reasons could include: a lack of market access, regulations, a lack of infrastructure; or, a lack of users to utilise the energy.

15. *Reserves and resources* consist of the energy that is technically possible to use at reasonable cost (i.e. useful solar energy). *Reserves and resources* are a fraction of total solar irradiation. Note: for more information on useful energy and its definition, see Section III.B. Useful solar energy.

16. The following terms related to solar energy are often found in the literature, hence a definition of each term is provided here (Renné, 2016):

- *Solar radiation*: This term is often used interchangeably with *solar energy* and *irradiation* and, less commonly, *insolation*.
- *Radiant energy*, or *radiance*: this is the amount of energy emanating from the sun. The sun radiates at an effective temperature of 5778 °K. Radiant energy (sometimes

referred to as *radiant intensity*) decreases at the rate of the inverse square of the distance from the source.

- *Irradiance*: The power density of radiation incident on a surface, or the rate at which *radiant energy* is incident on a surface, generally expressed in units of $W\text{-}m^{-2}$.
- *Irradiation* (or *insolation*): The quantity of solar energy (radiation) arriving at a surface during a specified period of time, generally expressed in units of $W\text{-}m^{-2}\text{-}hr^{-1}$ or $W\text{-}m^{-2}\text{-}yr^{-1}$, or occasionally in $MJ\text{-}m^{-2}$. Thus *solar energy* is synonymous with *solar irradiation*, and also represents the maximum theoretical *solar resource* available at a location over a specified time period if the technology was able to utilise 100% of the energy. In practice, technology is only able to utilise a fraction of this energy, and as such, *solar resources* (in the context of the UNFC) are a fraction of solar irradiation.[6]
- *Total solar irradiation* consists of direct beam and diffuse irradiance and their sum (global irradiation), as well as reflected irradiation. *Direct beam irradiation* is the energy directly from the sun coming along a straight line perpendicular to the sun. Diffuse irradiation is the energy from the sky other than the sun, including the scattered irradiation from both clouds and clear sky. Ground reflected irradiation is the energy from the sun that has been reflected upward from the ground. Sources of solar irradiance data are derived either from actual ground measurements or from models using weather satellite imagery (and occasionally from numerical weather prediction models), and are available through both public and private sources.

17. For *solar irradiation*, only the solar energy over the lifetime of a project or set period is recorded in Table 1. This is typically measured in units of MW-hr or equivalent units. For solar energy reserves and resources, the useful energy over the lifetime of a project, or a set period, is recorded along with the installed capacity and the anticipated price the energy will be sold for. When comparing more than one type of solar energy (e.g. thermal vs electricity) standard power units such as MW-hr-equivalent, or MWh_{th} vs MWhr can be used.

18. Table 2 provides hypothetical figures for solar reserves and resources as well as total irradiance. Table 2 also includes capacity, energy and price information for reserves and resources estimates. Total irradiation is an order of magnitude larger that reserves and resources.

[6] It is important to note: The common understanding and usage of the term “resource” differs between the wider solar community and its usage within the UNFC community. The solar community typically use the term “resource” to refer to total solar irradiance reaching the earth’s surface. Meanwhile the wider UNFC community uses the term “resource” to refer to amount of something that can be used (e.g. the quantity of energy that can be utilised, the quantity of mineral that can be extracted or the quantity of carbon dioxide that can be stored).

Table 2

A hypothetic portfolio of aggregate solar energy reserves and resources as well as total solar radiation.

	Confidence of useful energy estimate					
	P90			*P50*		
	MW	***MWh****	*$/MWh*	*MW*	***MWh*****	*$/MWh*
Reserves	10	**131,490** **92,043** **26,298** **13,149**	80 40 0 -20			
Resources				50	**1,446,390** **482,130**	80 0
	*MWh****			*MWh****		
Total irradiation				**43,830,000**		

*   *Remaining project lifetime: 15 years*

**   *Expected project lifetime: 20 years*

****Set period: 20 years*

Note: For more information on reserves and resources and the solar project cycle including milestones, please see Figure 3 and the accompanying text.

III. Solar Energy Definitions

A. Solar irradiation

19. *Solar energy* or *solar irradiation* consists of three components: direct beam irradiation from the sun, diffuse irradiation from clouds and sky, and ground reflected irradiation. The term *total solar irradiation* refers to the sum of the direct and diffuse components. For more information on solar irradiation, please see Box 1.

Box 1: Solar irradiation

Solar irradiance refers to the density of solar energy (radiation) reaching a surface during a specified period of time, generally expressed in units of W-m^{-2}-hr^{-1} or W-m^{-2}-yr^{-1}, or, more rarely, in MJ-m^{-2}. At the top of the atmosphere, the total irradiance from the sun is equal to 1366 W/m^2 This value has traditionally been called the *solar constant*. However, at the earth's surface, the sun's irradiance is attenuated by the earth's atmosphere so that the irradiance at the earth's surface is about 1,000 W/m^2 under clear sky conditions when the sun is near it's zenith. Solar energy is synonymous with solar irradiation (the quantity of energy reaching an area over a specified period of time), and also represents the theoretical potential.

Solar radiation occurs in a broad spectral band, encompassing visible, infrared and ultraviolet wavelengths. Visible light typically constitutes about 40% of the radiated energy, infrared 50% and ultraviolet the remaining 10%. Most of the infrared energy is "near infrared", with wavelengths shorter than 3,000 nanometres, and therefore are not considered "thermal radiation".

The solar radiation reaching the earth's surface varies throughout the day and year, and by location as a direct result from the earth's geography and its astronomical movements (its rotation towards the east, and its orbiting the sun). Solar irradiance can also vary substantially at a given point due to the passage of clouds and weather systems.

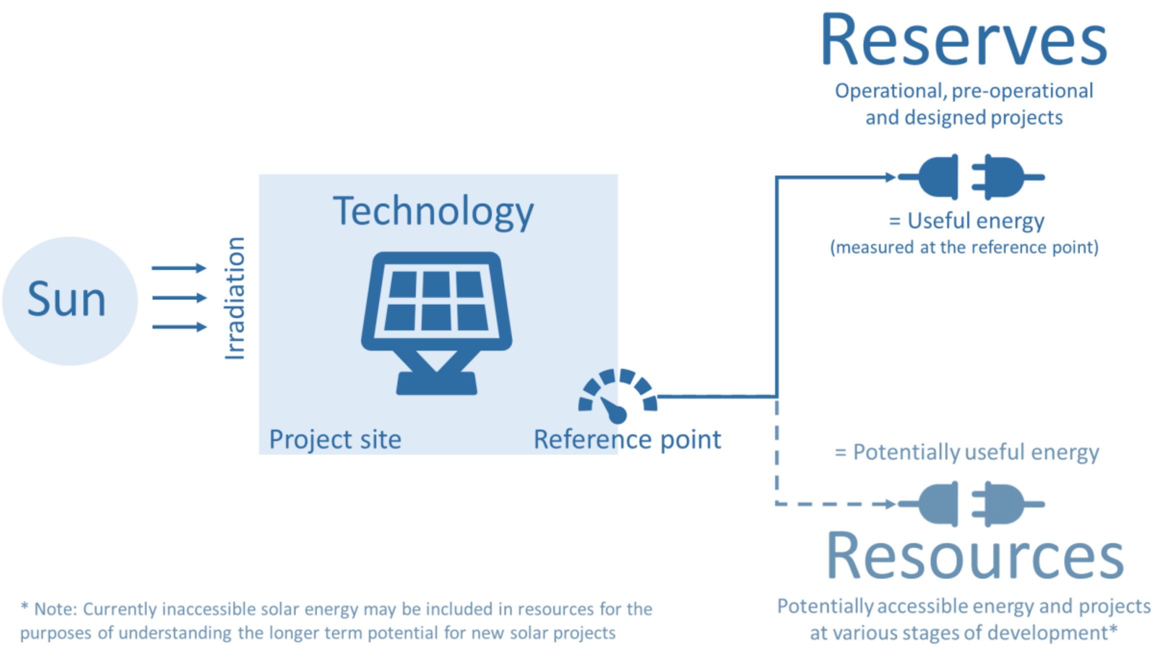
All places on earth have the same 4,380 hours of daylight hours per (non-leap) year; however, they receive varying yearly average amounts of energy from the sun.

B. Useful solar energy

20. *Useful energy* is the energy that can be used for some purpose. *Useful solar energy* is the quantity of *solar irradiation* that can be used directly, stored or transformed and used in some other form, over a specified period of time. *Useful solar energy* includes: daylight, heat from *solar irradiation*, e.g. passive and active systems; electricity generated using *solar irradiation*, e.g. solar photovoltaic (PV) generation or Concentrating Solar Power (CSP); the conversion of solar irradiation to other energy carriers, such as hydrogen; and, other solar energy applications. Daylighting measures make use of sunlight to reduce electricity demand associated with lighting.

21. For *solar irradiation* at a *site* to be utilised and become *useful energy* usually requires some form of technology (Figure 1). For example, *solar irradiation* can be used to generate electricity through the photovoltaic conversion of sunlight into electricity (i.e. solar PV) or the use of heat to drive turbines (e.g. CSP).

Figure 1
Schematic representation of how solar irradiation at a site coupled with technology can generate useful energy, in this case using a solar PV panel and other necessary technologies. Importantly, the useful energy is measured at the reference point.
Note: for some projects, there may be more than one energy type or more than one reference point.[7]



22. *Solar irradiation* can also be used to generate heat to be used directly or as steam for electricity production. *Solar irradiation* can also be used passively, such as for solar space heating when the sun shines through the windows of a building and warms the interior, or for daylighting where sunlight in a building's interior can be used instead of electrical lighting. Active solar heating systems are composed of a collector and a fluid that absorbs solar

[7] Technical Advisory Group has suggested revisions to this section. Issue related to the use of the term "reserves" and the definition of "resources" will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

radiation. Once heated, the fluid (air or liquid) is circulated to transfer the heat to a room or to a heat storage system.

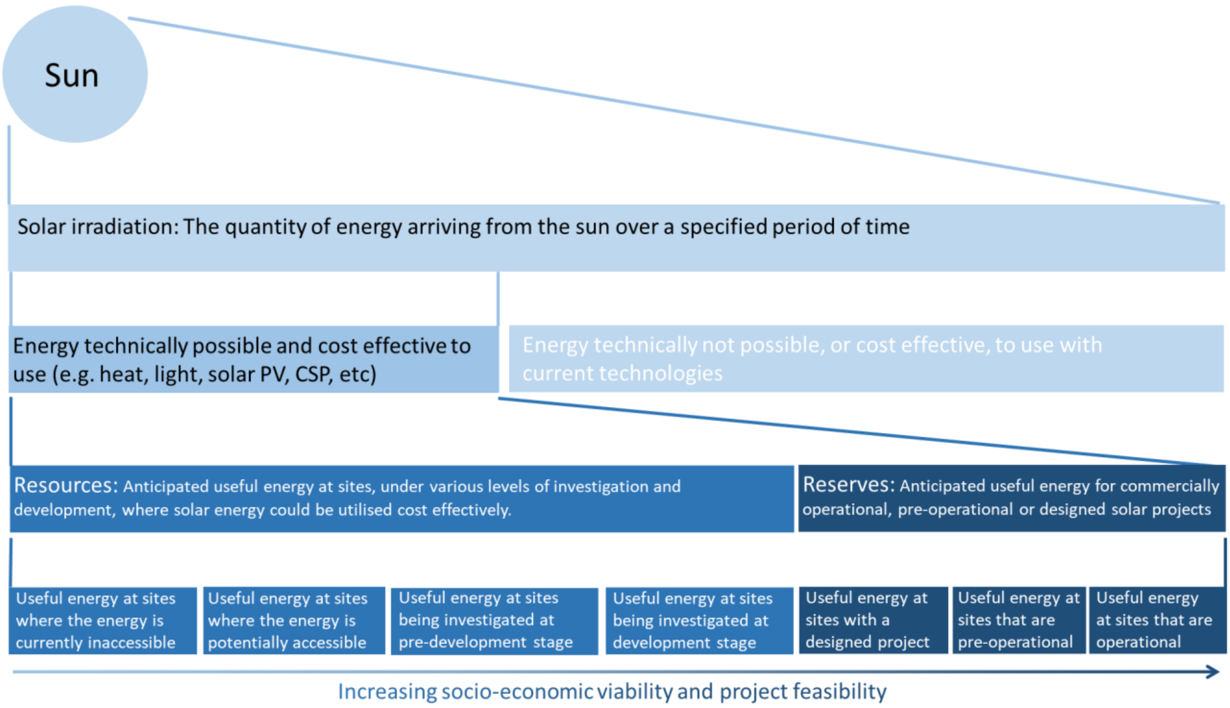
23. In addition to solar PV, other photoreactions can also be used, for example photocatalytic water detoxification. *Solar irradiation* can even be used as an input to the manufacture of energy vectors (i.e. things that can be used to transport and release energy on demand), notably hydrogen.

C. Solar reserves and resources[7]

24. *Solar reserves and resources* are the anticipated quantities of *useful energy* from a *solar project*, or a set of *solar projects*. *Solar reserves* consist of the anticipated useful energy for commercially operational, pre-operational and designed solar projects. *Solar resources* consist of anticipated useful energy for sites, under various levels of investigation, where solar energy could be utilised cost effectively. *Solar reserves and resources* can be estimated for an individual project, summed up from a portfolio of projects or estimated at the national level. See Section II. Solar Reserves and Resources Classification (above) for more information on the subcategories of solar reserves and resources. Section D (below) defines solar reserves and resources estimates. Subsequent sections define other important related concepts.

Figure 2

Solar irradiation in relation to the technical ability to use the energy, which in turn is broken down into reserves and resources, and the useful energy from various types of sites included in each of these categories.



D. Solar reserves and resources estimates[7]

25. At the project level, *solar reserves and resources estimates* are the quantities of *useful solar energy* expected to pass through a *reference point* over the remaining *project lifetime*. At the company level, *solar reserves and resources estimates* for each project may be added up to form total *solar reserves and resources estimates*. Similarly, *solar reserves and resources* may be compiled from solar project data for a geographic area and total *reserves and resources* summed for the area. However, there may be gaps in information, or some potential resources may not have been investigated as part of a solar project.

26. Instead of aggregating project resource quantities, estimates of useful solar energy at the national level can be estimated from solar irradiation (i.e. theoretical potential) using technical, economic and geographic filters in that order (Figure 2). Alternatively, solar irradiation can be filtered by geographic areas where solar energy could potentially be utilised under current ground and landcover conditions leaving the geographic potential, which in turn can be filtered by the fraction of energy that can be utilised using available technologies leaving the technical potential, which can be finally filtered in relation to cost effectiveness leaving the economic potential which is equivalent to national solar reserves and resources (Köberle et al 2015).

27. The differentiation of national solar reserves from national solar resources may involve use of aggregate project data on reserves. Alternatively, reserves can be estimated using installed capacity figures for solar at the national level, capacity factor(s) and a set period, for example the typical lifespan of a solar project or the lifespan of reserves against which solar reserves are being compared. For example, if solar reserves were being compared with national oil or gas reserves then the lifespan of oil or gas reserves should be used.

E. Confidence of solar reserves and resources estimates

28. Once *solar energy reserves and resources* have been estimated at either the project or national level, these estimates need to be assessed in terms of confidence. This includes identifying solar reserves and resources as P90, P50 and P10. Note: Typically, national reserves and resources estimates will have less confidence than many project based reserves and resources estimates where a greater level of investigation has usually been made.

F. Solar project, site(s) and technologies

29. A *solar project* consists of the site(s), technologies and activities over which decisions are made with the aim of getting energy from *solar irradiation*. A *solar site* is a location with access to *solar irradiation*. *Solar sites* have varying levels of access to *solar irradiation* depending on latitude, climate, topography and other characteristics. *Solar technologies* are the devices and practices that utilise energy from *solar irradiation*. *Solar technologies* only utilise a fraction of the energy contained in *solar irradiation*, and as such, the *useful solar energy* from a *project site* will always be less than the energy contained in *solar irradiation* at the *project site*.

30. The *project* is important as it includes issues of *entitlement*, risks and rewards. As such, an individual *project* may be of interest to businesses, governments and a range of other stakeholders including households and communities.

31. When a *project* includes *useful energy* from *solar irradiation* and other energy sources, only the *useful solar energy* will be classified as *solar reserves and resources*. The *useful energy* from other energy sources can be classified using other UNFC related specifications or classifications.

32. Note: there is no size limit to a project although it may not be practical to apply the Solar Specifications to an individual project at the household scale for example. However, a set of household projects might be grouped and assessed using the Solar Specifications and classified for comparison with other energy projects.

G. Socio-economic viability and project feasibility[8]

33. A *solar project* goes through a series of stages where the socio-economic viability and project feasibility is progressively determined through an iterative process of information gathering, design and assessments. Figure 3 presents a model for considering socio-economic viability and the feasibility of a *solar project.* The model draws upon "A Framework for Project Development in the Renewable Energy Sector" prepared by Springer (2013) for NREL. The framework was aligned with simplified UNFC categories from the UNFC (2009) to create the model in Figure 3. Not every *solar project* will follow this model, but most *solar projects* will have similar milestones, and as such it should be possible to classify using the model.

34. Prior to a *solar project* being initiated, the preconditions for a *solar project* need to be in place, and this includes having a regulatory regime that facilitates the utilisation of *solar radiation* as well as appropriate supporting infrastructure and market access for example. Otherwise potentially useful solar energy will be inaccessible.

35. A *solar project* starts with the identification of potentially accessible solar resources and the decision to investigate possible project site(s). *Pre-development* activities typically include a desktop feasibility study with broad assumptions around *solar irradiation*, the *solar technology's* ability to utilise *solar energy*, the ability the *solar project* to secure *entitlement* to the *site(s)* and *solar technologies*, the economics and financing of the project. From this, a project concept is created. This may also involve site visits and further data collection.

36. Project development involves greater investment of resources into designing the project and getting *entitlements*, such as permits, power purchasing agreements or access to sites, for the project. Project development also involves the assessment of site(s) as well as the validation and optimisation of models.

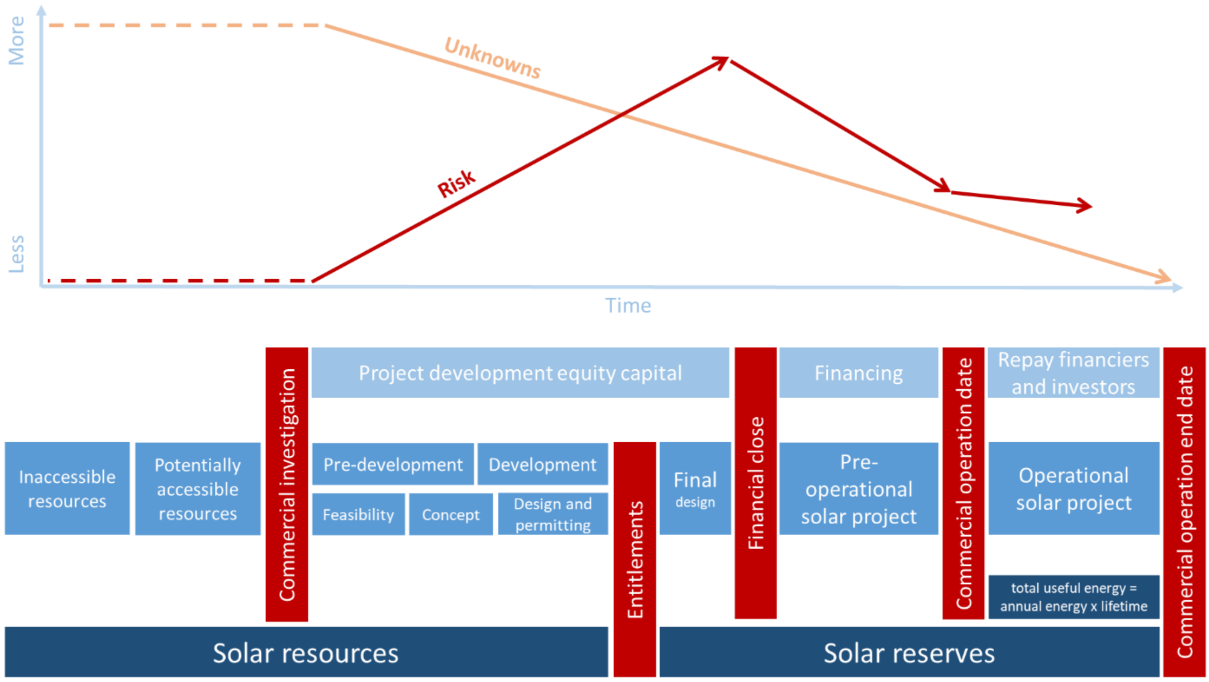
37. Once the design and *entitlements* have been developed, final project design is created upon which financing is sought. For more information on entitlements, see Section IV.C. Entitlement.

38. Pre-development and project development activities are typically undertaken for project development equity. This means the people leading the project are paying for pre-development and development stages of the project in exchange for equity (i.e. shares) in the project assuming it goes ahead.

[8] Technical Advisory Group has suggested revisions to this section. Issues related to entitlements and the definition of milestones, and the linkage to progression through resource categories, will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

Figure 3

Solar project cycle (blue) in relation to milestones (red), stages of project finance (light blue) and solar energy reserves and resources categories (dark blue) risks (red graph line) and unknowns (orange graph line).



39. If financing is arranged, and relevant agreements signed (i.e. at the financial close) then construction begins. Typically, a sales contract, such as a power purchase agreement, is needed for financial closing. Project risk is highest at this point due to the amount of money being invested and the number of things that can go wrong before the project starts operating. As construction progresses the number of unknowns decreases as does the risk of project failure.

40. At the commercial date of operation, the project begins actual operation, and *useful solar energy* is utilised. At this point, the project can start to pay back financiers and investors. The risks to the *project* continue to decline, however, because *solar projects* typically involve high upfront capital expenditures and low operational expenditures, there remains the risk that changes in regulations, or access to markets, could negatively affect the *project*.

41. The Solar Reserves and Resources Classification (Table 1) aligns with this solar project model along its vertical axis (see Section II. Solar Reserves and Resources Classification).

H. Reference point

42. A *reference point* is the location through which *useful energy* passes and the quantity of *useful energy* is measured or estimated. If a project has more than one type of useful energy (e.g. heat and electricity), then there may be more than one reference point, for example, one for each type of useful energy. In the case of electricity, whatever electricity passes through the reference point, regardless of whether it is AC or DC, is counted.

43. The *reference point* may either be the point of use in the case of direct use, the point of sale, or the point where custody is transferred from an intermediate stage of processing operations to 3rd parties which is a possibility in the case of heat. The custody transfer point will depend on the legal structure and contract terms of the project being evaluated. Note: Any energy losses after the reference point are ignored as the energy has already passed the reference point.

44. When the *reference point* is the point of sale, the reference point is located where energy ownership changes. This is usually the location where useful energy quantities are measured and paid for at agreed prices. This ensures consistency between quantities, prices and payments.

45. Estimates of the *useful energy* should be consistent with any conditions on the *solar project*. Conditions might include restrictions on market access, sales or the quality of *useful energy*. Note: The quality of *useful energy* can regard continuity of supply measured by the frequency and duration of interruptions; and voltage quality in terms of the magnitude or waveform deviation from ideal forms.

46. The location of *reference point(s)* should be disclosed with *solar reserves and resources estimates* including any changes from previously used reference points. Note: *Useful solar energy* that has been stored is included only if storage happens before the reference point.

I. Project lifetime[9]

47. The *project lifetime* is the remaining period of time that a project is expected to operate. For a pre-operational project, this is the period of time between the *commercial operation date* for the project (see Figure 3) and the end of the project. For an operational project the *project lifetime* is the remaining period of time between the *assessment date* and the *end of the project lifetime*. The *assessment date* is the date for which the assessment is made and may coincide with important reporting or accounting dates, for example, the end of the tax year. The *end of a project lifetime* is the date that a project is scheduled to cease operations. The *end of a project lifetime* can be based on the design life of a project, the remaining time before high-cost solar technologies need to be replaced, the warranty period for these technologies, or *project lifetimes* for other similar *solar projects*.

48. For some *solar reserves and resources estimates*, for example, national estimates, it may be appropriate to use a *set period*. In such situations, it is implicitly assumed that solar energy will continue to be utilised beyond the official project end date either due to project extension, investment in a new project at the same site or investment in a new project at another site.

49. A *set period* for a national level assessment may correspond with the *lifetime* of competing energy sources, for example, the *lifetime* of non-renewable energy reserves and resources, or alternatively an average *project lifetime*. The appropriate *set period* will depend on the type of analysis for which the *solar energy reserves and resources* are intended and the need to ensure balanced and comparable reserves and resources estimates.

50. In some cases, a *project lifetime* might become constrained by an *economic limit* which is a point in time when the anticipated cumulative net operating cash flows from the project are expected to be negative. The likelihood of this happening is low for many *solar*

[9] Technical Advisory Group has suggested revisions to this section. Issues will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

projects due to their low operating expenditures. However, this can happen when key contractual arrangements are modified or are about to expire and need to be renegotiated, or policies and regulations are changed. Important contractual arrangements include off-take agreements and leases related to *solar sites*; meanwhile institutional risks can affect access to markets, permissible contractual arrangements and prices paid for energy.

IV. Special Issues

A. Establishments, activities and national accounts

51. A *solar project* at a specific site will in many cases coincide with an *establishment*. This is important when it comes to national assessments of *solar energy reserves and resources* made using the System of Environmental and Economic Accounting (SEEA), which is a part of the System of National Accounts (SNA) because the establishment is the economic unit for which data is collected. This includes the utilisation of solar radiation, which goes from the environment into the economy (i.e. as natural resource flows and ecosystem inputs). According to the SNA, "An *establishment* is an enterprise or part of an enterprise that is situated in a single location and in which (a) only a single… …productive activity is carried out or (b) the principal productive activity accounts for most of the value added" (para 5.3 SNA 2008).

52. Establishments are classified using the International Standard Industrial Classification of All Economic Activities (ISIC) according to their *principle activity* (IRWS 2012). The *principal activity* of an establishment is the activity whose value added exceeds that of any other activity carried out within the same unit and whose output must be suitable for delivery outside the economic unit (para 5.8, SNA 2008).

53. ISIC (revision 4) includes the economic activities of "D. Electricity, gas, steam and air conditioning supply", which includes: "351. Electric power generation, transmission and distribution"; "352. Manufacture of gas; distribution of gaseous fuels through mains"; and, "353. Steam and air conditioning supply". In the case of utility-scale solar electricity generation, this would be classified under "351. Electric power generation, transmission and distribution". Note: Many industrial classifications used at the national level will have "electricity generation" as a separate category.

54. Where the utilisation of *useful solar energy* either for steam, air conditioning or electricity generation, is not the *principle activity* of an establishment, then it can be recorded as either a *secondary activity* or *ancillary activity*. A *secondary activity* is an activity carried out within a single economic unit in addition to the principal activity and whose output must be suitable for delivery outside the economic unit (para 5.9, SNA 2008).

55. The SNA also includes activities[10] that are incidental to the main activity of the economic unit. It facilitates the efficient running of an enterprise but does not normally result in goods and services that can be marketed (para 5.10, SNA 2008), meaning the useful solar energy is used within the enterprise.

56. For more information on statistical units related to energy, see Chapter 6 Statistical Units and Data Items from the International Recommendations for Energy Statistics (IRES 2016).

[10] The SNA calls these *ancillary activities*, not to be confused with *ancillary services*.

B. Business risk

57. There are a growing range of technologies, applications and business models for utilising useful solar energy. These include: utility-scale solar PV electricity supplying the grid; utility-scale concentrating solar power electricity generation for the grid; solar electricity generation for an independent micro-grid, solar electricity generation for own use; household solar PV electricity generation with a feed-in tariff; household solar water heating, solar space heating, community and shared solar; and more. When taking into account the financing, power purchase agreements and other arrangements, these business models and their risks quickly multiply in combination and number.

58. Irrespective of the business or contractual model used, the *project* should be able to demonstrate that it has considered: possible risks impacting the socio-economic viability and project feasibility; possible technical risks to the project; and, *entitlement* to benefit from utilising the useful solar energy. Annex 4 provides a list of indicative technical risks related to solar energy projects.

59. Important business risks to consider include technical risks and commercial risks. Technical risks can impact the levelised cost of electricity (LCOE) and the financial models. These technical gaps can take place across all project phases and impact the Capital Expenditure (CAPEX), Operation Expenditure (OPEX) and overall energy yield estimation. Yield estimation can be affected by lower than expected energy conversion levels or higher plant downtime and cost of repairs during operations. Commercialisation and price risks are associated with the regulatory compliance, marketing, and sales of useful solar energy.

C. Entitlement

60. *Entitlement* is defined as the quantity of *useful energy* that is legally and practically accessible to a *project*. A project's *entitlement* to *useful solar energy* may be limited by regulatory, contractual or other conditions. Business continuity provisions should also be considered as well as legal considerations related to solar project agreements. Issues of *entitlement* may mean that only a fraction of the technically possible *useful solar energy* may actually be utilised. Conversely, a project should be able to demonstrate that it has sufficient *entitlements* to deliver on its power purchase agreements or contracts for the provision of ancillary services. Note, it is important to account for a project's useful capacity and for useful ancillary services, such as voltage regulation and frequency control and short circuit capacity. Each of these things have a monetary value affecting the viability of projects. However, these things may need to be recorded in supplementary text, or tables, supporting the reporting of solar reserves and resources.

61. The duration of *entitlements* will affect the *lifetime* of the *solar project* and classification of *solar energy reserves and resources*. Regardless of whether a solar project is directly using *useful solar energy* or selling it, the *project* should be able to demonstrate *entitlement* to access *site(s)* and the *solar radiation* at the *site(s)*. There should also be consideration of the risks and uncertainties related to the project including natural hazards.

62. Legal agreements vary, but key terms and conditions to consider when classifying *solar reserves and resources* for *solar projects* that sell energy to other parties include: pricing; delivery incentives; penalties; energy quality and quantity conditions including allowance for variations; and, stipulations concerning the termination, extension and renewal of an agreement. Requirements necessary to secure financing for a project may also have a bearing on the socio-economic viability and project feasibility.

63. The price and margin risk should be considered when classifying solar reserves and resources. *Solar projects* with power purchase agreements and installed capacity typically

have higher *entitlement* and as such higher socio-economic viability and project feasibility. The *useful solar energy* from *solar projects* without power purchase agreements should be classified based on assumptions consistent with current market conditions and expectations around prices and contracts. A solar project, which has track record of lower than expected capacity factors, cost overruns, or receiving low energy prices for useful solar energy sold to other parties, will need to ensure that these risks are appropriately considered when classifying useful solar energy estimates.

64. *Solar reserves and resources* assessments of possible *project* extensions or new *projects* at existing *solar sites*, should consider how likely it is that *entitlements* will be extended. For many *solar sites*, with justification, it can be assumed that permits, land-lease agreements, and off-take agreements will be extended. Assessments should take into account the previous track record and capacity of those undertaking the solar project.

D. Variable production

65. Solar projects typically have variable energy flows through reference point(s). This variability can be due to a multitude of factors and occur over a range of timespans or frequencies. For example, daily variation in solar fluxes result in no production overnight in the case of solar PV, or alternatively, there may be seasonal variation, and in given years, weather patterns such as El Niño and La Niña affect cloud cover and useful solar energy quantities.

66. Useful solar energy estimates are generally based on historic climate data, including any available data from the solar site(s), coupled data on solar technologies and their ability to utilise solar irradiation. Variability should be reflected in estimated quantities of useful solar energy along with the confidence of these estimates (plotted on the horizontal axis of the Solar Reserves and Resources Classification).

67. If there is a reasonable expectation that a proportion of the useful solar energy will not be sold, sold at a zero or negative prices then useful solar energy estimates for each price bracket should be quantified and recorded accordingly in the Solar Reserves and Resources Classification (e.g. Table 2). However, these things may not be known in advance and might vary over the life of the plant due to conditions beyond the control of the project.

68. In most cases, force majeure event or unforeseen operational issues are not considered when making useful solar energy estimates. However, if such an event does occur and impacts useful solar energy quantities for more than a year, then the project classification should be reviewed based on revised expectations. For example, a resource report can be prepared which assesses the likelihood of utilising previously anticipated useful solar energy quantities.

E. Projects with multiple energy types

69. Some *solar projects* may involve two or more types of *useful energy* (e.g. heat and electricity) or other valuable services (e.g. capacity and/or ancillary services). In such circumstances, estimated quantities of *useful energy* should be reported separately. Where *useful energy* estimates have been aggregated for reporting purposes, accompanying footnotes should describe which types of *useful solar energy* have been aggregated. Ideally, a breakdown of *useful solar energy* estimates would also be provided. The provision of ancillary service might also require special consideration and reporting.

70. When a *project* requires significant direct use (e.g. electrical energy to drive pumps in thermal solar projects), these quantities should be estimated and separately reported. This

is "own use and internal power plant losses" that are recorded in electricity statistics as the difference between gross and net generation. Note: useful solar energy that is consumed before the *reference point* may be reported as UNFC category E.3.1 which covers quantities that are forecast to be utilised but which will not be available for sale. For example, this could be recorded as a footnote in the Solar Reserves and Resources Table. See the Table 4, on page 25, for more information on UNFC category E.3.1.

F. Curtailment

71. NREL defines curtailment "as a reduction in the output of a generator from what it could otherwise produce given available resources (e.g., wind or sunlight), typically on an involuntary basis." (page 1, Bird et al. 2014). Curtailed useful solar energy estimates should be recorded in the Solar Reserves and Resources Classification Table along with the useful solar energy that was actually utilised or sold.

72. As curtailment becomes of greater concern to energy producers, contract terms are evolving to include provisions addressing the use of curtailment hours including the sharing of risk between the project and useful energy off-taker. Some studies have shown that curtailed solar resources can provide ancillary services to aid in system operations, e.g. providing both up and down regulation reserves for the balancing area.

V. Managing and Comparing Solar and Other Energy Sources

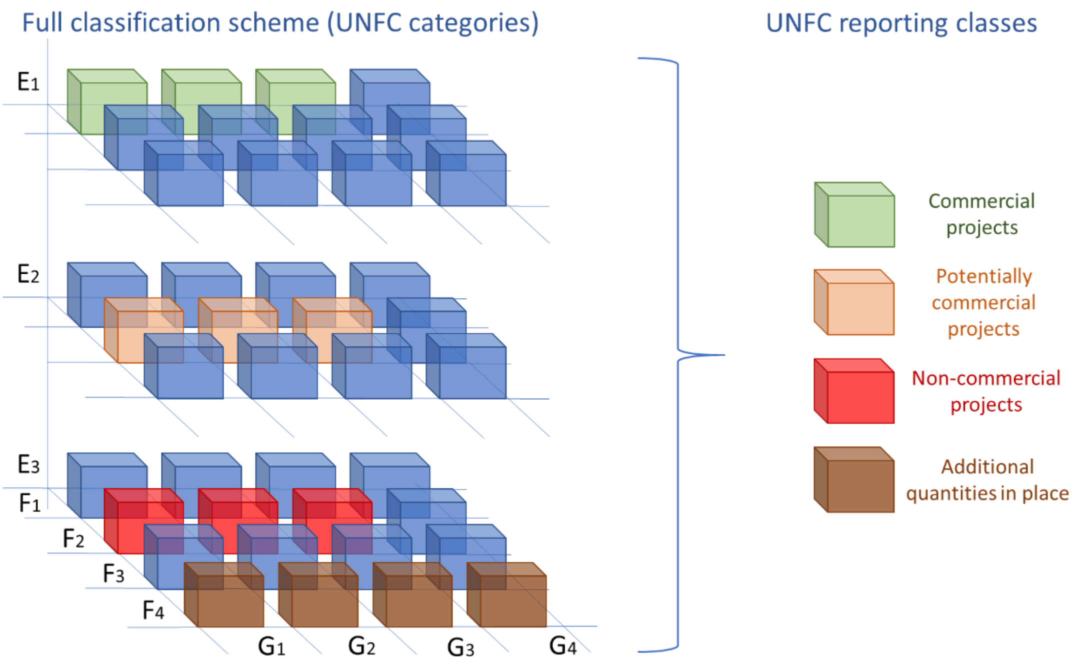
A. The UNFC

73. The UNFC has been designed to help classify resources, and support resources management, corporate business processes and financial reporting (UNFC 2009). However, the UNFC was originally developed to "…enable the incorporation of national and regional classification systems into a consistent, unified framework in order to make them compatible and comparable; help to enhance communication on a national and international level; provide for a better understanding and firmer knowledge of available reserves/resources…" (page 2, UN 1997). As such the UNFC has a greater level of detail than most energy or mineral reporting schemes, making it possible to map each classification scheme into the UNFC and then compare figures. To achieve this, the UNFC has 3 axes, consisting of the E, F and G axes. The E axis regards the socio-economic viability of the project. The F axis regards the project feasibility. The G axis regards the knowledge around the quantity of reserves or resources that are anticipated to be utilised or extracted. As such, the 3 axes of the UNFC from a 3-dimensional matrix (Figure 4).

74. To facilitate the comparison of solar energy reserves and resources with other energy sources, the following sections set out the UNFC E, F and G-axis categories and subcategories with definitions alongside comparable solar definitions for each category and subcategory. Note: The UNFC has a set of reporting classes (illustrated using different colours in Figure 4) and a table for reporting these. As the UNFC reporting classes are currently under review, they are not addressed in this document. For more information on the UNFC reporting see the UNFC webpage[11] on the ECE website.

[11] ECE UNFC webpage: https://www.unece.org/energywelcome/unfc-and-resource-classification.html

Figure 4
UNFC classification categories and UNFC classes for reporting.



B. E Axis[12]

75. According to the UNFC, "The first set of categories (the E axis) designates the degree of favourability of social and economic conditions in establishing the commercial viability of the project, including consideration of market prices and relevant legal, regulatory, environmental and contractual conditions." (page 4, UNFC 2009).

[12] Technical Advisory Group has suggested revisions to this section. Issues will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

Table 3

UNFC E-axis categories, definitions and explanations alongside comparable solar definitions and explanations.

UNFC Categories	*UNFC definition[a]*	*UNFC explanation[b]*	*Solar definition*	*Solar explanation*
E1	Extraction and sale has been confirmed to be economically viable. [c]	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe. Economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.	Useful solar energy has been confirmed to be economically viable.	Utilisation of useful solar energy is economic on the basis of current market conditions and realistic assumptions of future market conditions. All necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable time frame. Economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.
E.2	Extraction and sale is expected to become economically viable in the foreseeable future.[c]	Extraction and sale has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic extraction and sale in the foreseeable future.	Useful solar energy is expected to become economically viable in the foreseeable future.	Useful solar energy has not yet been confirmed to be economic but, on the basis of realistic assumptions of future market conditions, there are reasonable prospects for economic utilisation in the foreseeable future.
E3	Extraction and sale is not expected to become economically viable in the foreseeable future or evaluation is at too early a stage to determine economic viability.[c]	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future; or, economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration phase). Also included are quantities that are forecast to be extracted, but which will not be available for sale.	Potentially useful solar energy is not expected to become economically viable in the foreseeable future or at too early a stage to determine economic viability.	On the basis of realistic assumptions of future market conditions, it is currently considered that there are no reasonable prospects for economic utilisation of useful solar energy from the site, or set of sites, in the foreseeable future; or, economic viability of utilisation cannot yet be determined due to insufficient information (e.g. during the assessment phase). Also included are quantities of useful solar energy that are forecast to be used on-site in solar projects that sell energy to other parties.

[a] *The term "extraction" is equivalent to "production" when applied to petroleum.*

[b] *The term "deposit" is equivalent to "accumulation" or "pool" when applied to petroleum.*

[c] *The phrase "economically viable" encompasses economic (in the narrow sense) plus other relevant "market conditions", and includes consideration of prices, costs, legal/fiscal framework, environmental, social and all other non-technical factors that could directly impact the viability of a development project.*

76. Table 3 presents the E-axis categories E1 to E3 including UNFC definitions and explanations. Alongside are comparable solar definitions and explanations. Solar definitions and explanations are based on UNFC definitions and explanations but using solar terms presented earlier in the solar specifications. Similarly, Table 4 presents the UNFC E-axis subcategories E.1.1 through to E.3.3 including UNFC definitions alongside the comparable solar definition.

Table 4

UNFC E-axis subcategories and definitions alongside comparable solar definitions.

UNFC categories	*UNFC sub-categories*	*UNFC definition*	*Solar definition*
E1	E1.1	Extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions.	The utilisation of useful solar energy is economic on the basis of current market conditions and realistic assumptions of future market conditions.
	E1.2	Extraction and sale is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.	The utilisation of useful solar energy is not economic on the basis of current market conditions and realistic assumptions of future market conditions, but is made viable through government subsidies and/or other considerations.
NA	NA	No subcategories defined	No subcategories defined
E3	E3.1	Quantities that are forecast to be extracted, but which will not be available for sale.	Useful solar energy quantities that are forecast to be utilised but not available for sale from projects that sell useful energy to other parties.
	E3.2	Economic viability of extraction cannot yet be determined due to insufficient information (e.g. during the exploration E3 phase).	Economic viability of potentially useful solar energy cannot yet be determined due to insufficient information.
	E3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the foreseeable future.	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic utilisation of potentially useful solar energy in the foreseeable future.

C. F Axis[13]

77. According to the UNFC, "(the F axis) designates the maturity of studies and commitments necessary to implement… projects. These extend from early exploration efforts… through to a project that is extracting and selling a commodity..." (page 4, UNFC 2010).

78. Table 5 presents the F-axis categories F1 to F4 including UNFC definitions and explanations. Alongside these are comparable solar definitions and explanations. The solar definitions and explanations use solar terms presented earlier in the solar specifications. Following the same logic, Table 6 presents the UNFC E-axis subcategories F.1.1 through to F.4.3 including UNFC definitions alongside comparable solar definitions. Essentially the F-axis categories can be described as: F1 – is feasible; F2 – might be feasible; F3 – can't tell; and F4 – who knows.

[13] Technical Advisory Group has suggested revisions to this section. Issues will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

Table 5

UNFC F-axis subcategories, definitions and explanations alongside comparable solar definitions and explanations.

UNFC Category	*UNFC definition*	*UNFC explanation*	*Solar definition*	*Solar explanation*
F1	Feasibility of extraction by a defined development project or mining operation has been confirmed.	Extraction is currently taking place; or, implementation of the development project or mining operation is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.	Feasibility of solar energy utilisation by a defined solar project has been confirmed.	Utilisation of useful solar energy is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of utilisation by a defined solar project.
F.2	Feasibility of extraction by a defined development project or mining operation is subject to further evaluation.	Preliminary studies demonstrate the existence of a deposit in such form, quality and quantity that the feasibility of extraction by a defined (at least in broad terms) development project or mining operation can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of extraction.	Feasibility of utilising useful solar energy by a defined solar project is subject to further evaluation.	Preliminary studies demonstrate the existence of useful solar energy such that the feasibility of utilisation by a defined (at least in broad terms) solar project can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of utilisation.
F3	Feasibility of extraction by a defined development project or mining operation cannot be evaluated due to limited technical data.	Very preliminary studies (e.g. during the exploration phase), which may be based on a defined (at least in conceptual terms) development project or mining operation, indicate the need for further data acquisition in order to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.	Feasibility of utilising useful solar energy by a defined solar project cannot be evaluated due to limited technical data.	Very preliminary studies on a solar site indicate the need for further data acquisition in order to confirm useful solar energy at the site could be utilised using available technologies.
F4	No development project or mining operation has been identified.	In situ (in-place) quantities that will not be extracted by any currently defined development project or mining operation.	No solar project has been identified	Useful solar energy will not be utilised by any currently defined solar project or technology.

Table 6
UNFC F-axis subcategories and definitions alongside comparable solar definitions.

UNFC categories	*UNFC sub-categories*	*UNFC definition*	*Solar definition*
F1	F1.1	Extraction is currently taking place.	Utilisation of useful solar energy is currently taking place.
	F.1.2	Capital funds have been committed and implementation of the development project or mining operation is underway.	Capital funds have been committed and construction of the solar project is underway.
	F1.3	Sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a defined development project or mining operation.	Sufficiently detailed studies have been completed to demonstrate the feasibility of utilising the useful solar energy by implementing a defined solar project.
F2	F2.1	Project activities are ongoing to justify development in the foreseeable future.	Project activities are ongoing to justify development in the foreseeable future.
	F2.2	Project activities are on hold and/or where justification as a commercial development may be subject to significant delay.	Project activities are on hold or where justification as a commercial development may be subject to significant delay.
	F2.3	There are no current plans to develop or to acquire additional data at the time due to limited potential.	There are no current plans to develop or to acquire additional data at the time due to limited potential.
F3	F3.1	Where site-specific geological studies and exploration activities have identified the potential for an individual deposit with sufficient confidence to warrant drilling or testing that is designed to confirm the existence of that deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.	Where desktop studies have identified the potential for useful solar energy with sufficient confidence to warrant investigating the feasibility of a solar project.
	F3.2	Where local geological studies and exploration activities indicate the potential for one or more deposits in a specific part of a geological province, but requires more data acquisition and/or evaluation in order to have sufficient confidence to warrant drilling or testing that is designed to confirm the existence of a deposit in such form, quality and quantity that the feasibility of extraction can be evaluated.	Where desktop studies indicate the potential for useful solar energy at a site, or set of sites, but requires more desktop research in order to have sufficient confidence to warrant investigating a solar project.
	F3.3	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic extraction and sale in the Foreseeable Future.	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for a solar project at the site, or set of sites, in the foreseeable future.
F4	F4.1	The technology necessary to recover some or all of these quantities is currently under active development, following successful pilot studies on other deposits, but has yet to be demonstrated to be technically feasible for the style and nature of deposit in which that commodity or product type is located.	The technology necessary to utilise the potentially useful solar energy is currently under active development, with successful pilot studies at some sites, but has yet to be demonstrated as feasible over long periods or at sites with different conditions.
	F4.2	The technology necessary to recover some or all of these quantities is currently being researched, but no successful pilot studies have yet been completed.	The technology necessary to utilise potentially useful solar energy is currently being researched, but no successful pilot studies have yet been completed.
	F4.3	The technology necessary to recover some or all of these quantities is not currently under research or development.	The technology necessary to utilise potentially useful solar energy under conditions found at the site is not currently under research or development.

D. G Axis[14]

79. According to the UNFC, "(the G axis) designates the level of confidence in the geological knowledge and potential recoverability of the quantities." (page 4, UNFC 2009). Table 7 presents the UNFC F-axis categories G1 to G4 including UNFC definitions alongside comparable solar definitions that use terms presented earlier in the solar specifications to make them applicable to solar. The G axis does not have any sub-categories.

80. G1 is the highest degree of confidence for useful energy estimates. For petroleum "If probabilistic methods are used, there should be at least a 90% probability that the quantities actually recovered will equal or exceed the estimate." (Page 28, PRMS 2007). For solar projects, in many cases site visits and data collection will be required to reach this confidence. However, given the availability of satellite based meteorological data for the last 30 years coupled with ground based meteorological data, many solar sites have *useful solar energy* quantities that can be estimated with this confidence. Such data are often used as a basis for household solar systems. For minerals, G1 is often applied qualitatively based on criteria related to the level of exploration undertaken.

81. G2 is the second highest degree of confidence for useful energy estimates. For petroleum "…when probabilistic methods are used, there should be at least a 50% probability that the actual quantities recovered will equal or exceed the… …estimate." (Page 28, PRMS 2007). With satellite based meteorological data for the last 30 years and ground based meteorological data, most solar sites around the planet have useful solar energy estimates with this confidence. For minerals G2 is often applied qualitatively.

82. G3 is the second lowest level of confidence for energy and mineral estimates under the UNFC, but for solar projects, it is the lowest level of confidence. For petroleum "When probabilistic methods are used, there should be at least a 10% probability that the actual quantities recovered will equal or exceed the… …estimate." (Page 29, PRMS 2007). The availability of satellite-based and ground-based meteorological data means all solar sites around the planet can have *useful solar energy* quantities estimated with this as a minimum confidence. For minerals, G3 is usually applied qualitatively.

Table 7
UNFC G-axis definitions alongside comparable solar definitions.

Category	*UNFC definition*	*Solar definition*
G1	Quantities associated with a known deposit that can be estimated with a high level of confidence	Quantities of useful solar energy associated with a project that can be estimated with a high level of confidence (e.g. P90).
G2	Quantities associated with a known deposit that can be estimated with a moderate level of confidence.	Quantities of useful solar energy associated with a project that can be estimated with a moderate level of confidence (e.g. P50).
G3	Quantities associated with a known deposit that can be estimated with a low level of confidence.	Quantities of useful solar energy associated with a project that can be estimated with a low level of confidence (e.g. P10).
G4	Estimated quantities associated with a potential deposit, based primarily on indirect evidence.	Estimated quantities of useful solar energy associated with a site, or set of sites, based primarily on indirect evidence.

E. UNFC and solar classification categories

83. Table 8 presents the Solar Reserves and Resources Classification and the corresponding UNFC categories in brackets. For example, operational solar reserves with a useful energy confidence of greater than P90 have to have the characteristics described by the UNFC categories E.1, F.1.1 and G.1. The UNFC categories are put in brackets to

[14] Technical Advisory Group has suggested revisions to this section. Issues will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

signify that only projects with this combination of characteristics can be included. For some cells in Table 8, there are more than one set of combinations in brackets meaning that projects with any of these combinations of characteristics can be included.

Table 8

Solar Reserves and Resources Classification Table showing the location of comparable UNFC categories and *subcategories*[15].

Solar energy categories and sub-categories		*Confidence of useful energy estimate*		
		P90	*P50*	*P10*
- - Commercial operation end date - -				
Reserves	Operational	(E.1, F.1.1, G.1)	(E.1, F.1.1, G.1) +(E.1, F.1.1, G.2)	(E.1, F.1.1, G.1) +(E.1, F.1.1, G.2) +(E.1, F.1.1, G.3)
	- - Commercial operation date - -			
	Pre-operational	(E.1, F.1.2, G.1)	(E.1, F.1.2, G.1) +(E.1, F.1.2, G.2)	(E.1, F.1.2, G.1) +(E.1, F.1.2, G.2) +(E.1, F.1.2, G.3)
	- - Financial close - -			
	Designed	(E.1, F1.3, G1)	(E.1, F1.3, G1) +(E.1, F1.3, G2)	(E.1, F1.3, G1) +(E.1, F1.3, G2) +(E.1, F1.3, G3)
- - Entitlements - -				
Resources	Under development	(E.1, F2.1, G1)	(E.1, F2.1, G1) +(E.1, F2.1, G2)	(E.1, F2.1, G1) +(E.1, F2.1, G2) +(E.1, F2.1, G3)
	Pre-development	(E.2, F.2.1, G.1)	(E.2, F.2.1, G.1) +(E.2, F.2.1, G.2)	(E.2, F.2.1, G.3)
	- - Decision to investigate - -			
	Potentially accessible	(E.2, F.2.2, G.1) +(E.2, F.2.3, G.1) +(E.2, F.3, G.1)	(E.2, F.2.2, G.1) +(E.2, F.2.3, G.1) +(E.2, F.3, G.1) +(E.2, F.2.2, G.2) +(E.2, F.2.3, G.2) +(E.2, F.3, G.2)	(E.2, F.2.2, G.1) +(E.2, F.2.3, G.1) +(E.2, F.3, G.1) +(E.2, F.2.2, G.2) +(E.2, F.2.3, G.2) +(E.2, F.3, G.2) +(E.2, F.2.2, G.3) +(E.2, F.2.3, G.3) +(E.2, F.3, G.3)
	Inaccessible	(E.3.2, F.4, G.1) +(E.3.3, F.4, G.1)	(E.3.2, F.4, G.1) +(E.3.3, F.4, G.1) +(E.3.2, F.4, G.2) +(E.3.3, F.4, G.2)	(E.3.2, F.4, G.1) +(E.3.3, F.4, G.1) +(E.3.2, F.4, G.2) +(E.3.3, F.4, G.2) +(E.3.2, F.4, G.3) +(E.3.3, F.4, G.3)
Technically and cost effectively possible to use - -				

Footnotes

*Assessment period (years): e.g. project lifetime of the set period for a national assessment

[15] Expert Group reviewers should compare categories and subcategories in **Error! Reference source not found.** (above) with the categories and subcategories from Figure 3 in the UNFC (2009). The Technical Advisory Group has suggested revisions to this section. Issues will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

84. The Solar Reserves and Resources Classification, along its horizontal axis, aligns with the G axis of the UNFC but only from G1 to G3. Like petroleum classifications, the Solar Reserves and Resources Classification uses the probability of energy being realised to gauge confidence of energy estimates. As such, the confidence of useful energy is divided into three levels of confidence consisting of greater than P90 aligning with G.1, P50 aligning with G.1+G.2, and P10 aligning with G.1+G.2+G.3. In practice it would be rare for a solar site to have a confidence of less than P50 unless there was a new technology being tested.

85. Solar reserves that are operational, pre-operational and designed as well as solar resources under development all align with E1, but with differing F-axis categories. E1 means useful solar energy has been confirmed to be economically viable including securing relevant entitlements.

86. *Solar reserves* that are operational are aligned with F.1.1, meanwhile *solar reserves* that are pre-operational are aligned with F.1.2. F.1.1 means utilisation of *useful solar energy* is currently taking place. F.1.2 means capital funds have been committed and construction of the *solar project* is underway. Reserves that have a designed project are aligned with F.1.3. meaning sufficiently detailed studies have been undertaken to demonstrate the feasibility of utilising the useful solar energy.

87. *Solar resources* that are under development are aligned with E.1 and F.2.1 meaning the utilisation of the useful solar energy is economic based on realistic assumptions and project activities are ongoing to justify development in the foreseeable future. *Solar resources* that are at the pre-development stage are aligned with E.2 and F.2.1 meaning the utilisation of the *useful energy* has not been confirmed to be economic but there is a realistic expectation of cost-effective utilisation in the future, meanwhile *project* activities are ongoing to justify development in the foreseeable future.

88. Potentially accessible *solar energy resources* are aligned with E.2 as well as F.2.2, F.2.3 and F.3. E.2 means *useful solar energy* is expected to become economically viable in the foreseeable future. F.2.2 means there are *project* activities are on hold or there is expected to be a significant delay. F.2.3 means there are no plans to develop a *project* or acquire data to investigate a *project*. F.3. means the feasibility of a *project* can't be assessed due to a lack of data.

89. Inaccessible *solar energy resources* are aligned with F.4. as well as E.3.2 and E.3.3. F.4 means no solar project has been identified. E.3.2 means the economic viability of potentially *useful solar energy* cannot yet be determined due to insufficient information. E.3.3 means that on the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic utilisation of potentially *useful solar energy* in the foreseeable future. Some projects in F.1, F.2 or F.3 categories could be reclassified in the inaccessible solar energy resource category if, for example, regulations were changed and made *projects* untenable

VI. Applying the Solar Specifications

A. Evaluators – competent persons[16]

90. *Evaluators* are the people that estimate the quantity of *useful solar energy* from a project and classify this in relation to the Solar Reserves and Resources Classification or

[16] Technical Advisory Group has suggested revisions to this section. Issues such as clarifying the distinction between evaluators and competent persons will be considered along with other suggestions that may come from the 9th session of the Expert Group on Resource Classification.

some other set of criteria. *Evaluators* should have an appropriate level of expertise and relevant experience in the estimation of *useful solar energy* quantities, and as such, should be a competent person. According to the UNFC, a competent person "is one who has the ability to put skills, knowledge and experience into practice in order to perform activities or a job in an effective and efficient manner for resource classification, management and reporting." (para 7, ECE 2017b). For guidance on competent persons see the ECE website on competent persons including information on evaluators, qualifications and requirements (ECE 2017c)[17].

B. Classifying projects

91. The classification of resources is one step within a wider information cycle (Figure 5). Steps leading up to the classification of solar reserves and resources consist of: 1. Collecting data on projects or possible project sites; and, 2. Calculating the useful solar energy from each project or possible project site should take into account expectations around energy prices, costs, and the ongoing economics of solar *projects*.

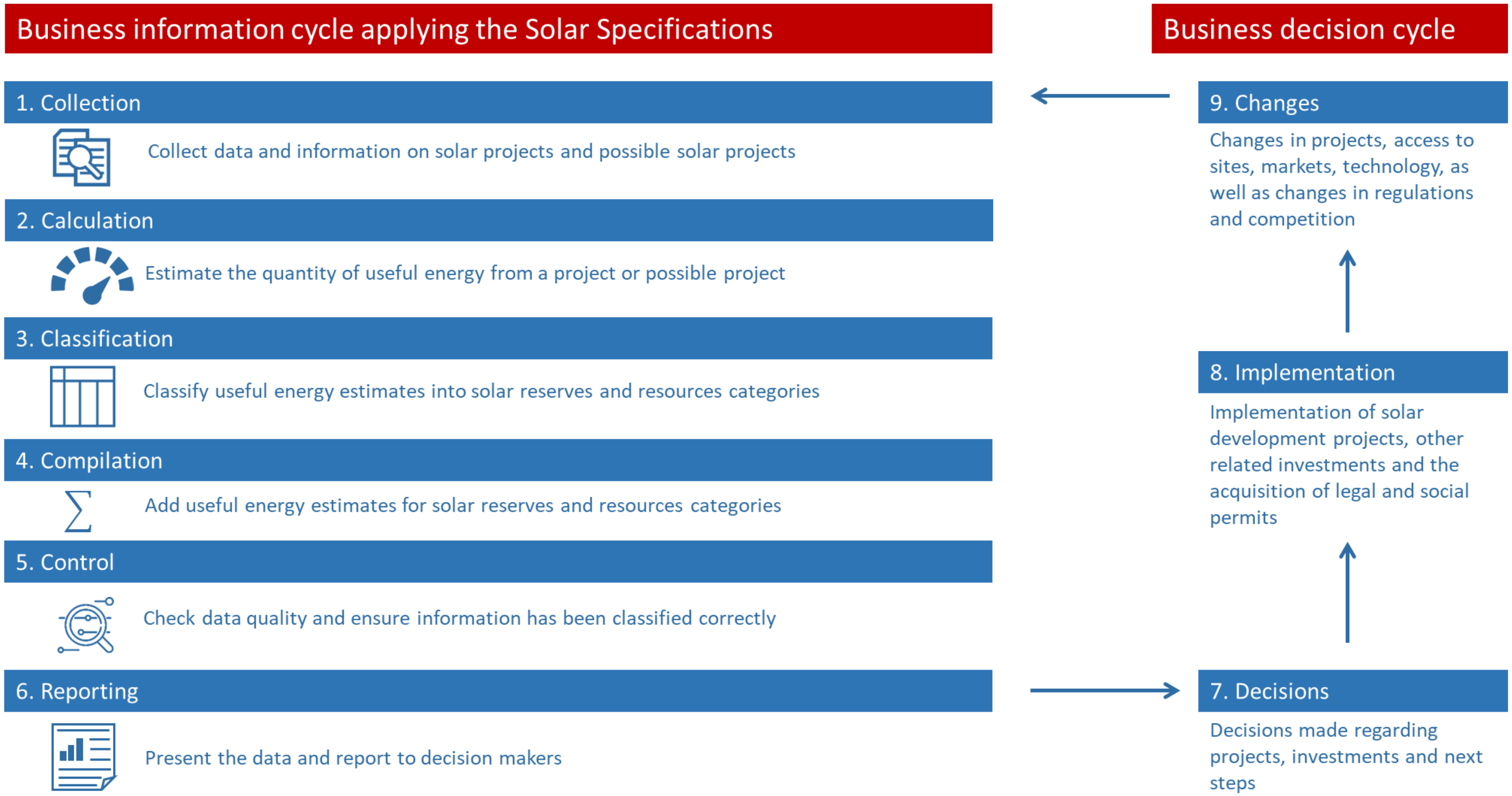
92. Step 3 is the actual classification of solar energy reserves and resources. This involves reviewing the data collected on projects, and possible projects, and then determining which category a project or potential project belongs in, based on the definitions provide in this document.

93. After classifying projects, there are a series of other steps consisting of: 4. Compiling useful energy estimates in the same Solar Reserves and Resources Classification categories and calculating totals for each category (e.g. total reserves and total resources); 5. Controlling for data quality e.g. checking calculations and the classification of projects; 6. Reporting of information to decision makers typically in reports, but also through business information systems and governmental surveys.

94. Data classified using the Solar Reserves and Resources Classification can serve as an input to decisions either by business leaders, government agencies or others, on issues of whether to progress projects or make new investments. The implementation of these decisions then leads to changes which are captured in updated Solar Reserves and Resources Classification exercises e.g. as projects go from concept to construction, resources are reclassified as reserves.

[17] Competent persons, see the ECE website: http://www.unece.org/energywelcome/areas-of-work/httpswwwuneceorgenergysereserveshtml/applications/unfc-and-competent-persons.html

Figure 5
The process for identifying estimating, classifying and reporting solar energy project reserves and resources using the UNFC.



C. National estimates

95. In addition to corporations and investors, the Solar Reserves and Resources Classification can also be used by governments and institutions to assess or monitor solar energy potentials and projects. Government agencies may have an interest in solar energy reserves and resources within the territories over which they have jurisdiction. This might include an interest in understanding: solar energy reserves and resources being utilised; solar energy reserves and resources at various stages of development or are expected to be commercially viable in the foreseeable future; and, solar energy resources currently inaccessible including the reasons why these resources are currently inaccessible. Furthermore, the Solar Reserves and Resources Classifications creates the opportunity for governments to compare useful solar energy estimates with energy reserves and resource from other sources.

96. Importantly the International Recommendations for Energy Statistics note that energy reserves and resources classified using the UNFC are within the scope of energy statistics (IRES 2016). In principle, solar reserves and resources should be included in environmental, economic accounts and a national system of energy statistics.

97. The government information cycle is similar to the business information cycle (Figure 6). Key differences include data collection methods and sources, compilation methods and gap filling, as well as the types of decisions the information is used for.

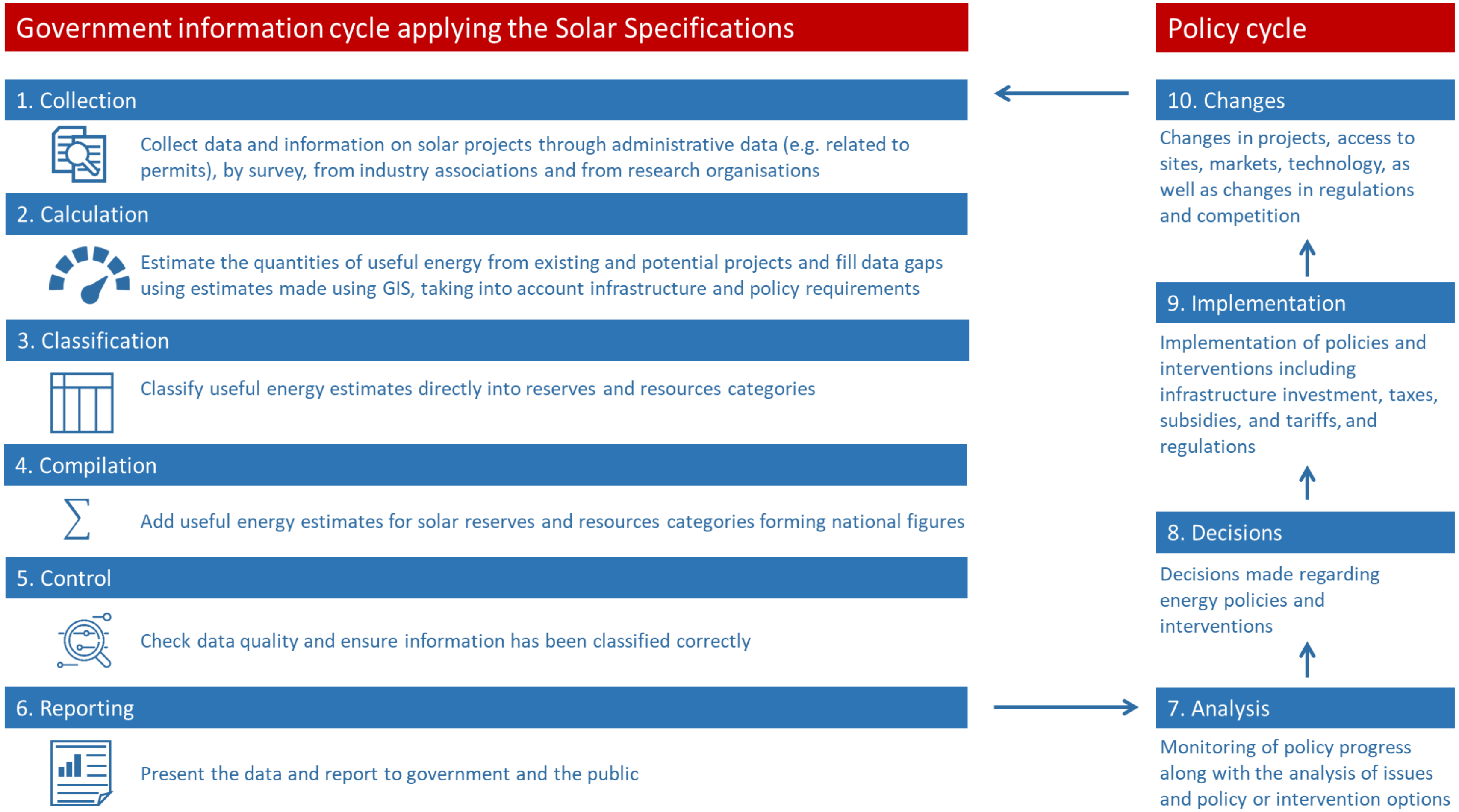
98. Data collection by government can include project data from its own investments, as well as project data collected from administrative sources (e.g. data collected as part of permitting processes), surveys of projects, industry associations representing solar projects as well as research organisations including universities. To get a complete picture of solar energy reserves and resources, during the calculation stage governments will usually fill gaps in data on solar resources through an analysis of theoretical, geographic, technical and economic potentials using Geographic Information Systems (GIS) and related models. These models taking into account infrastructure, energy demand, technologies, and regulations (see Section III.D. Solar reserves and resources estimates).

99. After data checking and quality control, national solar energy reserve and resources estimates are published and shared with government decision makers and the public including business, civil society and researches. In many instances there will be additional analysis of solar energy reserves and resources, for example to assess progress against policy targets and objectives, to understand issues or create policy options for consideration by government leaders. Governments might also use the Solar Reserves and Resources Classification to monitor their own solar energy projects.

100. Government decisions generally regard policies including legislation, regulations, taxes and subsidies, as well as projects and energy related investments. These decisions not only direct government interventions, but also influence business enterprises, establishments and their economic activities including solar energy projects. As such, government decision can spur many changes and these are in turn monitored through successive rounds of data collection.

Figure 6

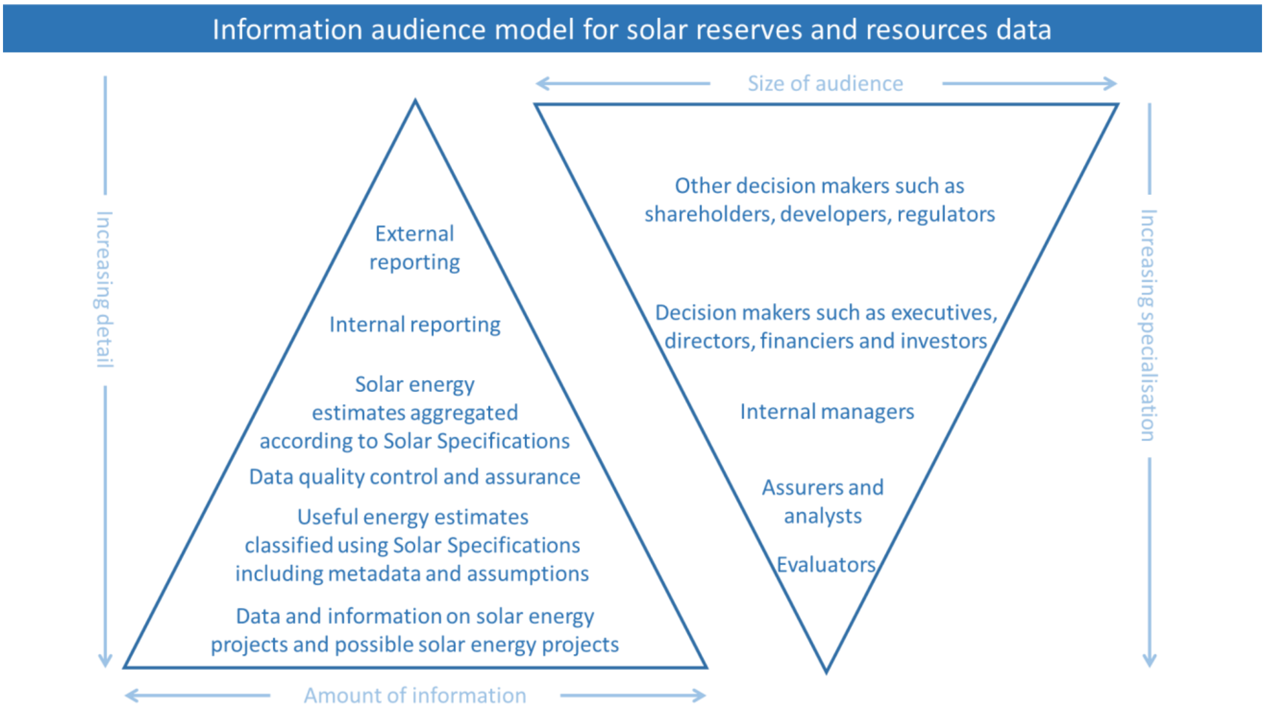
Process of organising solar energy reserves and resources data for input to government energy analysis and decision making



D. Solar information users

101. Figure 7 illustrates the information-audience model for solar reserves and resources data. This includes an information pyramid with detailed information on *solar projects* and possible project *sites* (e.g. in GIS or a database) at the base. Information is successively aggregated, or estimated, forming summary information toward the top of the pyramid. For each layer of information there are different users. For the most detailed information, users consist of a few *evaluators* that estimate the useful solar energy and classify these estimates. Above the evaluator are analysts who review the work and use it to support business analyses. Externally reported information will typically have the largest and widest audience including investors, developers, regulators and others. In between there are managers, executives and directors for example, who receive and use internally reported resource data and analyses to support their decision-making.

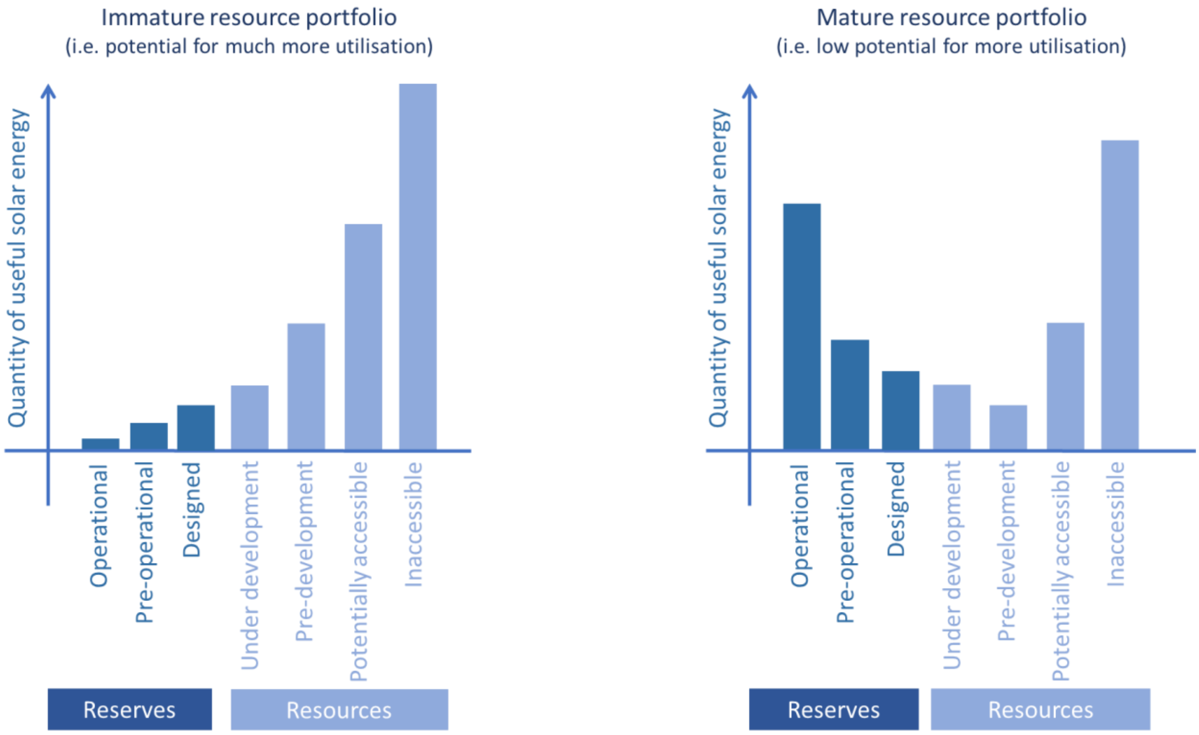
Figure 7
Information audience model for solar energy resource estimates classified using the UNFC.



E. Assessing the future of solar energy

102. For companies and governments alike, there is an interest in the project pipeline and potential for new solar projects. Using the Solar Reserves and Resources Classification to organise useful solar energy estimates, capacities and prices for solar projects helps generate a picture of progress utilising solar energy. Filling project data gaps, including GIS based estimates of resources, creates a comprehensive picture of solar portfolio maturity.

Figure 8
Immature versus mature national solar energy portfolios.



103. Figure 8 illustrates portfolio maturity with two hypothetical graphs showing aggregate useful energy levels for solar energy reserves categories and solar energy resources categories. The graph on the left illustrates an immature resource portfolio with plenty of opportunity for new projects, meanwhile, the graph on the right illustrates a mature resource portfolio with limited opportunity for new projects. However, it is important to note that changes in regulations, market conditions, prices or technology can make inaccessible resources attractive for development. Furthermore, improvements in solar technology efficiencies means that there is the possibility that more of the energy contained in solar irradiation will become accessible as useful solar energy and as such, even a relatively mature solar portfolio may still yield large amounts of new energy in the future.

104. Project level data can also give a sense of the project pipeline, i.e. the projects that can be considered for further development or construction. For large companies it may be important to have a portfolio of projects at different stages of development, construction and operation, so that they can grow. Similarly, governments may want to understand the portfolio of projects within a country, and their stages of development, for the purposes of energy planning. Table 9 illustrates how reserves and resources estimates might be coupled with assumptions regarding technology change as well as energy prices, taxes, subsidies and regulations to make projections around the amount of solar energy that will be viable in the short, medium and long term.

Table 9

The economic viability and the pipeline of solar energy reserves and resouces for development.

	Currently economic	*Economic in the short to medium term^*	*Potentially economic in the long term^^*
	*MWh-equivalent**	*MWh-equivalent**	*MWh-equivalent**
Reserves			NA
Resources			

Footnotes

**Assessment period (years): e.g. project lifetime or the set period for a national assessment*

^ *Assumptions regarding prices, technology, taxes, subsidies and regulations*

^^ *Assumptions regarding prices, technology, taxes, subsidies and regulations*

Note: see Annex 4 for a detailed table on the economic viability and pipeline of solar energy reserves and resources for development.

F. Other applications

105. There are a wide range of other potential applications or benefits that the Solar Specification may contribute to. For example, solar energy reserves could potentially be used in energy company Reserve Replacement Ratios (RRR) facilitating the inclusion of renewable energy investments in accounting measures traditionally used to assess the health of oil and gas companies. This would also facilitate that transition from non-renewable energy to renewable energy sources by large energy companies.

106. The Solar Specifications may lower the cost of assessing solar energy projects by introducing consistency of reporting. Furthermore, the Solar Specifications could support the development of standardised Solar Energy Reserves reporting (i.e. disclosure of assets) for public companies. This would be similar to disclosure requirements for oil and gas companies under stock exchange rules. Ideally, the reporting of solar energy projects, and reserves, using the UNFC might attract investors that have not traditionally invested in renewable energy projects or companies.

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Annex I

United States Energy Reserves and Resources 1989

1. The "Characterization of US Energy Resources and Reserves" published by the United States Department of Energy (DOE) in 1989 assessed energy reserves and resources from a variety of renewable and non-renewable energy sources (Table 10).

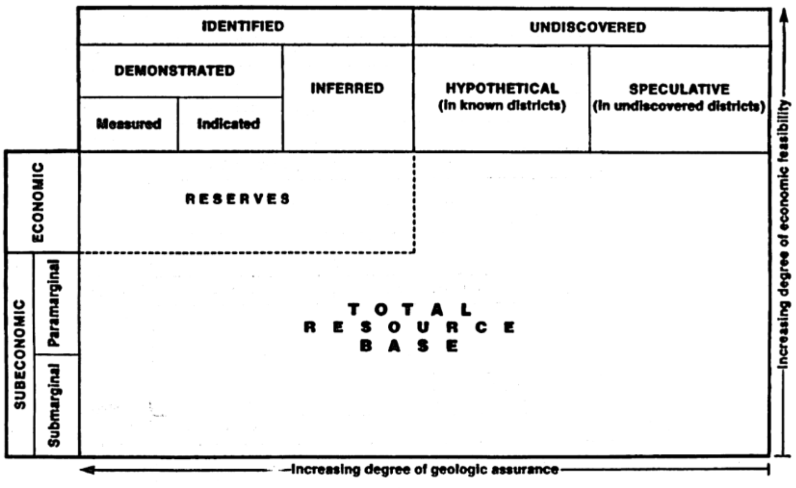
Table 10
Energy sources assessed in the characterisation of US energy resources and reserves.

Renewable energy sources	*Non-renewable energy sources*
Geothermal	Coal
Hydropower	Natural gas
Photoconversion (consisting of solar and bioenergy)	Peat
Wind	Petroleum
	Shale oil
	Uranium

2. Reserves and resources were classified using three simplified categories drawing from the McKelvey diagram (Figure 9). The McKelvey diagram provided a two dimensional framework for classifying energy sources according to the degree of physical assurance (i.e. geological assurance for energy minerals and petroleum) on the horizontal axis, and the degree of economic feasibility on the vertical axis. The three simplified categories drawn from the McKelvey diagram consisted of: reserves, accessible resources and total resource base.

3. Reserves had the greatest physical assurance and economic feasibility and were defined as "a subset of the accessible resource which is identified and can be economically and legally extracted using current technology to yield useful energy." (page 1, DOE 1989). Accessible resources were defined as "The portion of the total resource base, without regard to current economics, that can be captured, mined, or extracted using current technology or technology that will soon be available or economically extracted." (page 1, DOE 1989). Accessible resources were the portion of the total resource base that had been identified (see Figure 9). The total resource base was defined as the "Total physically available energy that encompasses both identified and undiscovered resources, regardless of whether or not they can be practically or economically extracted." (page 1, DOE 1989). The total resource base included both identified and undiscovered energy sources.

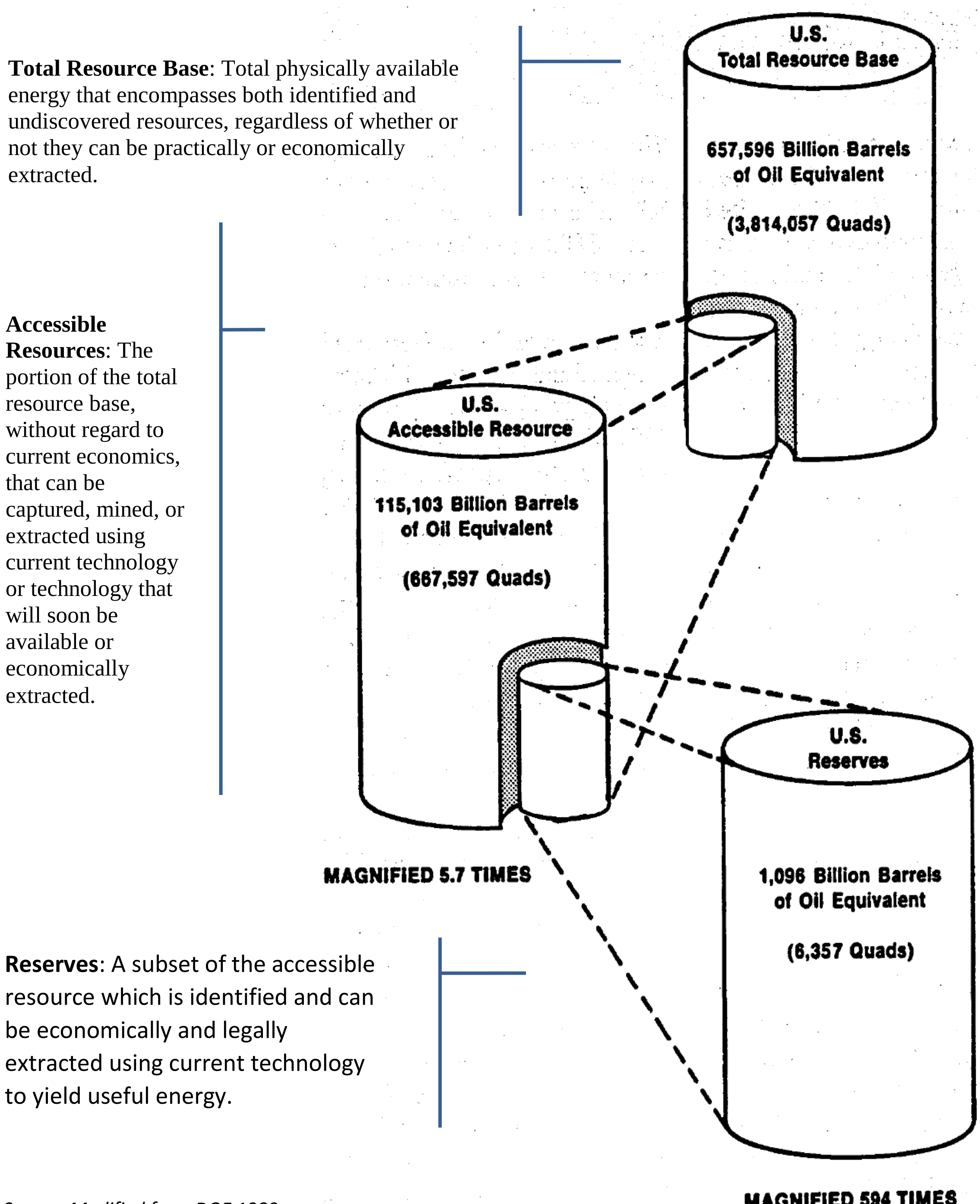
Figure 9
McKelvey diagram.



5. The DOE made estimates of the reserves, accessible resources and total resource base for the energy sources in Table 10 and presented the results graphically (see Figure 10 and Figure 11). Figure 10 presented the total energy reserves and illustrated the relative proportions. Figure 11 presents the results for each type of energy source.

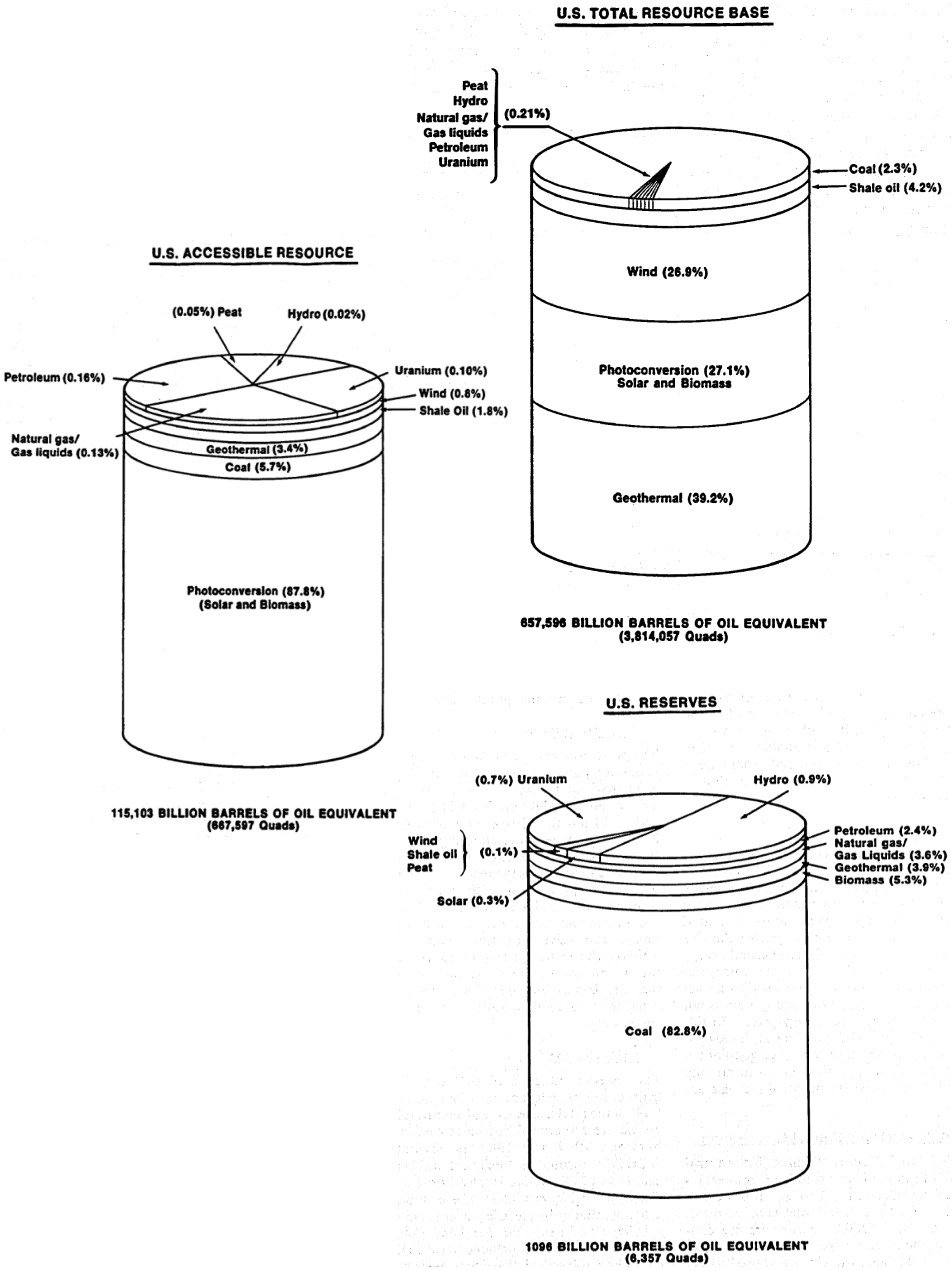
Figure 10

United States total energy reserves, accessible resources and resource base estimates from 1989.



Source: Modified from DOE 1989

Figure 11
United States total energy reserves, accessible resources and resource base estimates from 1989.



Source: DOE 1989

Annex II

Similar Resource Classifications and Methodologies

1. The World Energy Council (WEC) in its report from 1994, titled "New Renewable Energy Resources - a guide to the future" used 4 categories from van Wijk and Coelingh (1993) for assessing renewable energy. The four categories consisted of theoretical potential, geographic potential, technical potential and economic potential. These categories are important because they reflect a methodology for progressively estimating the useful energy (i.e. economic potential) using GIS (e.g. Hermann 2014).

2. When applied to solar energy:

(a) Theoretical potential can be defined as "the total primary solar energy flux hitting the Earth's surface suitable for PV and CSP" (page 2, Köberle et al 2015) in the case where PV and CSP are being assessed.

(b) Geographic potential can be defined as "the primary energy flux in suitable and available geographic areas of the globe" (page 2, Köberle et al 2015).

(c) Technical potential can be defined as "the geographic potential after any efficiency losses of the primary to secondary conversion process are accounted for" (page 2, Köberle et al 2015) when applied to generation of electricity for example.

(d) Economic potential can be defined as "the economically feasible technical potential" (page 2, Köberle et al 2015).

3. Figure 12 represents the four categories of potential from the WEC (1994) and Köberle et al (2015) with the titles on the left-hand side of the diagram. The economic potential is a portion of the technical potential which is a portion of the geographic potential, which in turn is a portion of the theoretical potential. Solar reserves and resources divide the economic potential into two parts. The reserves consist of the economic potential under production or construction, meanwhile the resources make up the remainder of the economic potential (see the top of the diagram).

Figure 12
Potential defined by the World Energy Council and used by IRENA, in relation to solar reserves and resources.

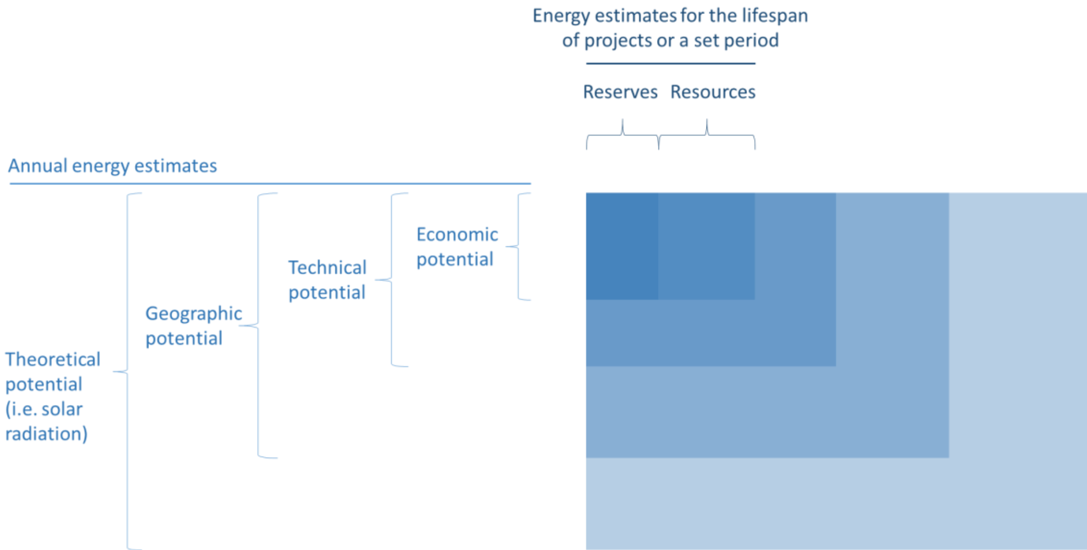
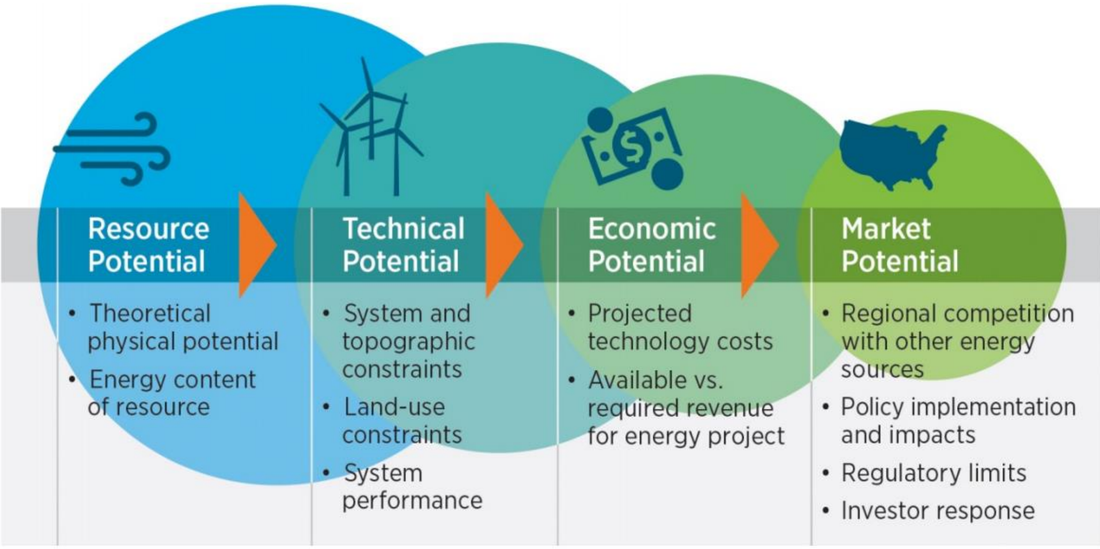


Figure 13

Types of renewable electricity generation potential identified by NREL.

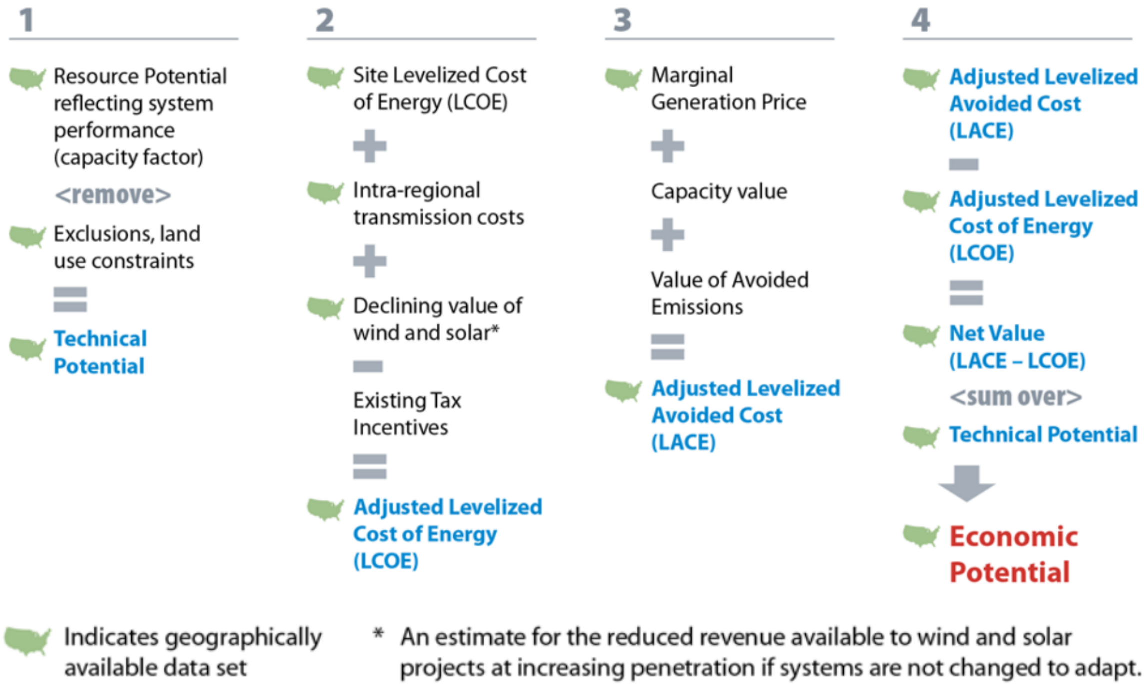


Source: Brown et al 2016.

4. The United States National Renewable Energy Laboratory (NREL) also made renewable energy assessments using a methodology similar to WEC and others. This includes assessments made by Lopez et al (2012) and Brown et al (2016). These studies identified a set of potentials (Figure 13). "Resource potential" consisted of the theoretical energy content from a source, which in the case of solar was irradiation. The "technical potential" limits the quantity energy by taking into account land use and topographic constraints as well as system performance including, for example, the capacity factors likely to be achieved. The "economic potential" took into account energy costs, including the Levelised Cost of Energy (LCOE) for renewable energy at a site (or area) and the Levelised Avoided Cost of Energy (LACE) which was the cost of energy from some other source. If LACE – LCOE was positive, then the renewable energy at the site (or area) was considered economic and the theoretical potential for the site (or area) was included in the economic energy estimate (Figure 14). The "market potential" included policies such as tax incentives or avoided costs related to health or climate change for example. More information on the methodology used can be found in Brown et al 2016.

Figure 14

Generalized NREL method for calculating economic potential of renewable energy sources based on high geospatial resolution data.



Source: Brown et al 2016.

Annex III

Modified Solar Reserves and Resources Classification Table

In addition to classifying and presenting useful energy estimates (e.g. measured in MWh) (see Table 1), it is possible to include supplementary capacity (e.g. measured in units of MW) and price information (e.g. measured in units of $/MWh) in a modified version of the Solar Reserves and Resources Classification (Table 11).

Table 11
Solar energy categories and sub-categories including the installed capacity, useful energy and price expectations for grid connected electricity projects.

Solar energy categories and sub-categories		*Confidence of useful energy estimate*								
		P90			*P50*			*P10*		
		MW	***MWh****	*$/MWh*	*MW*	***MWh****	*$/MWh*	*MW*	***MWh****	*$/MWh*
Reserves	Operational									
	Pre-operational									
	Designed									
Resources	Under development									
	Pre-development									
	Potentially accessible									
	Inaccessible									

Footnotes

**Assessment period (years): e.g. project lifetime or the set period for a national assessment.*

Annex IV

Technical Risks

Table 12
Indicative list of technical risks for solar PV projects.

Stage	*Activity*	*Risks*
Operation	Maintenance	Module cleaning missing or frequency too low.
		Missing or inadequate maintenance of the monitoring system.
	Day to day operations	Incorrect or missing specification for collecting data for availability evaluations: incorrect measurement sensor specification, incorrect irradiance threshold to define time window of operation for availability calculation.
		Missing guaranteed key performance indicators (availability or energy yield).
		Inadequate or absence of devices for visual inspection to catch invisible defects/faults.
		Selected monitoring system is not capable of advanced fault detection and identification.
Commercial operation date		Technology does not perform or last as long expected, construction is faulty.
Pre-operations	Securing acceptance (performance testing)	Incorrect or missing specification for collecting data for availability evaluations: incorrect measurement sensor specification, incorrect irradiance threshold to define time window of operation for availability calculation.
		Missing final performance check and guaranteed performance.
		Missing short-term performance check at provisional acceptance test, including proper correction for temperature and other losses.
		Inadequate protocol or equipment for plant acceptance visual inspection.
	Installation	Missing intermediate construction monitoring.
		Inadequate quality procedures in component un-packaging and handling during construction by workers.
	Transport	Absence of standardised transportation and handling protocol post the Reference Point, which creates uncertainty of the Solar Energy Product(s) delivery.
Financial close		Market conditions change for example due to regulations or false assumptions.
Designed or under development	Useful solar energy estimation	Incorrect availability assumption to calculate the initial yield for project investment financial model.
		Incorrect degradation rate and behaviour over time assumed in the yield estimation.
		The effect of long-term trends in the solar resource is not fully accounted for.
	Technology selection and testing	Absence of adequate independent product delivery acceptance test and criteria.
		Inadequate component testing to check for product manufacturing deviations.
		Insufficient technical specifications to ensure that selected components are suitable for use in the specific plant environment of application.

Source: Modified and adapted from Tjengdrawira et al 2017.