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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 document provides Specifications for the application of the United Nations Framework Classification for Resources (UNFC) to Solar Energy (also known as Solar Specifications). The intended use of this document is in conjunction with UNFC and the Specifications for the Application of UNFC to Renewable Energy Resources (Renewables Specifications). The Renewables Specifications represent rules of application of UNFC to renewable energy resources, while this document represents rules of application of UNFC to solar energy resources via the Renewables Specifications. Growing awareness and interest in renewable energy resources, including solar energy resources, has highlighted a need to normalize the way in which renewable energy potential is reported. It is hoped that the inclusion of Solar Specifications within UNFC will facilitate the appreciation of the potential role that solar energy specifically, and renewable energy in general, must play as part of a rapidly changing energy sector.

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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 the standardised reporting of energy resources estimates for projects and at national and international levels.

Work on an international framework classification for 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. The Expert Group was then renamed as the Expert Group on Resource Management in December 2018. 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. 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, responsible for 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 Specifications for the Application of the United Nations Framework Classification for Resources to Solar Energy (also known as Solar Specifications). The Solar Working Group began its work in August 2016. The Solar Working Group was charged with preparing the Solar Specifications with the aim of improving the consistency and interpretation of reported solar energy resources estimates while at the same time facilitating comparisons with other energy sources. In April 2017, the Solar Working Group and Renewables Task 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 classification of solar energy 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 resources 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

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David Renne, Fred Morse, Jenny Chase, Kamel Ben Naceur, Luc de Marliave, 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 and Marcus Klingbeil the Wind Subgroup Leads, 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 valuable feedback from Divyam Nagpal and Bernard Seiller.

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I. Introduction

1. The Solar Specifications provide a framework for assessing quantities of useful solar 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 address: confidence of useful solar 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 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. resources) management by companies including corporate business process management. The Solar Specifications also support national energy assessments by governments and international energy studies. These national energy assessments can be used to inform national and international energy policies and agreements as well as natural resources management. 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 and assist in capital allocation. Intended users for the Solar Specifications include governments, businesses and others interested in solar energy.

2. The Solar Specifications presents the 3-dimensional United Nations Framework Classification for Resources (UNFC), and highlights how solar energy estimates classified using te UNFC can be compared with other renewable and non-renewable energy resources. As such, UNFC provides a powerful framework for understanding and managing solar and other energy 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 (see Annex I). Further efforts to establish renewable energy definitions were published by NREL (Maxwell and Renné, 1994). In the report the authors contrasted 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). To date, the classification of renewable energy has been restricted to ad hoc classification exercises.

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

[1] "Useful solar 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).

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 delineating it into commercial and other solar energy resources using the revised UNFC.

5. 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 an evaluator could take the Solar Specifications and work out how to classify solar projects based on the data and information they have.

6. It should be noted that the Solar Specifications does not provide step-by-step guidance on how to classify solar energy 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, leaving issues of data sources, estimation methods and rules of application for future guidance documents. However, the Solar Specifications does describe resource reporting cycles related to businesses and projects as well as governmental and national assessments.

7. When classifying solar energy resources, the Solar Specifications should be used in conjunction with revised UNFC (to be published soon), along with the Specifications for the Application of UNFC to Renewable Energy Resources (i.e. Renewables Specifications, ECE 2016a). Other very useful references include the Geothermal Specifications (ECE 2016b), Bioenergy Specifications (ECE 2017a) and the Wind Specifications (under preparation).

II. Definitions

A. Solar irradiation

8. 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 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[2]

- *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.

9. *Solar irradiation* is typically measured in units of MW-hr or equivalent units. For solar energy resources, the *useful solar energy* over the lifetime of a project, or a set period, is recorded, while the remainder of the irradiation can be recorded as "*additional quantities*" in the UNFC or "*additional solar energy*" when applying the Solar Specifications. *Additional solar energy* refers to solar energy that may become recoverable in the future as technological developments occur, however, some or all of these quantities may never be utilised.

10. *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 its 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.

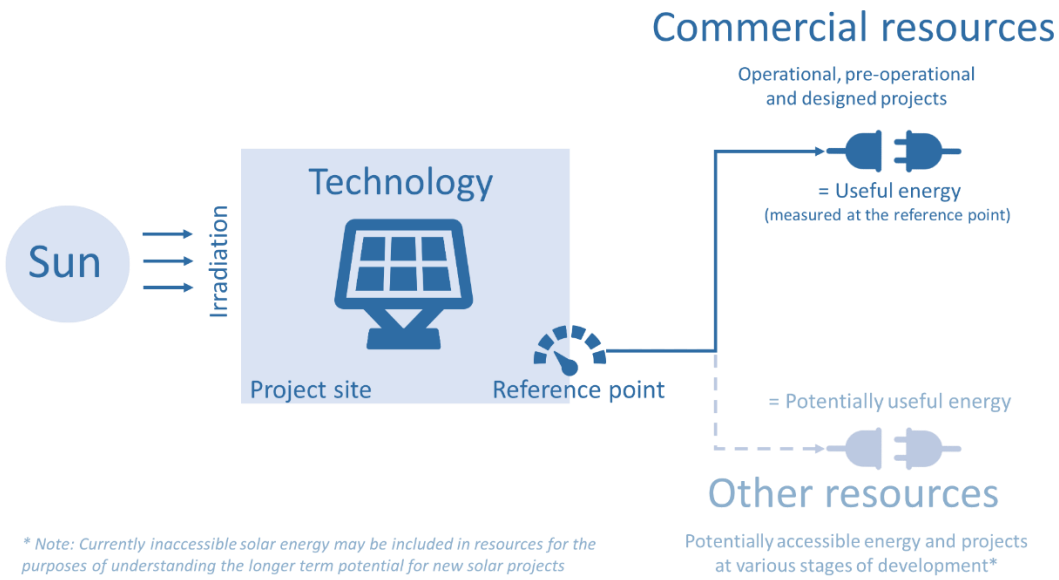
[2] It is important to note: The common understanding and usage of the term "resource" differs between the wider solar community and its usage within the UNFC community. The solar community typically use the term "resource" to refer to total solar irradiance reaching the earth's surface. Meanwhile the 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).

B. Useful solar energy

11. *Useful solar 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.

12. For *solar irradiation* at a *site* to be utilised and become *useful solar 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 I
Schematic representation of how solar irradiation at a site coupled with technology can generate useful solar energy, in this case using a solar PV panel and other necessary technologies. Importantly, the useful solar energy is measured at the reference point[3]



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

[3] Note: for some projects, there may be more than one energy type or more than one *reference point.* 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.

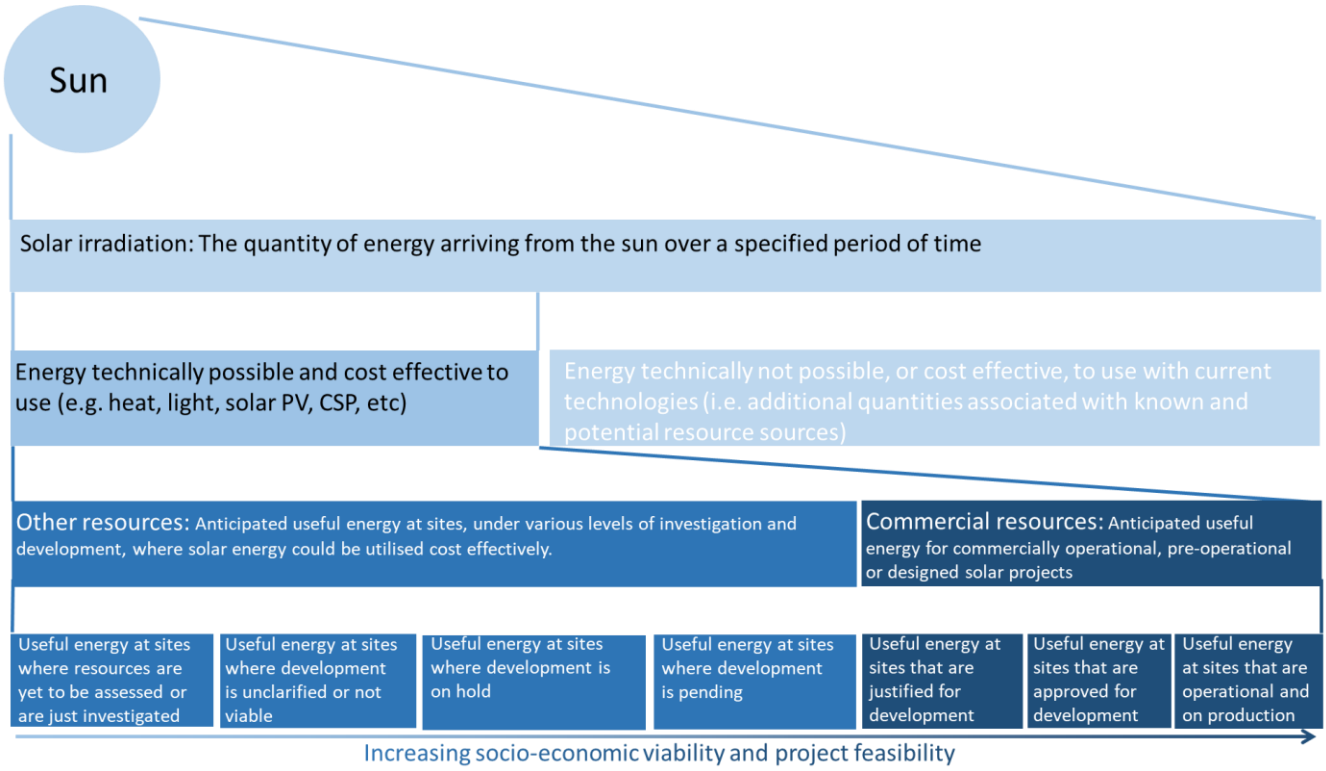
14. In addition to solar PV, other photoreactions can also be used, for example photocatalytic water detoxification. *Solar irradiation* can even be used as an input to the manufacture of energy vectors (i.e. things that can be used to transport and release energy on demand), notably hydrogen.

15. 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.

C. Solar resources

16. *Solar resources* are the anticipated quantities of *useful solar energy* from a *solar project*, or a set of *solar projects*. As such, *solar resources* consist of the energy that is technically possible to use at reasonable cost (i.e. *useful solar energy*). *Solar resources* are a fraction of total *solar irradiation*. *Commercial solar resources* consist of the anticipated *useful solar energy* for operational solar projects that are on production (i.e. utilising solar energy), pre-operational solar projects approved for development and solar projects that have been designed and justified for development. *Other solar resources* consist of anticipated *useful solar energy* for sites, under various levels of investigation, where solar energy could be utilised cost effectively. *Solar resources* can be estimated for an individual project, summed up from a portfolio of projects or estimated at the national level. Section D (below) defines solar resources estimates. Subsequent sections define other important related concepts.

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



D. Solar resources estimates

17. At the project level, *solar 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 resources estimates* for each project may be added up to form total *solar resources estimates*. Similarly, *solar resources* may be compiled from solar project data for a geographic area and total *solar resources* summed for an area such as a city, province or country. However, there may be gaps in information, or some potential resources may not have been investigated as part of a solar project.

18. Instead of adding up project resource quantities, estimates of *useful solar energy* at the city, provincial or national level can be estimated from the top down based on solar irradiation (i.e. theoretical potential) using technical, economic and geographic filters (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 (Köberle et al 2015) which is equivalent to solar resources.

19. *Commercial solar resources* and *other solar resources* can be estimated at the national level by adding up project data on *commercial solar resources* and *other solar resources*. Alternatively, *commercial solar resources* 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 other commercial energy resources against which *commercial solar resources* are being compared. For example, if *commercial solar resources* were being compared with national oil or gas resources then the *lifespan* of oil or gas resources should be used.

E. Confidence of solar resources estimates

20. Once *solar energy resources* have been estimated at either the project or national level, these estimates need to be assessed in terms of confidence. See Section IV.D. regarding the UNFC G-axis for more information. Note: Typically, national resources estimates will have less confidence than many project-based resources estimates where a greater level of investigation has usually been made.

F. Solar project, site(s) and technologies

21. 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*.

22. The *solar 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.

23. When a *solar project* includes *useful solar energy* from *solar irradiation* and other energy sources, only the *useful solar energy* will be classified as *solar resources*. The

useful solar energy from other energy sources can be classified using other UNFC related specifications or classifications.

24. 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

25. 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 revised UNFC (under preparation) to create the model in Figure 3. Not every *solar project* will follow this model, but most *solar projects* will have similar stages, and as such it should be possible to classify solar resources using the model.

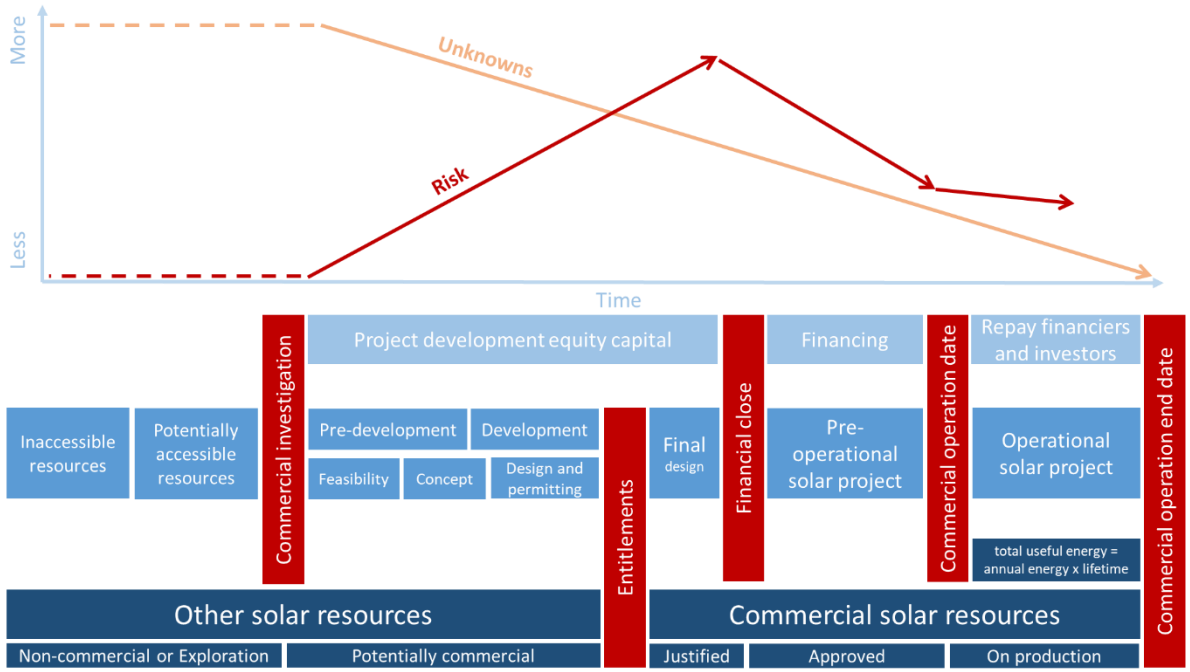
26. Prior to a *solar project* being initiated or explored, the preconditions for a *solar project* need to be in place, and this includes having a regulatory regime that facilitates the utilisation of *solar radiation*. For solar energy being produced for sale, this might include supporting infrastructure and market access for example. Otherwise potentially *useful solar energy* will be inaccessible and considered to be *non-commercial solar resources*.

27. A *solar project* starts with the identification and *exploration* of potentially accessible solar resources and the decision to investigate possible project site(s).

28. *Potentially commercial solar resources* are identified through pre-development and development activities. 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. 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.

29. 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 III.C. Entitlement.

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



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

31. If the project is *approved*, financing arranged, and relevant agreements signed (i.e. at the financial close) then construction can begin. 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.

32. At the commercial date of operation, the project becomes *operational*, 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 operating expenditures, there remains the risk that changes in regulations, or access to markets, could negatively affect the *project*.

33. In Figure 3 classes and subclasses of solar resources and projects are presented in dark blue at the base of the diagram. The revised UNFC includes the classes of projects consisting of: commercial projects, potentially commercial projects, non-commercial projects, exploration projects as well as additional quantities. These types of projects are defined in Table 1. Table 1 also includes subclasses and a column for recording resources according the confidence of each estimate. For a detailed description of how solar energy resources can be classified using classes and subclasses consistent with Table 1, see Table 7.

Table 1
Abbreviated version of UNFC showing classes and subclasses relevant to solar projects and confidence levels

Class	*Description*	*Subclass*	*Resource confidence*		
			High	*Medium*	*Low*
Commercial Projects	Projects that have been confirmed to be technically, economically, environmentally and socially feasible.	On Production Approved for Development Justified for Development			
Potentially Commercial Projects	Projects that are expected to be developed in the foreseeable future, in that the quantities are assessed to have reasonable prospects for eventual economic production, but technical and/or commercial feasibility has not yet been confirmed. Consequently, not all Potentially Commercial Projects may be developed.	Development Pending Development on Hold			
Non-Commercial Projects	Projects that are at an early stage of evaluation in addition to those that are considered unlikely to become commercially feasible developments within the foreseeable future.	Development Unclarified Development Not Viable			
Exploration Projects	Projects associated with the investigation of one or more potential resource sources.	NA			
Additional quantities associated with known and potential resource sources	Quantities that may become recoverable in the future as technological developments occur. Some or all of these quantities may never be utilised.	NA			

H. Reference point

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

35. 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*.

36. 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 solar energy* quantities are measured and paid for at agreed prices. This ensures consistency between quantities, prices and payments.

37. Estimates of the *useful solar energy* should be consistent with any conditions on the *solar project*. Conditions might include restrictions on market access, sales or the quality of *useful solar energy*. Note: The quality of *useful solar 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.

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

I. Project lifetime

39. The *project lifetime* is the minimum remaining period of time that a project is expected to operate. For a project that is not yet operational, 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*.

40. For some *solar resources estimates*, e.g. national estimates, it may be appropriate to use a *set period*. In such situations, it may be 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 *solar site(s)* or investment in a new project at another *solar site*. 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 resources, or alternatively an average *project lifetime*. The appropriate *set period* will depend on the type of analysis for which the *solar energy resources* are intended and the need to ensure balanced and comparable resources estimates. If a *set period* is used, this should be stated and made clear in the table and related documentation.

41. 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 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.

III. Special Issues

A. Establishments, activities and national accounts

42. A *solar project* at a specific *solar site* will in many cases coincide with an *establishment*. This is important when it comes to national assessments of *solar energy 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).

43. *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).

44. 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.

45. 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).

46. The SNA also includes activities[4] 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.

47. 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).

B. Business risk

48. 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 or large energy users; utility-scale concentrating solar power electricity generation for the grid or large energy users; solar electricity generation for an independent micro-grid, solar electricity generation for own use; household solar PV electricity generation with a

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

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.

49. 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.

50. Important business risks to consider include technical risks and commercial risks. Technical risks can impact the levelised cost of electricity (LCOE) and 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 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

51. *Entitlement* is defined as the quantity of *useful solar 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*. *Ancillary services* are "services that assist the grid operator in maintaining system balance" (NREL 2011). 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 resources.

52. The duration of *entitlements* will affect the *lifetime* of the *solar project* and classification of *solar energy 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.

53. Legal agreements vary, but key terms and conditions to consider when classifying *solar 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.

54. The price and margin risk should be considered when classifying solar 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.

55. *Solar 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

56. *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.

57. *Useful solar energy* estimates are generally based on historic climate data, including any available data from the solar site(s), coupled with 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.

58. 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. 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.

59. 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

60. Some *solar projects* may involve two or more types of *useful solar energy* (e.g. heat and electricity) or other valuable services (e.g. capacity and/or *ancillary services*). In such circumstances, estimated quantities of *useful solar energy* should be reported separately. Where *useful solar* 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 services* might also require special consideration and reporting.

61. 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 separately from solar energy that passes through the *reference point*.

F. Curtailment

62. 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 along with the useful *solar energy* that was actually utilised or sold.

63. 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 solar 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.

IV. Managing and Comparing Solar and Other Energy Sources

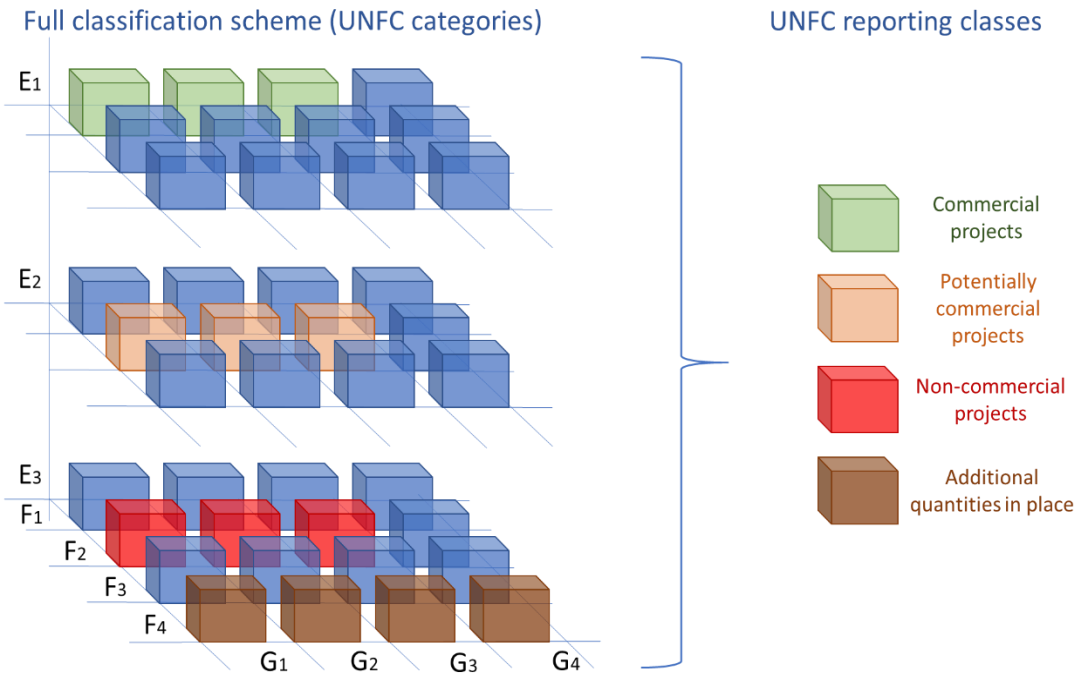
A. The UNFC

64. 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 resources that are anticipated to be utilised or produced. As such, the 3 axes of the UNFC from a 3-dimensional matrix (Figure 4).

65. To facilitate the comparison of solar energy 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. For more information on the UNFC reporting see the UNFC webpage[5] on the ECE website.

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

Figure 1
UNFC classification categories and UNFC classes for reporting



B. E Axis

66. According to the revised UNFC, "The first set of categories (the E axis) designates the probability of social and economic conditions in establishing the commercial viability of the project, including consideration of market prices and relevant legal, regulatory, social, environmental and contractual conditions." (under preparation).

67. Table 2 presents the E-axis categories E1 to E3 including revised UNFC definitions and explanations. Alongside are comparable solar interpretations 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 3 presents the revised UNFC E-axis subcategories E1.1 through to E3.3 including revised UNFC definitions alongside the solar interpretations.

68. Key terms in the revised UNFC definitions of E categories and sub-categories include *reasonable expectations*, reasonable *time frame* and *foreseeable future*. The term *reasonable expectations* is used within the E1 classification and concerns the likelihood of obtaining necessary regulatory approvals, permits and contracts necessary to implement the *solar project*.

69. For the condition of *reasonable expectations* to apply in the case of governmental approvals or permits, the application or submission shall have been made together with supporting information. Aside from minor additional information requests or clarifications, there should be justification to expect that the application will be approved within a period that is typical for applications of that type in the jurisdiction concerned. The condition of *reasonable* expectations can also apply in circumstances when the application is still to be made or to be fully completed so long as there is a demonstrated track record of obtaining such approvals.

70. For the condition of *reasonable expectations* to apply to commercial/financing contracts or agreements, negotiations shall be underway, with the specific justification that agreement will be achieved within a time period that would be typical for such contracts or agreements. The conditions of *reasonable expectations* can also apply in the circumstance when negotiations have not commenced, provided there is a demonstrated track record of negotiating similar contracts/agreements.

71. The term *reasonable time frame* concerns the time frame within which all approvals, permits and contracts necessary to implement the *solar project* are to be obtained. This should be the time generally accepted as the typical period required to obtain approval, permits or contracts.

72. The *foreseeable future* is the period of time that a *solar project* can make a reasonable projections of future market conditions, events or other conditions that determine the economic viability or other factors of a *solar project*.

Table 2
Revised UNFC E-axis categories, definitions and explanations alongside comparable solar definitions and explanations

UNFC Categories	*UNFC definition*	*UNFC explanation*	*Solar interpretation*	*Solar explanation*
E1	Production for sale or direct use[a] has been confirmed to be economically, socially and environmentally viable.	Production for sale or direct use[a] is economically, socially and environmentally viable on the basis of current market conditions and realistic assumptions of future conditions. All necessary conditions have been confirmed or there are *reasonable expectations* that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to a market or place of use. 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.

UNFC Categories	*UNFC definition*	*UNFC explanation*	*Solar interpretation*	*Solar explanation*
E2	Production for sale or direct use[a] is expected to become economically, socially and environmentally viable in the *foreseeable future*.	Production for sale or direct use[a]Error! Bookmark not defined. has not yet been confirmed to be economically, socially, and environmentally viable but, on the basis of realistic assumptions of future conditions, there are reasonable prospects for economic, social and environmental viability 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	Production for sale or direct use is not expected to become economically, socially and environmentally viable in the *foreseeable future* or evaluation is at too early a stage to determine economic, social and environmentally viability.	On the basis of realistic assumptions of future market conditions, it is currently considered that there are not reasonable prospects for economic, social or environmental viability in the *foreseeable future*; or, this cannot yet be determined due to insufficient information. Also included are quantities that are forecast to be produced and used to assist with the production and processing of the resource, and 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]..Direct use for productive purposes or domestic end use. This excludes non-sales production of a resource intended to assist with the production and processing of the same resource, for example coal used to power activities at a coal mine.

Table 3
Revised UNFC E-axis subcategories and definitions alongside comparable solar definitions

UNFC categories	*UNFC sub-categories*	*UNFC definition*	*Solar interpretation*
E1	NA	Production for sale or direct use is economically, socially and environmentally viable on the basis of current market conditions and realistic assumptions of future conditions. All necessary conditions have been confirmed or there are *reasonable expectations* that all necessary conditions will be met within a reasonable timeframe and there are no impediments to the delivery of the product to a market or place of use. Viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive.	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.
E2	E2.1	Not all economic, social and environmental contingencies have been resolved, but there is a high probability that they will be resolved within the *foreseeable future*.	Not all economic, social and environmental contingencies have been resolved in relation to the *useful solar energy* quantities, but there is a high probability that they will be resolved within the *foreseeable future*.
	E2.2	Not all economic, social and environmental issues have been resolved, but there is a medium probability that they will be resolved within the *foreseeable future*.	Not all economic, social and environmental issues have been resolved in relation to the *useful solar energy* quantities, but there is a medium probability that they will be resolved within the *foreseeable future*.
E3	E3.1	Quantities that are forecast to be produced and used to assist with the production and processing of the resource and 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 solar energy* to other parties.
	E3.2	Economic, social and environmental viability cannot yet be determined due to insufficient information.	Economic viability of potentially *useful solar energy* cannot yet be determined due to insufficient information.

UNFC categories	*UNFC sub-categories*	*UNFC definition*	*Solar interpretation*
E3	E3.3	It is currently considered that there are not reasonable prospects for economic, social and environmental viability 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

73. According to the revised UNFC, "(the F axis) designates the maturity of studies and commitments necessary to implement development projects. These extend from early conceptual studies and exploration efforts before a resource source has been confirmed to exist through to a project that is producing and selling, or directly using, a product type, and reflect standard value chain management principles." (under preparation).

74. Table 4 presents the F-axis categories F1 to F4 including revised UNFC definitions and explanations. Alongside these are solar interpretations and explanations. The solar interpretations and explanations use solar terms presented earlier in the solar specifications. Following the same logic, Table 5 presents the UNFC E-axis subcategories F.1.1 through to F.4.3 including revised UNFC definitions alongside solar interpretations. Essentially the F axis categories can be described as: F1 – is feasible; F2 – might be feasible; F3 – can't tell; and F4 – who knows. For F1, F2 and F3 a development plan is required but not for F4.

Table 4
Revised UNFC F-axis subcategories, definitions and explanations alongside comparable solar definitions and explanations

UNFC Category	*UNFC definition*	*UNFC explanation*	*Solar interpretation*	*Solar explanation*
F1	Feasibility of production by a defined project has been confirmed.	Production is currently taking place; or, implementation of the project is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of production by implementing a defined project.	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.

UNFC Category	*UNFC definition*	*UNFC explanation*	*Solar interpretation*	*Solar explanation*
F2	Feasibility of production by a defined project is subject to further evaluation.	Preliminary studies demonstrate the existence of quantities that the feasibility of production by a defined (at least in broad terms) project can be evaluated. Further data acquisition and/or studies may be required to confirm the feasibility of production.	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 production by a defined development project cannot be evaluated due to limited technical data.	Very preliminary studies which may be based on a defined project (at least in conceptual terms), indicate the need for further data acquisition in order to confirm the existence of quantities that the feasibility of production 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 has been identified.	Quantities that will not be produced by any currently defined project.	No solar project has been identified	*Useful solar energy* will not be utilised by any currently defined solar project or technology.

Table 5
Revised UNFC F-axis subcategories and definitions alongside comparable solar definitions

UNFC categories	*UNFC sub-categories*	*UNFC definition*	*Solar interpretation*
F1	F1.1	Production 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 project.	Capital funds have been committed and implementation of the solar project is underway.
	F1.3	Sufficiently detailed studies have been completed to demonstrate the feasibility of production by implementing a defined project.	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.

D. G Axis

75. According to the revised UNFC, "(the G axis) designates the level of knowledge and/or confidence in estimates of quantities." (under preparation). Table 6 presents the revised UNFC G-axis categories G1 to G4 including revised UNFC definitions alongside solar interpretations that use terms presented earlier in the solar specifications to make them applicable to solar. The G axis does not have any sub-categories relevant to solar resources.

76. From the revised UNFC, the level of confidence for quantities that are classified on the G axis as G1, G2 and G3 is defined as "high", "medium" and "low", respectively. These are not specified more precisely because there are fundamental differences between the approaches that are appropriate for different resources types. For solar it is common to use probabilistic methods for assessing high, medium and low confidence. A quantity of *useful solar energy* with a 90 probability of being exceeded (P90) is a commonly used as a high confidence estimate. Medium confidence estimates often use P50 (i.e. have only a 50% probability of being exceeded). For solar energy projects banks typically want to see P90 and P50 estimates before providing finance (Dobos et al 2012). A low confidence estimate would be P10.

77. G4 regards other energy that might be utilised at project locations. In the case of solar this energy will often require improvements in technology if it is to be utilised.

Table 6
Revised UNFC G-axis definitions alongside comparable solar definitions

Category	*UNFC definition*	*Solar interpretation*
G1	Quantities associated with, or can be produced from, a known resource source 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, or can be produced from, a known resource source 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, or can be produced from, a known resource source 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, or recoverable from, a potential resource source, 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 Classification of Solar Energy Resources

78. Table 7 provides a framework for classifying solar energy resources including revised UNFC categories in brackets. The UNFC categories are put in brackets to signify that only projects with this combination of characteristics can be included. For some cells in Table 7, there are more than one set of combinations in brackets meaning that projects with any of these combinations of characteristics should be included.

Table 7
Abbreviated version of UNFC adapted to solar showing classes and subclasses

			Resource confidence		
			High	*Medium*	*Low*
Class	*Description*	*Subclass*	*(UNFC resource categories)*		
Commercial solar resources	Quantities of *useful solar energy* that have been confirmed to be technically, economically, environmentally and socially feasible.	On Production	(E1, F1.1, G1)	(E1, F1.1, G2)	(E1, F1.1, G3)
		Approved for Development	(E1, F1.2, G1)	(E1, F1.2, G2)	(E1, F1.2, G3)
		Justified for Development	(E1, F1.3, G1)	(E1, F1.3, G2)	(E1, F1.3, G3)
Potentially commercial solar resources	Quantities of useful that are expected to be developed in the foreseeable future, in that the quantities are assessed to have reasonable prospects for eventual economic production, but technical and/or commercial feasibility has not yet been confirmed. Consequently, not all potentially commercial resources may be developed.	Development Pending	(E2, F2.1, G1)	(E2, F2.1, G2)	(E2, F2.1, G3)
		Development on Hold	(E2, F2.2, G1)	(E2, F2.2, G2)	(E2, F2.2, G3)
Non-commercial solar resources	Quantities of *useful solar energy* that are at an early stage of evaluation in addition to those that are considered unlikely to become commercially feasible developments within the foreseeable future.	Development Unclarified	(E3.2, F2.2, G1)	(E3.2, F2.2, G2)	(E3.2, F2.2, G3)
		Development Not Viable	(E3.3, F2.3, G1)	(E3.3, F2.3, G2)	(E3.3, F2.3, G3)
Solar resources being explored	Quantities of *useful solar energy* under investigation.				(E3, F3, G4)
Additional solar energy	Solar energy that may become recoverable in the future as technological developments occur. Some or all of these quantities may never be utilised.		(E3, F4, G1)	(E3, F4, G2)	(E3, F4, G3) (E3, F4, G4)

V. Applying the Solar Specifications

A. Evaluators

79. *Evaluators* are the people that estimate the quantity of *useful solar energy* from a project and classify solar energy resources according to the UNFC or some other set of criteria. *Evaluators* should have an appropriate level of expertise and relevant experience in the estimation of *useful solar energy* quantities.

B. Classifying projects

80. The classification of resources is one step within a wider information cycle (Figure 5). Steps leading up to the classification of solar 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*.

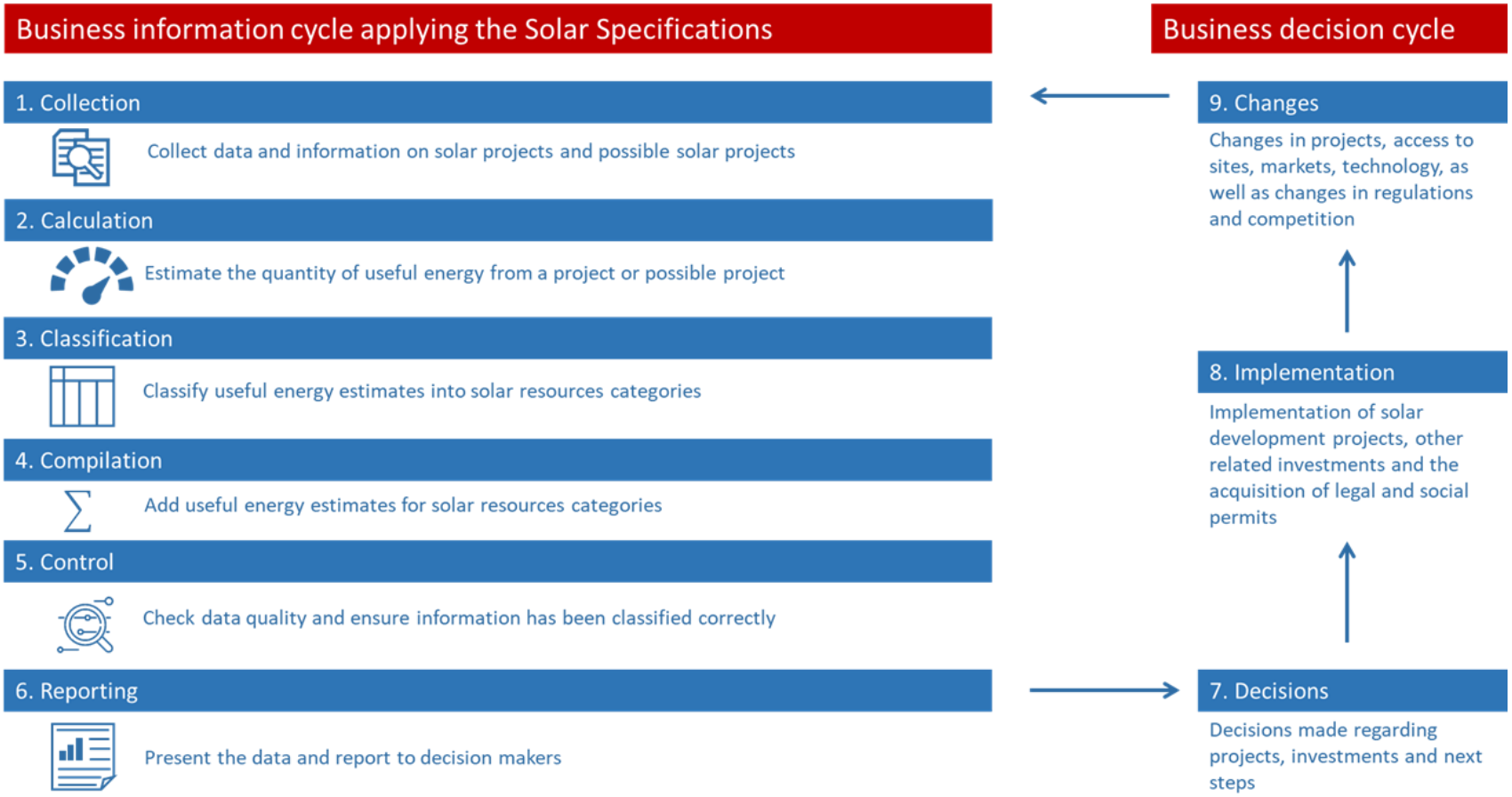
81. Step 3 is the actual classification of solar energy resources. This involves reviewing the data collected on projects, and possible projects, and then determining which category a project or potential project belongs in, based on the definitions provide in this document.

82. After classifying projects, there are a series of other steps consisting of: 4. Compiling *useful solar energy* estimates in the same UNFC classes and subclasses and calculating totals for each; 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.

83. Data classified UNFC 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 resources classification exercises e.g. as projects go from *development pending* to *development justified*, *potentially commercial resources* are reclassified as *commercial resources*.

Figure V

Process for identifying estimating, classifying and reporting solar energy project resources using the UNFC



C. National estimates

84. In addition to corporations and investors, the UNFC 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 resources within the territories over which they have jurisdiction. This might include an interest in understanding: solar energy resources being utilised; solar energy 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 UNFC creates the opportunity for governments to compare *useful solar energy* estimates with other energy resource estimates.

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

86. 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.

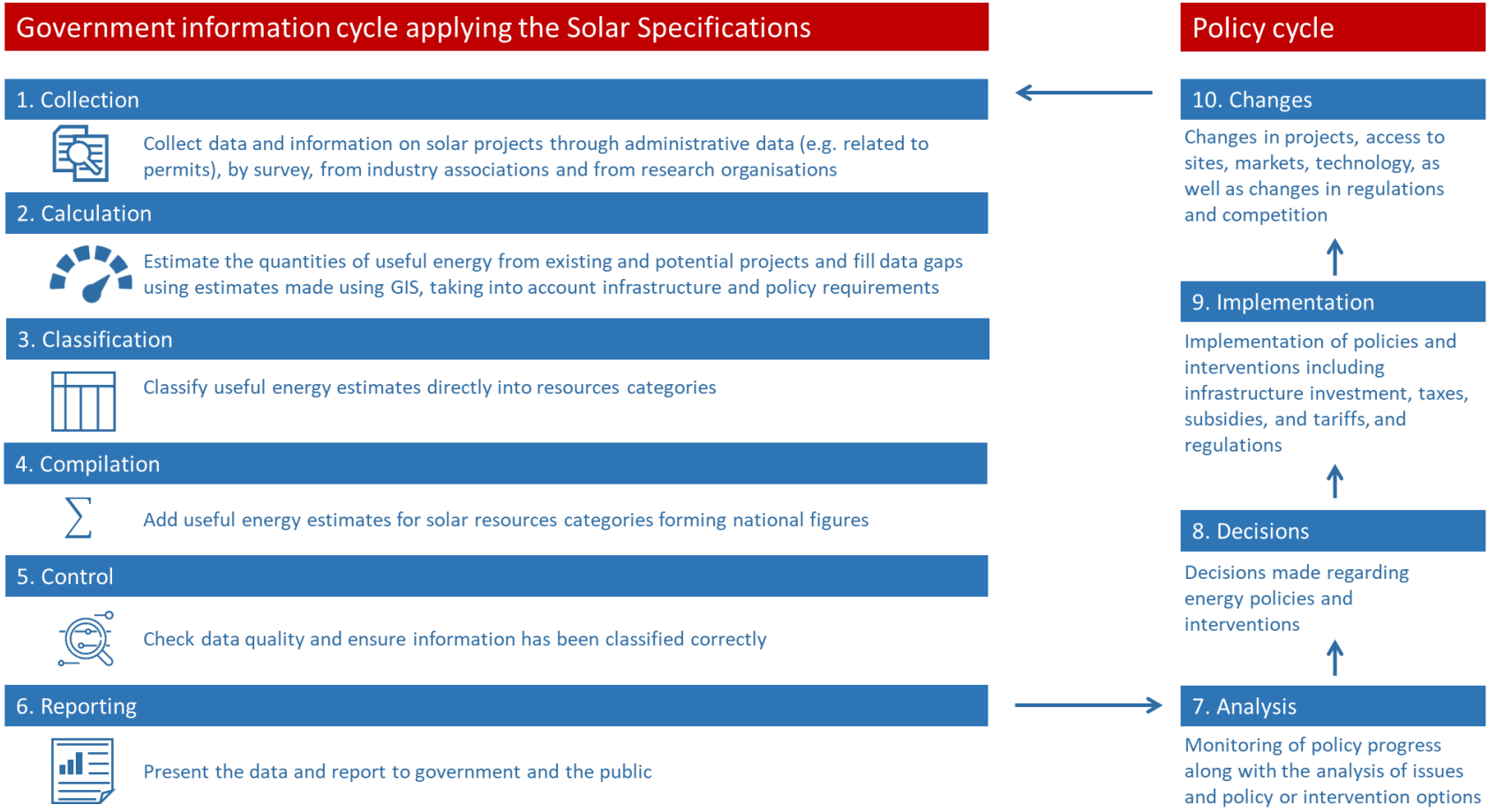
87. Data collection by government can include project data from its own investments, as well as project data collected from administrative sources (e.g. data collected as part of permitting processes), surveys of projects, industry associations as well as research organisations including universities. To get a complete picture of solar energy 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 II.D. Solar resources estimates).

88. After data checking and quality control, national solar energy resources estimates are published and shared with government decision makers and the public including business, civil society and researchers. In many instances there will be additional analysis of solar energy 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 resources Classification to monitor their own solar energy projects.

89. 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 VI

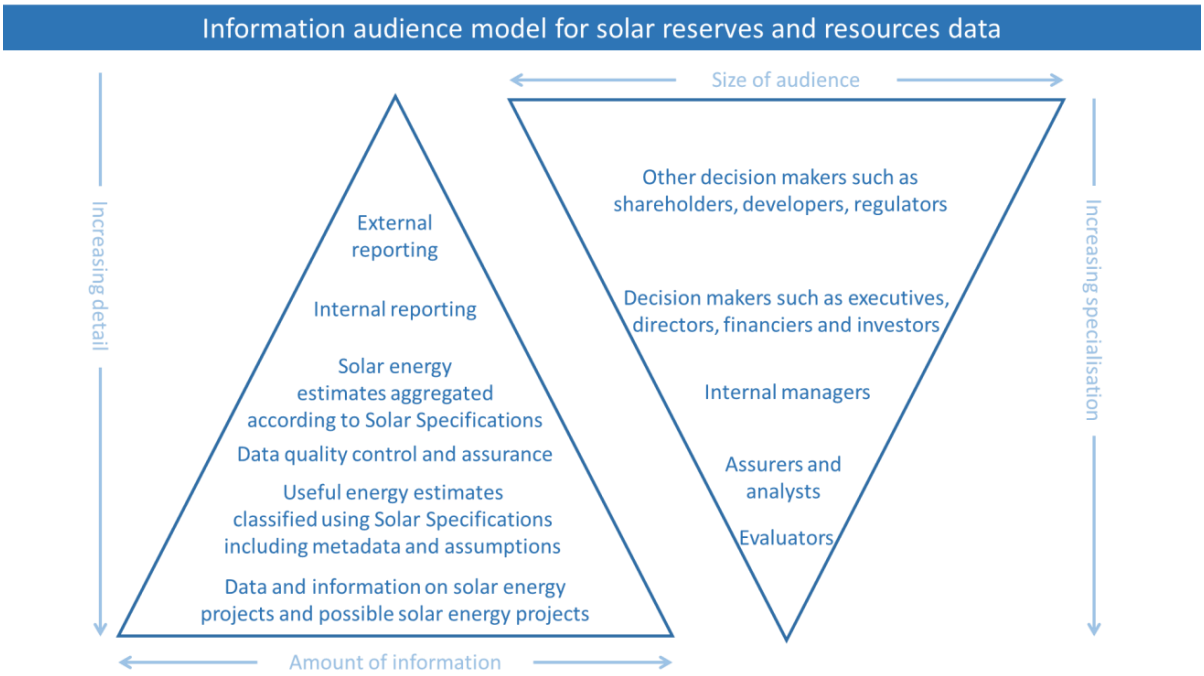
Process of organising solar energy reserves and resources data for input to government energy analysis and decision making



D. Solar information users

90. Figure 7 illustrates the information-audience model for solar 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 VII
Information audience model for solar energy resource estimates classified using the UNFC



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Glossary

Additional solar energy: Solar energy that may become recoverable in the future as technological developments occur, however, some or all of these quantities may never be utilised.

Additional quantities (associated with known and potential resource sources): Energy that may become recoverable in the future as technological developments occur. Some or all of these quantities may never be utilised.

Ancillary services: Services that assist the grid operator in maintaining system balance.

Assessment date: the date for which the assessment is made.

Commercial projects: Projects that have been confirmed to be technically, economically, environmentally and socially feasible.

Curtailment: 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.

Direct beam irradiation: the energy directly from the sun coming along a straight line perpendicular to the sun.

Diffuse irradiation: The energy from the sky other than the sun, including the scattered irradiation from both clouds and clear sky.

Economic limit: A point in time when the anticipated cumulative net operating cash flows from the project are expected to be negative.

Entitlement: The quantity of *useful solar 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.

Establishment: 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.

Exploration projects: Projects associated with the investigation of one or more potential resource sources.

Foreseeable future: The period of time that a *solar project* can make a reasonable projections of future market conditions, events or other conditions that determine the economic viability or other factors of a *solar project*.

Ground reflected irradiation: the energy from the sun that has been reflected upward from the ground.

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 $W\text{-}m^{-2}$.

Non-commercial projects: Projects that are at an early stage of evaluation in addition to those that are considered unlikely to become commercially feasible developments within the foreseeable future.

Potentially commercial project: Projects that are expected to be developed in the foreseeable future, in that the quantities are assessed to have reasonable prospects for eventual economic production, but technical and/or commercial feasibility has not yet been confirmed. Consequently, not all Potentially Commercial Projects may be developed.

Project lifetime: the minimum remaining period of time that a project is expected to operate.

Radiant energy (or radiance): The amount of energy emanating from the sun. Radiant energy (sometimes referred to as radiant intensity) decreases at the rate of the inverse square of the distance from the source.

Reasonable expectations: The likelihood of obtaining necessary regulatory approvals, permits and contracts necessary to implement the *solar project*.

Reasonable time frame: The time frame within which all approvals, permits and contracts necessary to implement the *solar project* are to be obtained. This should be the time generally accepted as the typical period required to obtain approval, permits or contracts.

Reference point: The location through which useful solar energy passes and the quantity of useful solar energy is measured or estimated.

Set period: For a national level assessment this may correspond with the *lifetime* of competing energy sources, for example, the *lifetime* of non-renewable energy resources, or alternatively an average *project lifetime*.

Solar 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 $MJ\text{-}m^{-2}$.

Solar radiation: This term is often used interchangeably with solar energy and irradiation and, less commonly, insolation.

Solar resources being explored: Quantities of *useful solar energy* under investigation.

Solar site: a location with access to solar irradiation.

Solar technologies: The devices and practices that utilise energy from solar irradiation.

Total solar irradiation: Direct beam and diffuse irradiance and their sum (global irradiation), as well as reflected irradiation.

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.

Solar project: the site(s), technologies and activities over which decisions are made with the aim of getting energy from solar irradiation.

Annex I

United States Energy Resources 1989

1. The "Characterization of US Energy Resources and Reserves" published by the United States Department of Energy (DOE) in 1989 assessed energy resources from a variety of renewable and non-renewable energy sources (Table 8).

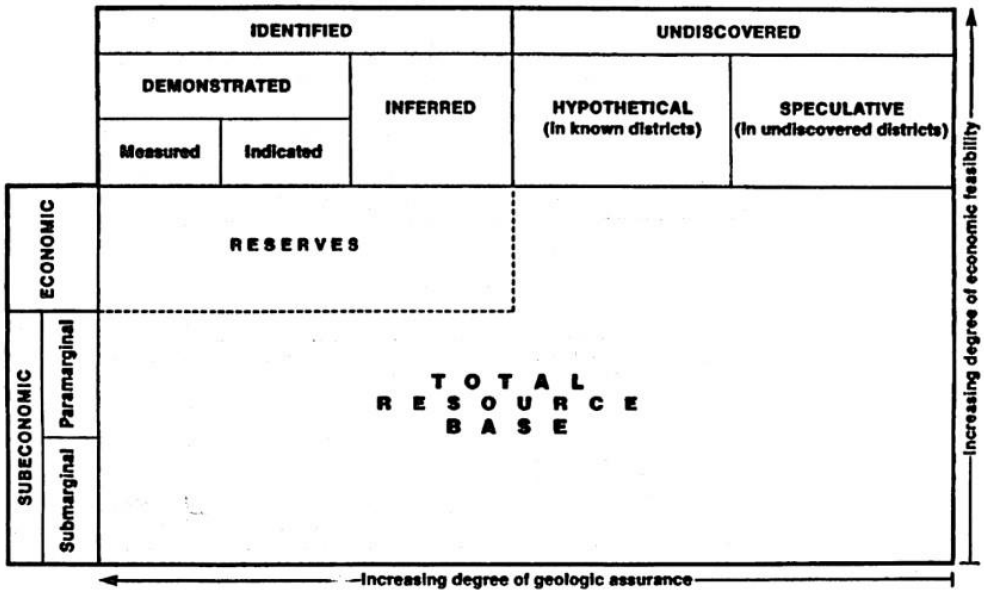
Table 8
Energy sources assessed in the characterisation of US energy resources and reserves

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. Resources were classified using three simplified categories drawing from the McKelvey diagram (Figure 8). 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.

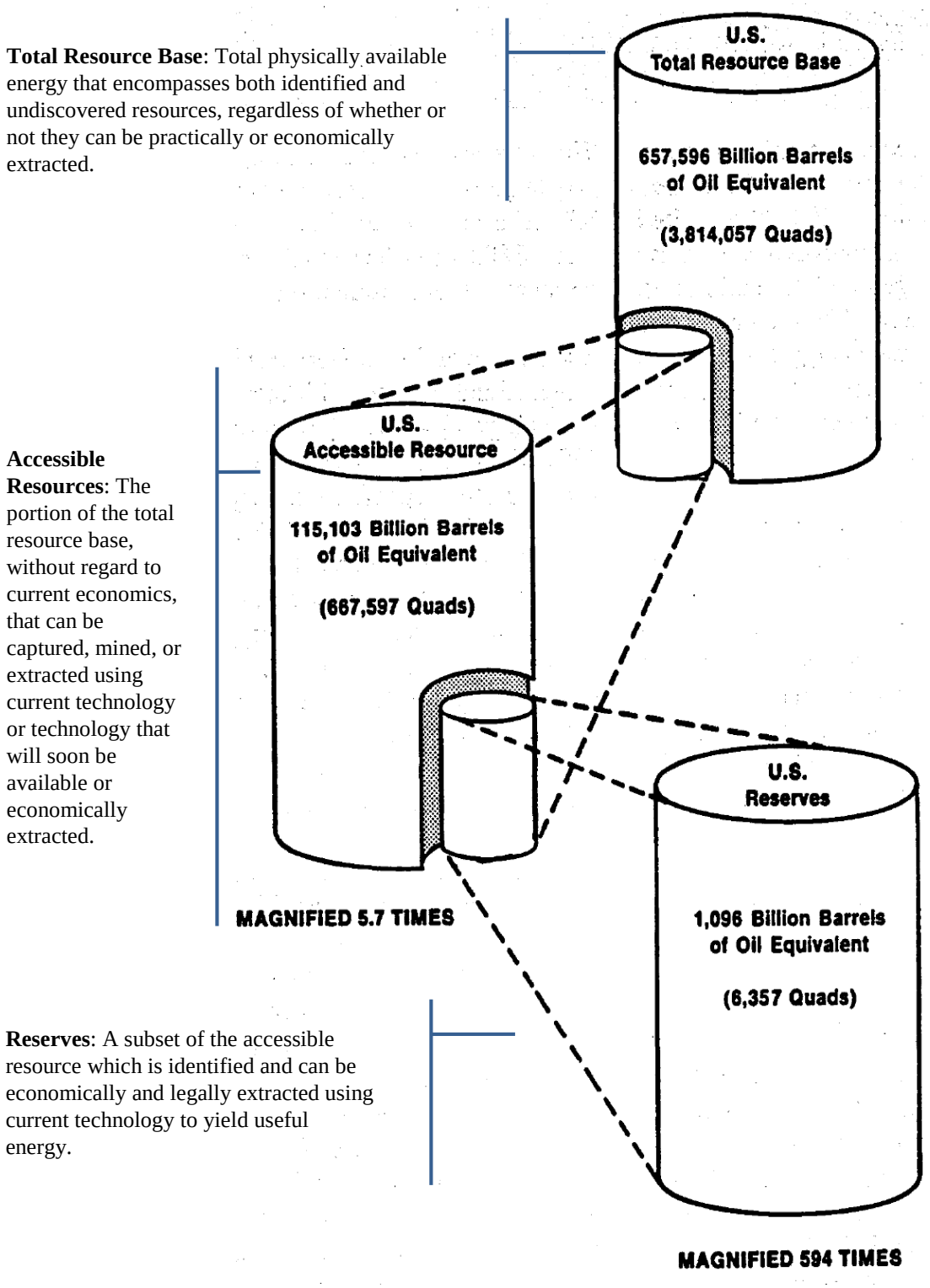
3. Reserves had the greatest physical assurance and economic feasibility and were defined as "a subset of the accessible resource which is identified and can be economically and legally extracted using current technology to yield *useful solar energy*." (page 1, DOE 1989). Accessible resources were defined 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 VIII
McKelvey diagram



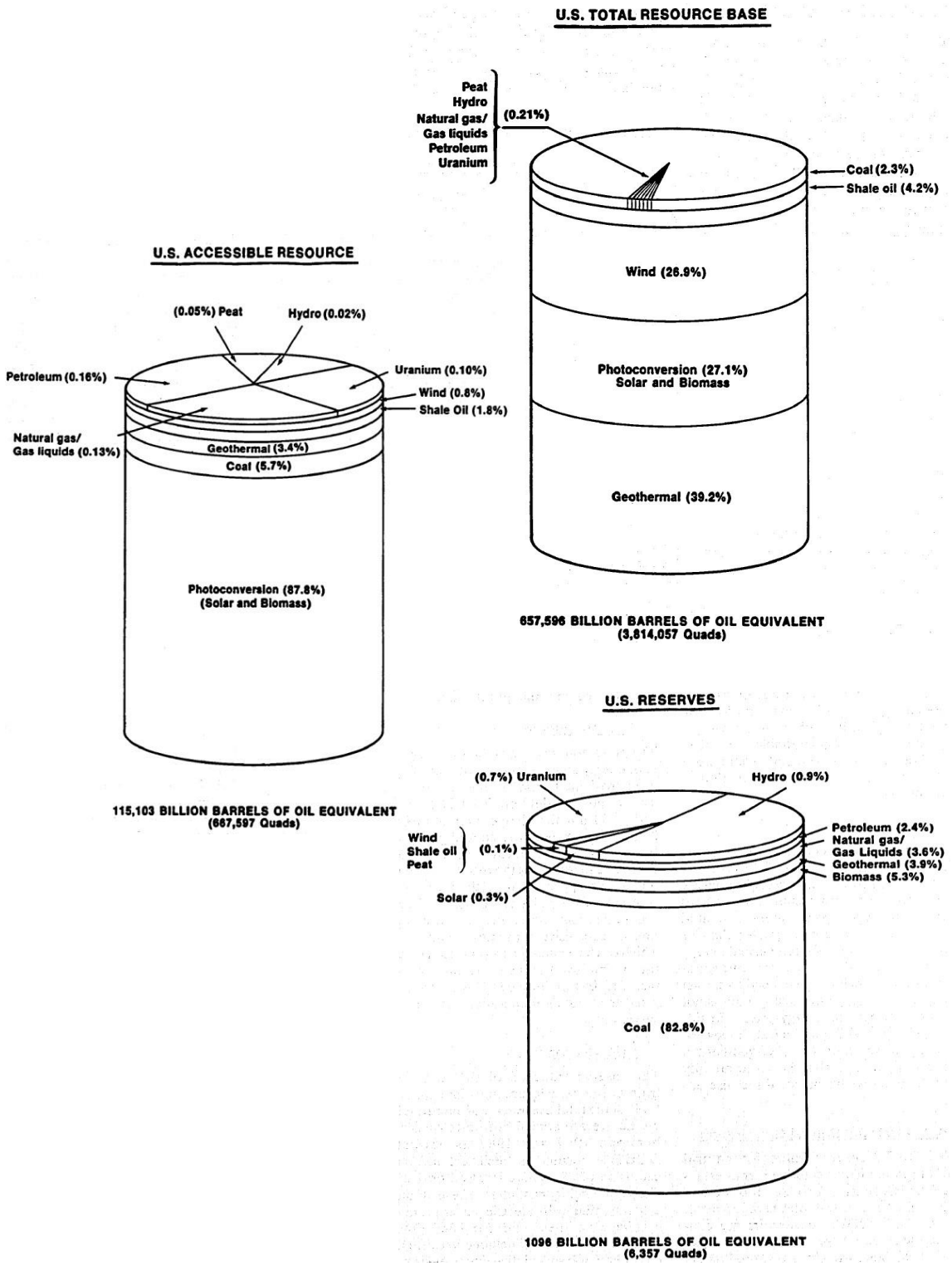
4. The DOE made estimates of the reserves, accessible resources and total resource base for the energy sources in Table 10 and presented the results graphically (see Figure 9 and Figure 10). Figure 9 presented the total energy reserves and illustrated the relative proportions. Figure 10 presents the results for each type of energy source.

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



Source: Modified from DOE 1989.

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



Source: DOE 198.

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 solar 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 11 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 resources divide the economic potential into two parts with the darkest part being commercial solar resources and the slightly lighter part being other solar resources.

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

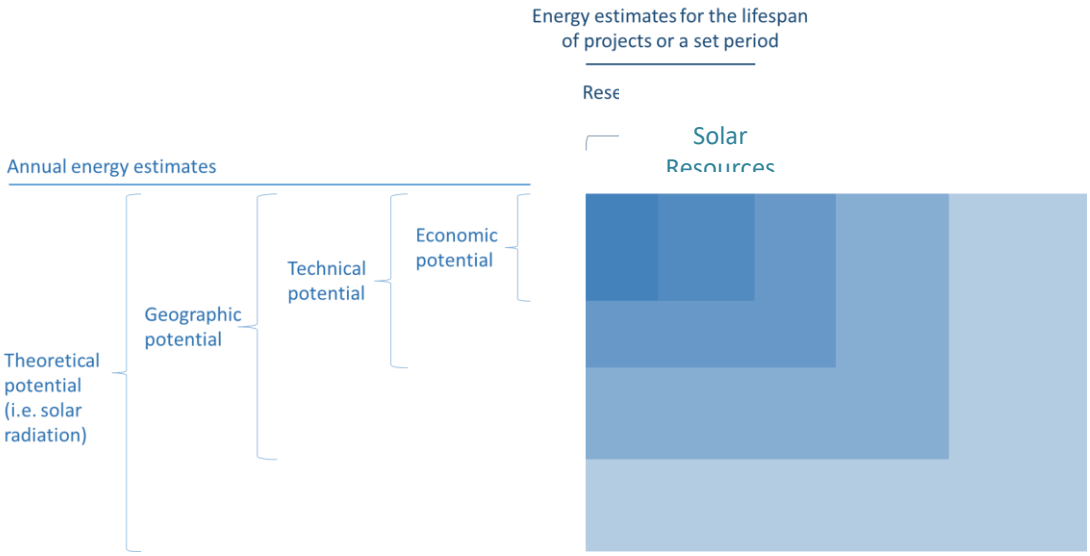
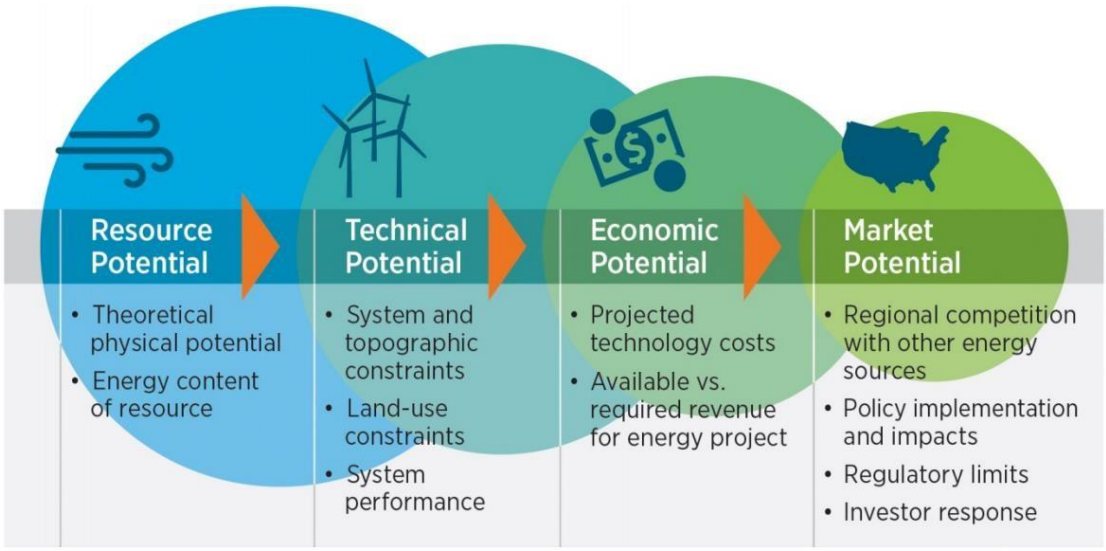


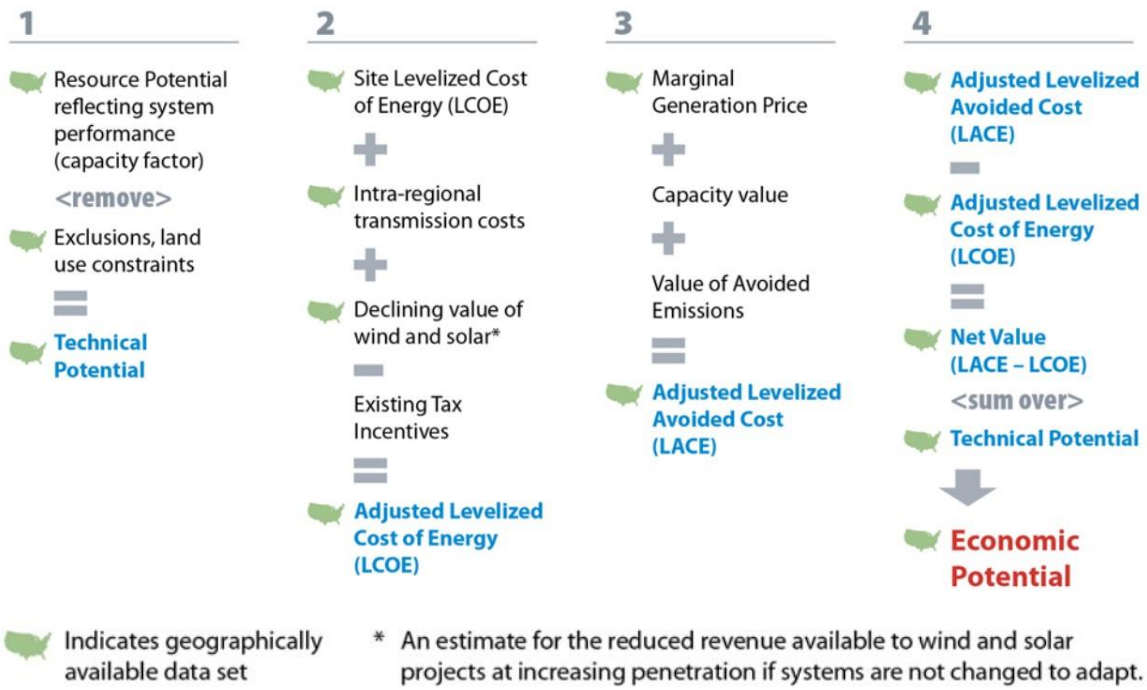
Figure XII
Types of renewable electricity generation potential identified by NREL



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 12). "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 13). 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 XIII
Generalized NREL method for calculating economic potential of renewable energy sources based on high geospatial resolution data



Source: Brown et al. 2016.

Annex III

Technical Risks

Table 9
Indicative list of technical risks for solar PV projects

Stage	*Activity*	*Risks*
On production (i.e. operational)	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-operational	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.

Stage	*Activity*	*Risks*
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