Twenty-first meeting of the Advisory Expert Group on National Accounts

Washington, D.C.
October 18–20, 2022

SNA/M4.22/14

WS.11 Renewable energy resources

Guidance note on the treatment of renewable energy resources as assets

2025 SNA Revision

April 2022

Summary of recommendations

This guidance note recommends recognition of renewable energy resources under certain conditions as natural resource assets in the revised SNA. The absence of renewable energy resources from the current SNA asset boundary is a concern from the point of view of assessing the environmental sustainability of economic activity. Since fossil fuel resources are included within the asset boundary, there is an imbalance in the way in which the national accounts treat non-renewable and renewable energy resources. Given the climate-related consequences of fossil fuel use, this imbalance risks sending distorted signals to decision makers regarding the relative economic importance of carbon-intensive, non-renewable energy sources versus less climate-damaging renewable sources. Renewable energy resources already account for 30% of global electricity production and are the fastest growing source, according to the International Energy Agency. Moreover, governments are beginning to capture the associated rents. They have long done so in the case of hydroelectric resources and are starting to do so in the case of newer renewables, like wind in the United Kingdom and Canada. As they expand in the future, the overall value of renewable energy resources will become too economically important to ignore in the national accounts. Doing so would permit an imbalance between the value of the assets recognized in the capital account and the income measured in the production account.

It is important to be clear as to what “renewable energy resources” are and how they are related to the topic of interest here, renewable energy assets. In keeping with the renewable energy specifications of the United Nations Framework Classification for Resources (UNFC; United Nations Economic Commission for Europe, 2020), it is taken that renewable energy resources comprise the cumulative quantities of kinetic, heat or radiative energy recoverable from moving water (hydro and ocean energy), moving air (wind energy), hot underground and surface rock and water (geothermal resources) and incident solar radiation (solar resources). The physical unit of measure for these resources is the joule in the SI system (other units that could be used include BTUs, tonnes of oil equivalent or watt-hours).

Not all renewable energy resources qualify as economic assets however. In further keeping with the general definition of an asset, only those renewable energy resources that are viable for use in economic production under prevailing technological and economic conditions qualify as assets. These resources correspond to those that would be classified to the UNFC category “commercial projects”. More specifically, these are the renewable energy resources that provide inputs into renewable energy production facilities where extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions; all necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe; economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive; extraction is currently taking place; or, implementation of the development project is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a development project.

The stock of renewable energy assets in a country at a given point in time is, then, the cumulative quantity of renewable energy resources “harvestable” by the commercial renewable energy projects in existence at the time. The UNFC recommends limiting the quantification of renewable energy resource stocks to by considering lifetimes for existing commercial projects. Lifetimes can be determined from the design basis of the facilities or based on industry practice/benchmarks. The fact that renewable energy assets can be characterized in physical terms permits use of the standard accounting concept of “price times quantity” as the basis for valuing the assets, where their price is the rent that arises during their use in a production process.

Given the above, it is clear that a remote river with no hydroelectric generation facilities on it, nor any under such facilities under construction, is not a renewable energy asset. Nor is an air current in which no wind turbine currently stands (or is imminently being installed) or a ray of incident solar radiation that does not fall on an existing or imminent energy capturing device such as a photovoltaic cell or a mirror in a concentrated solar plant. This is consistent with the treatment of other natural resource assets in the SNA and SEEA-CF. For example, the SNA and SEEA-CF recognize timber in a forest (another renewable resource) as an asset only in instances where that timber may be commercially logged at a profit under existing technological and economic conditions. Remote forests with no potential for logging do not qualify as assets. Similar criteria are applied to defining other renewable and non-renewable natural resources as assets in the SNA and SEEA-CF.

In this guidance note, we review the accounting concepts and methods relevant to treating renewable energy resources as assets and make several recommendations for their application in the context of the revised SNA. These recommendations are rooted in both the theory and practice of national economic and environmental accounting as laid out in the SNA and the SEEA-CF. Where best practices are unclear or simply unrealistic, our recommendations are guided by the need to provide practical, useful information to allow management of a country's natural resource assets.

Neither the SNA nor the SEEA-CF defines a complete and internally consistent approach to the treatment of renewable energy resources as assets. The SNA has little to say about these resources explicitly but what is written implies they do not qualify as economic assets because ownership rights cannot be enforced. The SEEA-CF treats them in detail, considering their asset value to be captured in associated land values. We find, however, that this treatment fails to adequately address renewable energy generation that 1) is not associated with land (offshore wind, solar and ocean resources); 2) exists under ownership rights clearly separated from land (hydroelectric and most geothermal resources); or 3) is associated with land that has no economic value and does not appear in the national accounts (hydroelectric and most utility-scale solar/wind resources). In the few cases where renewable energy resource use is in fact bundled with land that is both owned and valued in the national accounts (for example, wind turbines on agricultural land), the SEEA-CF's approach assumes that land markets accurately "price in" the value of associated resources. While the SEEA-CF's argument has *prima facie* appeal, we find the assumptions underlying it do not stand up fully under examination and that is unlikely (impossible in many instances) that existing land values in the SNA will capture renewable energy asset values. We find as well that a review of the empirical literature on the relationship between renewable energy production supports this view. Available studies do not point to a consistently positive relationship between renewable energy production and land values. Evolutions in market participants' knowledge and policy contexts both within and among countries appears to play a significant role in determining the size – and even the direction – of the relationship between land values and renewable energy production.

We recommend instead that a separate asset category for renewable energy resources be created within the revised SNA (and, ultimately, the SEEA-CF) and that the value of these assets be partitioned between their governments (their legal owners) and renewable energy companies, since both governments and renewable energy companies may be considered economic owners of the resources.[1] We consider the risk of double

---

[1] Here we refer to the guidance on this issue laid out in the *Guidance note on Accounting for the Economic Ownership and Depletion of Natural Resources* prepared by Peter van de Ven and Mark de Haan.

counting between the existing land asset and this new asset category to be low on both economic and accounting grounds; specifically, land markets today likely fail to completely internalize renewable energy resource values (where such resources are bundled with land) and there is rivalry between use of some land (e.g., farmland) for renewable energy generation and other uses. Furthermore, national accountants can employ practical means in compiling national balance sheets that avoid of double counting.

If, as we recommend, renewable energy resources are to be recognized as assets in the revised SNA, a method must be found to value them. **The SEEA-CF and (somewhat less clearly) the SNA recommend a residual value method for natural resource assets in general. In this, asset value is taken to be equal to the present value of the future stream of rent flowing from the resource. Rent, for its part, is calculated as the difference between resource revenues (less specific subsidies received plus specific taxes paid) and production costs, including returns to labour and produced capital. We recommend that the same approach be applied to the valuation of renewable energy resources in most instances in the revised SNA, noting that pilot empirical work by the World Bank (Smith et al., 2021) demonstrates that this approach yields results that are both plausible and defensible in the context of broader economic trends.**

The validity of the residual value method rests on an assumption of renewable energy markets approximating long-run competitive equilibrium and we acknowledge that markets in many countries – especially in the developing world – do not meet this standard. However, data from the OECD suggest considerable movement toward competitiveness since deregulation of electricity markets began, at least in developed countries. Heavy subsidization of renewable energy production and consumption remains, however, and this poses a clear theoretical challenge to the residual value method. **Where the residual value method is inappropriate due to subsidization or other market distortions, an alternative approach, known as the "least-cost alternative" method is recomended.** This approach attempts to identify rents by comparing the cost of electricity generation with and without renewable resources. This technique has been applied with varying sophistication to the valuation of hydroelectric resources.

Our primary rationale for recommending the residual value method in most instances is consistency: the method is widely applied in country practice and by the World Bank[2] and UNEP[3] to other environmental assets that policy-makers must evaluate against renewable energy resources. We consider the potential pitfalls of applying this approach, notably the payment of subsidies on renewable energy production, consumption and equipment manufacture. While care must be taken, we note that heavy subsidization is not unique to the renewable energy sector.

---

[2] See the World Bank's *Changing Wealth of Nations* series of reports.

[3] See the World Bank's *Inclusive Wealth* series of reports.

1 Introduction[4]

In this guidance note (GN), we address the treatment of renewable energy resources as assets in the *System of National Accounts 2008* (SNA; European Commission *et al.*, 2008) and in the related *System of Environmental-Economic Accounting 2012 – Central Framework* (SEEA-CF; United Nations *et al.*, 2014a). We find that current guidance in the SNA and the SEEA-CF does not define a fully satisfactory approach to measuring renewable energy resources. The SNA currently excludes them from its natural asset boundary and offers only a limited discussion of them. The SEEA-CF's treatment, while more extensive, is found to require re-examination in certain aspects. In particular, the SEEA-CF's view that renewable energy resource values are already captured in the value of the associated land does not address renewable energy generation that 1) is not associated with land (offshore wind, solar and ocean resources); 2) exists under ownership rights clearly separated from land (hydroelectric and most geothermal resources); or 3) is associated with land that has no economic value and does not appear within the scope of land resources measured in the SNA (hydroelectric and most utility-scale solar/wind resources). Only the value of privately owned land used for renewable energy generation (e.g., solar and wind installations on private land) is liable to reflect the value of the renewable energy resources.

The absence of renewable energy resources from the SNA's asset boundary is a concern from the point of view of assessing the environmental sustainability of economic activity. Fossil fuel resources are included within the SNA's asset boundary, leading to an imbalance in the way in which the system treats energy resources. Given the climate-related consequences of fossil fuel use, this imbalance risks sending distorted signals to decision makers regarding the relative economic importance of carbon-intensive, non-renewable energy sources versus less climate-damaging renewable sources.

To address this concern, we propose creation of a new asset category for renewable energy resources in the revised SNA (and in any future revision of the SEEA-CF) and the partitioning of the value of the assets between their legal owners (governments) and economic owners (renewable energy companies). We argue that valuation of these resources can proceed in most instances *via* the "residual value" method recommended in the SEEA-CF (and the SNA) for the valuation of other natural resource assets. An alternative approach, known as the "least-cost alternative" method, may also be applicable, particularly in countries where electricity markets are very far from equilibrium.

The significant and growing importance of renewables means there is an economic case for their inclusion within the revised SNA's asset boundary. Available evidence, limited as it may be, suggests that renewable energy assets – especially hydroelectric resources – may already be worth trillions of dollars worldwide. Extrapolating from partial findings for Canada (Gillen and Wen, 2000), Canada's hydroelectric resources alone may be worth $US380 billion in current dollars. This would place them on par with the value of Canada's large fossil fuel reserves. As solar and wind energy expand and nascent technologies like geothermal and wave energy are developed, the overall value of renewable energy assets will likely become too economically important to ignore in the national accounts. Doing so would permit an imbalance between the

---

[4] This note has been prepared by Robert Smith of Midsummer Analytics. We wish to thank Karen Wilson and Patrick O'Hagan, both formerly of Statistics Canada, for sharing their knowledge and insights regarding the national accounts and its treatment of natural resource assets. We are grateful as well to Grzegorz Peszko, Glenn-Marie Lange, Albertine Potter van Loon, Shun Chonabayashi, Stefanie Onder and Catherine Van Rompaey of the World Bank for their helpful direction and comments during its preparation. Any errors or omissions remain entirely our own.

value of the assets recognized in the capital account and the income measured in the production account.

Our discussion in this GN is focused on geothermal, hydroelectric, solar and wind resources and primarily on their use to generate electricity. We realize this ignores other important benefits of these resources; for example, the use of geothermal and solar resources directly as sources of heat. We realize as well that other renewable energy resources are of economic importance, most notably biological resources (fuelwood and other biomass) but also ocean energy (waves and tides). Our restricted focus is partly pragmatic – to keep the GN to a reasonable length – but also reflects the fact that there is great attention focused today on renewable electricity generation. Renewable resources offer the possibility of an emissions-free source to meet the world's growing need to provide homes, factories, communications and, increasingly, transportation networks with electricity. We would note, however, that the arguments we present with respect to geothermal, hydroelectric, solar and wind electricity apply equally to other renewable energy sources.

The remainder of the GN proceeds as follows. In Section 2 we discuss the treatment of renewable energy resources as assets, starting from what is proposed in the SNA and SEEA-CF. Section 3 is devoted to a discussion of the options considered for the inclusion of renewable energy assets in the SNA and our recommended approach, which is grounded in theory but with due regard for practicality. Section 4 deals with the conceptual aspects of our recommended approach, while Section 5 deals with its practical aspects. Several appendices provide additional information where necessary.

2 Existing material

In this section, we discuss the current treatment of renewable energy resources as economic assets. This requires discussion of the way assets are defined in general terms in SNA and the SEEA-CF. We follow this with more detailed discussions of their treatments of natural resources broadly and of renewable energy resources specifically. The SEEA-CF treatment of renewable energy assets, in particular, is reviewed thoroughly.[5]

2.1 Renewable energy resources as economic assets

2.1.1 Assets in general terms in the SNA and SEEA-CF

Assets are socially defined entities that can, and do, evolve over time. Both the asset boundary (the criteria that separate assets from non-assets) and the domains over which it extends depend on specific economic and institutional arrangements. The evolution of asset definitions is of central importance to any effort to account for renewable energy resources, because these resources are emerging as important parts of economic life across the globe. Some, like run-of-river hydropower, have been used for millennia. Others, such as geothermal, solar and wind electricity, have only emerged recently as widespread inputs to production as technology and consumer preferences change.

When natural resources serve no purpose in economic production, no reason exists for them to be recognized as assets. Conversely, when resources become productive (that is, used in economic activity), they can be recognized as assets for national accounting purposes (see, for example, the case of the radio spectrum discussed in Section 2.1.3). The emergence of newly productive economic resources is often followed by legal recognition of associated property rights, a pre-condition for the resources to be viewed as assets. This is already occurring in the instance of renewable energy resources. For example, Danish authorities have awarded damages to the owner of a wind energy farm due to losses caused by construction of another farm upwind, implying that the wind is a resource with benefits to which one individual's access is not to be unduly restricted by another (Diamond, 2015). In the United States, governments have begun to develop regulations to ensure access to sun and wind for the production of energy by restricting development on neighbouring properties (Diamond and Crivella, 2011; Landis, 2019).

According to the SNA, an asset is an entity over which ownership rights are enforced "by some unit, or units, and from which economic benefits are derived by their owner(s) by holding or using them over a period of time." (SNA ¶1.46). Key to this definition is the notion of an *economic* benefit, which is defined in the SNA as a benefit, measurable in monetary terms, from the use of an entity in the context of a market activity (production, consumption or accumulation) or from holding the entity as a store of monetary value (SNA ¶3.19). For something to be considered an asset, then, any benefits it provides must flow in the context of productive activity. This excludes entities that provide benefits outside the scope of human productive actives from consideration as assets. This approach means that economic assets are "revealed" by these activities (often market activities); anything outside them may be excluded.

Also key to the SNA asset definition is the notion of ownership. The SNA is explicit in noting that ownership need not be private for an entity to qualify as an asset (SNA ¶1.46). Collective ownership by all members of a country is acceptable, allowing the SNA to define natural

---

[5] Brief descriptions of renewable energy resources in physical terms are provided in Appendix 1.

resources – like oil reserves – owned by governments on behalf of all citizens as assets. Collective ownership does not extend beyond the national level, however, since the focus of the SNA is on accounting for the economies of nation states; this explains the SNA's rejection of the high seas as an economic asset.

The SEEA-CF follows the SNA almost completely in its basic asset definition, with one difference. Unlike the SNA, which focuses only on assets that provide economic benefits, the SEEA-CF extends its asset boundary to include "all resources that may provide benefits to humanity", opening the door to inclusion of resources that provide both economic and non-economic benefits (SEEA-CF ¶5.14). However, resources of the latter type are measured only in physical terms in the SEEA-CF and are not referred to as "economic" assets. Only assets that provide economic benefits are measured in monetary terms in the SEEA-CF. For example, in physical terms, all land within a country lies within the asset boundary of the SEEA-CF, while, in monetary terms, some land may have zero economic value and hence be excluded from consideration as an economic asset.[6]

2.1.2 Natural resources as assets in the SNA and SEEA-CF

In keeping with its general definition of assets, the SNA recognizes as assets only natural resources over which ownership rights can be – and are – enforced. The specific natural resources recognized as assets in the SNA are:

- land (including soil and associated surface water)
- mineral and energy resources found on and under the earth's surface (including underwater)
- biological resources (trees, plants and animals) that grow under natural conditions (as opposed to those, like farm animals or plantation forests, that grow under managed conditions)
- surface and groundwater, so long as it is regularly used for extraction
- electromagnetic (radio) spectrum used for telecommunications purposes.

As with its basic definition of assets, the SEEA-CF largely mirrors the SNA in its recognition of natural resources as assets, though it treats some resources – especially land – differently. The SEEA-CF places land in a separate category from other natural resource assets, seeing it as an asset only from the perspective of its use for the provision of space (¶1.49). "Soil resources" are a separate asset unto themselves in the SEEA-CF. In contrast, the SNA considers "land" to comprise both the space it provides as well as the soil underlying it. The other assets in the SEEA-CF natural resource category are, as in the SNA: mineral and energy resources, biological resources and water resources. Interestingly, however, the SEEA-CF does not recognize the radio spectrum as a natural asset, arguing that it is "not part of the biophysical environment" (SEEA-CF ¶5.36, footnote 48).

When it comes to the question of ownership of natural resource assets, the SNA is clear that the general principle upon which asset ownership is to be determined is economic ownership: "assets appear on the balance sheet of the unit that is the economic owner[7]". The SNA goes on,

---

[6] The classic example is remote public land, such as a wild forest, that provides no economic benefits. Such land is generally not included on national balance sheets. Australia is an exception to this; a measure of the value of "other land" (government-owned land that is not used for residential, commercial or other economic purposes) is included on Australia's national balance sheet (Cadogan-Cowper and Comisari, 2009).

[7] The economic owner of an asset is an entity that has agreed by way of contract to accept the risks and rewards of using the asset in production in return for an agreed amount to be paid to the asset's legal owner. The legal owner is the unit entitled in law to the benefits of the asset's use (SNA ¶2.47).

however, to note that “when a natural resource is the subject of a resource lease, the asset continues to appear in the balance sheet of the lessor [e.g., a government] even though most of the economic risks and rewards of using the asset in production are assumed by the lessee [e.g., a resource company]” (SNA ¶13.3). There is, then, an inconsistency in the SNA’s approach to asset ownership; ownership is attributed to the economic owner unless the asset in question is a natural resource, in which case ownership is attributed to the legal owner. The SNA explains this by stating "…there is no wholly satisfactory way in which to show the value of the [natural resource] asset split between the legal owner and the extractor, [so] the whole of the resource is shown on the balance sheet of the legal owner” (SNA ¶13.50). The SNA acknowledges that this treatment is not “wholly” satisfactory. One concern is that the value of any natural asset recorded on a government’s balance sheet (as the legal owner) would not be in line with the actual rent earned by the government on that asset except in cases where royalty payments succeed in extracting all resource rent from resource companies. This is rarely, if ever, the case. Thus, the valuation of the asset on the national balance sheet would not, in fact, reflect the actual economic value of the asset to the government.

The SEEA-CF, for its part, states that “the economic value of mineral and energy resources should be allocated between the extractor and the legal owner” (SEEA-CF preface ¶33) and that “the allocation of assets and the resulting estimates of institutional sector net worth should reflect the expected future income streams for each unit from the extraction of the resources” (SEEA-CF ¶5.223). There is no more explicit statement in the SEEA-CF regarding the recommended approach to attributing ownership of natural resource assets. Based on these two excerpts, the SEEA would seem to diverge with SNA treatment, suggesting that the value of natural resource assets should be divided between the legal and economic owners rather than being attributed wholly to the former.

A clear and explicit treatment of this issue is found in the *Guidance note on Accounting for the Economic Ownership and Depletion of Natural Resources* prepared by Peter van de Ven and Mark de Haan. **We agree with the approach to sharing of ownership of natural resources laid out in that note and recommend that it be considered as the guidance for treating the ownership of renewable energy resources as well.** We would note that the guidance of van de Ven and de Haan is consistent with the approach taken by Statistics Canada (2015), the only statistical agency worldwide to have developed sectored and quarterly balance sheet accounts for natural resources.[8]

2.1.3 Renewable energy resources as assets in the SNA and SEEA-CF

The SNA says little regarding the specific treatment of renewable energy resources as assets. It simply states, as noted earlier, that entities “over which no property rights can be exercised” do not qualify as assets, using the high seas and atmosphere as examples. This suggests that both solar and wind resources would not be recognized as assets within the SNA, since they are closely linked to the atmosphere. What the SNA actually intends with respect to solar and wind resources is unclear, however, as neither is mentioned anywhere in the text. It is worth recalling that the SNA does recognize the radio spectrum used by telecommunications companies as a natural resource asset (SNA ¶10.185). The reasons for this are not fully spelled out but appear related to 1) the unprecedented demand for access to the spectrum created by the arrival of 3G cellular telephone technology in the early 2000s and 2) the fact that use of the spectrum is rival (users can disrupt and degrade one another’s signals) but not physically excludable (no user can physically prevent another’s use). In response, governments expanded regulation of access to the spectrum through auctioning of cellular communications licenses beginning in the late

---

[8] Statistics Canada, Table 36-10-0580-01, *National Balance Sheet Accounts*. Available here.

1990s. This generated very large public revenues (Jilani, 2015). Acknowledging this, the drafters of the SNA[9] agreed to include the radio spectrum within its asset boundary. Interestingly, they argued that "land, mineral deposits and the spectrum are similar types of assets" and consequently classified the spectrum as a natural resource asset (SNA ¶17.317). This is an example of an entity previously deemed to have no economic value and over which ownership rights were not exercised subsequently meeting both SNA asset boundary requirements through government's decision to exercise public ownership rights prompted by changing economic circumstances. The potential parallels with renewable energy resources are clear.

As with solar and wind resources, the SNA is silent on geothermal and hydroelectric resources. It does, however, acknowledge that water "regularly" used for extraction can be considered a natural resource asset. Assuming the temporary diversion of water through electric power turbines constitutes regular extraction, it is plausible that water in a hydroelectric power reservoir could be considered an asset in the SNA. Similarly, extraction of hot water from an underground geothermal reservoir may be sufficient for the SNA to recognize those reservoirs as assets (though it is unlikely that extraction of heat from dry, hot bedrock would qualify). Again, the SNA's intentions are unclear, as neither resource is mentioned explicitly.

In contrast to the SNA, the SEEA-CF is explicit and detailed in its discussion of renewable energy resources as assets. The SEEA-CF recognizes that energy from renewable sources is important in many countries and increasingly seen as an alternative to fossil fuels and nuclear power. Renewable energy resources recognized in the SEEA-CF include, in addition to the four considered in this note, wave/tidal power and undefined "other" sources. The SEEA-CF argues that these resources

> "cannot be exhausted in a manner akin to fossil energy resources and, unlike biological resources, they are not regenerated. Thus, in an accounting sense, there is no physical stock of renewable sources of energy that can be used up or sold" (SEEA-CF ¶5.226).[10]

The SEEA-CF therefore limits physical measurement of these resources to measurement of the flows of energy produced from them; no measurement of the stock of the resources in physical terms is proposed. Further, physical measurement of renewable energy production is limited to the amounts actually produced by currently installed generation infrastructure. No account is taken of the potential amounts of energy that could be produced from renewable sources if investment and technology were to change in the future. This is consistent with the SEEA-CF's exclusion of sub-soil energy resources that are not currently under active development from consideration as natural resource assets.

Though the SEEA-CF argues that the concept of a physical stock does not apply to renewable energy resources, it does acknowledge that the resources have value unto themselves, recognizing that a resource does not have to be measurable in physical terms in order to have a monetary value. The SEEA-CF argues that the value of renewable energy resources should be captured in the value of the land associated with renewable energy generation facilities: "Opportunities to earn resource rent based on sources like wind, solar and geothermal should be expected to be reflected in the price of land" (SEEA-CF ¶5.228).[11] Thus, the asset value of

---

[9] The SNA was undergoing a major revision around the same time as the spectrum issue came to the fore.

[10] The viewpoint that renewable energy resources cannot be "regenerated" is puzzling, as solar, wind, hydroelectric and geothermal resources would all seem to be so. The first three will regenerate so long as the sun shines. The fourth will regenerate so long as the earth's core remains molten. In both cases, the processes of regeneration are expected to last for billions of years.

[11] For its part, the specialized SEEA-Energy handbook devoted to accounting for energy resources (United Nations, 2019) states that "the sun and the wind are not considered to be environmental assets" for its purposes (¶2.24) and

wind power should, according to the SEEA-CF, be captured in the value of land where windmills are sited or where they might be one day. Similarly, the value of solar and geothermal resource assets should be reflected in the value of the associated land, even though it is not clear in the case of geothermal resources (particularly deep-earth geothermal) what would constitute the associated land. In the case of hydro resources, the SEEA-CF argues it is more relevant to consider the value in relation to the water used to generate the energy than to an area of land. Thus, in the case of hydropower, it is the value of the water resource that would capture the value of the hydro asset according to the SEEA-CF.

2.1.4 Exploring the assumptions underlying the SEEA-CF's treatment of renewable energy resources

While the SEEA-CF's argument that renewable energy resource values will arise "due to the scarcity of the sites used for energy generation" (SEEA-CF ¶5.310), has *prima facie* appeal, the assumptions underlying it deserve further examination.

The SEEA-CF's argument seems predicated[12] on the notion that if two parcels of otherwise identical land differ only in their use (or potential use) to generate renewable energy, their market price should reflect this difference (with the one with higher renewable energy generation or potential being the more highly valued). Sites for renewable energy production are not infinite in supply, especially not for geothermal and hydroelectric resources, both of which depend on specific attributes of the earth's crust or its hydrologic features. Thus, it would be reasonable to expect areas of land with high geothermal or hydroelectric potential to command relatively higher prices than those without, other things equal. Sites suitable for solar and wind production are also in limited supply, even if the sun shines and the wind blows everywhere. Variations in both the degree of sunshine/wind speed and the physical characteristics of sites (angle to the sun or wind, obstructions, prohibitions, existing land uses) impact suitability – and therefore value – for solar/wind production.[13]

Several assumptions are implicit in the SEEA-CF's argument around the value of renewable energy resources in relation to land:

- markets for renewable energy production are in something close to long-term competitive equilibrium
- property rights to land include the rights to the economic benefits flowing from any associated renewable energy generation, and
- land associated with renewable energy production has a positive and measurable economic value and that this value is captured, at least in principle, in the national accounts.

Each of these assumptions is considered in turn below.

---

repeats the SEEA-CF position that renewable energy resource values should be captured in the value of the associated land (¶2.50).

[12] We say "seems predicated" because the basis for the SEEA-CF's argument is not spelled out explicitly anywhere in the text.

[13] Arguably, this is not true in the case of nations, like Saudi Arabia, with vast areas of desert with largely undifferentiated potential for solar power production and no other meaningful potential for economic use. Even in such cases, however, the principles of valuation would apply – but the supply of suitable land would so far outstrip demand that no opportunity cost would arise.

2.1.4.1 Renewable energy markets are close to equilibrium

For the value of land to reflect the value of any associated renewable energy assets, markets for renewable energy must be in something close to long-term competitive equilibrium. For long-term equilibrium to obtain, buyers and sellers of land require clear and reliable information to account for renewable energy generation potential in their assessments of land value. The points on which land buyers/sellers require clear and reliable information include, *inter alia*:

- the physical potential of the land in question for renewable energy production
- how the use of the land for renewable energy production might affect its value for other purposes (e.g., how installation of a wind turbine on farmland might affect its value as potential residential development site)
- the current and future demand for different forms of renewable energy
- the legal and regulatory frameworks for renewable energy, including property rights to the economic benefits of renewable energy production, government support for renewable energy production and capture of the associated resource rent, and
- the capital and operating costs of renewable energy production.

The extent to which clear and reliable information on these points is actually available to renewable energy investors is difficult to determine. Moreover, this availability likely differs considerably from country to country. In jurisdictions with relatively long histories of renewable energy production, such as Denmark and Holland, it may be the case that there is sufficient certainty on the above points for land transactions to reflect the value of renewable energy production. In jurisdictions where renewable energy production is newer and/or markets are in rapid evolution (which includes most of the world), it seems likely that uncertainty exists on many of these points, meaning that the economic benefits of renewable energy resources will be, at best, imperfectly factored into land prices. As an example of the uncertainty investors face, public perception of the desirability of renewable energy infrastructure – especially wind turbines and solar panels – is fickle. While citizens in many countries support renewable energy (PEW Research, 2018; European Commission, 2017), they can also object when projects are developed “in their backyards”. Opposition is driven by socioeconomic concerns, visual and sound impacts and environmental concerns (Bidwell, 2016; Enevoldsen and Sovacool, 2016) and has resulted in planned developments being scrapped, such as the Cape Wind project in Nantucket Sound, Massachusetts (Smith, 2007) and the White Pines wind project in Ontario.

Uncertainty regarding legal and regulatory environments can create considerable distortions in markets. A rational investor would want clarity regarding the allocation of the economic benefits of renewable energy production before making a large land purchase. Since those benefits would be expected to play out over decades, the challenges posed for the investor by uncertainties are multiplied. In another example, a solar energy investor in California had its panels blocked by neighbouring redwood trees. After a lengthy lawsuit, the owner of the solar array won out and the trees had to be removed (Borenstein, 2011). This suggests that property rights to renewable energy resources are recognized but are still a matter of some debate, even in California with its long history of production. Appendix 2 explores another source of uncertainty – what governments might do in the long run regarding solar and wind property rights.

The foregoing is not intended to suggest that renewable energy markets are chaotic and that long-run market equilibrium is but a distant dream. In fact, as discussed in Section 4.1.3 below, some renewable electricity markets – and electricity markets more generally – have moved in recent years toward long-run competitive equilibrium even if they cannot all be considered to have arrived there yet. Rather, the point is simply that enough uncertainty remains in many renewable energy markets to question whether the SEEA-CF’s assertion that land prices will capture renewable energy resource rents is valid. Our view is that it may be in a few instances but not in most. This view is supported by the empirical literature, which we review briefly below for both renewable energy production on farmland and on private residences.

Studies on the relationship between farmland prices and renewable energy demonstrated a mixed set of results, with some studies pointing to a positive relationship, others to a negative relationship and still others to ambiguous results. Haan and Simmler (2018), in a study for Germany, find that German feed-in tariff's for wind power led to capitalization of 18% of wind turbine profits into land prices.

Lai et al. (2019), in a spatially explicit study for Taiwan covering 2013-2017, find increased value of farmland in parts of their study area due to installation of solar panels, both for farmland used for solar power production and for surrounding farmland not yet used for such production. However, farmland in other parts of their study area showed decreased value. Lai et al. speculate this is because of differences in the installed solar capacity in different areas, with areas where full capacity has been reached showing negative effects and vice versa. Lee et al. (2021), in another study for Taiwan covering the period 2012-2019, considered the impact of Taiwan's "Two-Year Solar PV Promotion Plan" on farmland prices. They found that farmland prices fell after implementation of this policy, which, they hypothesize, is due to the Taiwanese government's declaration that only agriculturally inefficient farmland can be used for solar farms.

Lehn and Bahrs (2018a), in a study for North Rhine-Westphalia in Germany for the year 2013, find a statistically, though not economically, significant relationship between wind power production and farmland value. They conclude that agricultural characteristics of farmland (such as livestock density) and proximity of land to population centres were the main factors driving farmland value. In a related, spatially explicity study, again for North Rhine-Westphalia for 2013, Lehn and Bahrs also find a statistically signification relationship between farmland value and wind power production but only for farmland in the 90th percentile of value; for farmland in lower value quantiles, no statistically significant relationship was found.

Myrna et al. (2019), in a study for Saxony-Anhalt, Germany covering the period 2007-2016, show a small (0.4%) increase in farmland value for a doubling in installed wind turbine capacity. Sardaro et al. (2019) consider the impact of wind turbine production on farmers when the turbines are owned by a separate power utility rather than by the farmers. They find that renewable energy production has a negative value on farmland in these instances. Seifer et al. (2020), in another study for Germany that placed considerable emphasis on information asymmetries in farmland markets (which they characterise as "thin"), find that wind power is not a statistically significant variable in farmland prices. They note their findings are inconsistent with other studies (e.g., Haan and Simmler, 2018) but note these other studies referred to periods during which feed-in tariffs large and economically attractive to famers whereas their study includes transactions for 2014-2017 and German wind-energy tariff rates became variable in 2017.

As for studies considering the impacts on residential property prices from solar power production, several were found and all showed either small, positive or no net increases in property values. Qui et al. (2017), in a study for Arizona, USA, found a gross increase in house price of $28,000 (equivalent to 17% of median prices), which translated to a net increase of about $5,000 after the average cost of solar rooftop installation was considered. They found no price premium for houses with solar hot water heaters. In a study for Hawaii, USA, Wee (2016) found similarly that the net effect of solar rooftop installations on property values after accounting for installation costs was about $5000. Dastrup et al. (2012) in a study for California, USA, found essentially no net price increase after accounting for installation costs. In another study for California, USA, Hoen et al. (2012) concluded that "homes with PV systems sold for a premium over comparable homes without PV systems" but only yielding a "*near* full return on investment." (emphasis added). In a larger, multi-state study for the USA, Hoen et al. (2017) found that the price premium paid for houses with solar electric rooftop systems essentially exactly offset the average costs of installing those systems.

In a study for Perth, Australia, Ma et al. (2015) found that the premium received on residential properties seemed to cover both the costs of installation of the systems plus, in cases where the system qualified for preferred feed-in tariff (FiT) rates from government incentive programs, the future value of those benefits. A more recent study for Queensland, Australia (Lan et al., 2020) found that the average net price premium (exclusive of installation cost) was 21,403 AUD for properties with systems operating under a generous FiT rate of 44 cents/kWh but just 5,600 AUD when the FiT rate dropped to 8 cents/kWh. Both these Australian studies demonstrate the important of renewable energy policy contexts for determining the impact of RE production on property prices. They suggest that where FiT policies exist, property buyers will take those into account when purchasing a property with an existing rooftop solar system. They will pay a premium for those properties that reflects not just the cost of installation of the system, but also the value of the future payments made under the FiT regime. In cases where FiT policies are not in place, buyers seem in some cases to value the savings in energy costs solar systems offer (by paying small net premiums for properties with systems) and in other cases not to value these savings (paying premiums that cover only the cost of installation of the system itself). This suggest that buyers do not uniformly understand the economic benefits of solar rooftop ownership.

Overall, the farmland and residential property price studies we reviewed support the SEEA's contention that renewable energy production can positively influence land values where the benefits of that production accrue to the owners of the land. However, they also support our contention that even on private land, the size (and even direction) of this change is unpredictable today because markets are not yet in equilibrium. These studies point to the importance of real-world buying and selling decisions, which are influenced by both policy contexts and market participants' knowledge, both of which continue to evolve within and among countries. The simulations of the impact of policy reforms on the value of renewable and non-renewable energy wealth in Angola and South Africa in Smith et al. (2021) further demonstrate how policies can destroy or increase the resource rents accruing to renewable energy resources.

Thus, our view remains that evolving market conditions mean that land values cannot yet be taken as reliable guides to the value of renewable energy assets exploited by private landowners, even if they should in theory.

2.1.4.2 Property rights and renewable energy resources

For the value of land to positively reflect the value of any associated renewable energy assets, it must be the case that the land owner also owns the rights to the economic benefits associated with the renewable energy resources. Where ownership rights accrue to a party other than the land owner, the study by Sardaro et al. (2019) suggest land values can actually fall as a result of renewable energy production.

The only case in which it would seem to be true that the benefits of renewable energy production clearly accrue to land owners is that of solar and wind energy production on privately owned land. When a farmer erects a wind turbine on his farm or a homeowner installs solar panels on her roof, for example, the economic benefits of the energy production will be conferred on him/her simply by the fact of his/her ownership of the associated land. As the literature review above demonstrates, empirical evidence supports the notion that land values can increase in such instances, though they do not uniformly do so today due to market imperfections.

In the case of renewable energy production on public land/water, it is true that the rights to both the land/water and the economic benefits of the energy production vest in the same unit (in this case, the government on behalf of the public). However, as we argue more fully in Section 2.1.4.3, in those cases the land in question is likely not traded in markets and has no economic value (at least, no value that is observed within the national accounts). There is, therefore, no recorded value that renewable energy production on public land might influence, even if the property rights to the resource are clear in this case.

The case of geothermal resources is the most problematic from the perspective of property rights, as rights to these resources in most countries – as with the rights to sub-soil resources in general – are assumed not by the owner of the land above them but by the government on behalf of all citizens (see Appendix 3). The United States is something of an exception to this, as sub-soil resource rights there are legally conferred by default on the owners of the associated surface land. However, it is common in the United States for rights to the surface and mineral estates to have been severed at some point in the past, meaning that the rights to the two are frequently owned by different parties today. Thus, in most countries, including the United States, it is not clear that the presence of geothermal resources on or under a given piece of land would have any positive impact on the value of the land. Indeed, a case could be made that the opposite is true. To the extent that geothermal energy production disrupts surface land uses and/or raises concern for groundwater quality, the exploitation of geothermal resources could cause land values to fall, not rise.[14]

2.1.4.3 Land value is already captured in the national accounts

For the value of land to reflect the value of any associated renewable energy assets, it goes without saying that the land in question must have a non-zero economic value in the absence of renewable energy production and that its value must be captured, at least in principle, in the national accounts. Otherwise, there is no observed land value for renewable energy assets to impact. This is germane in two instances: renewable energy production on land with no other practical use; and production that effectively occurs in the absence of land (for example, off-shore wind farms and deep-well geothermal). Only in the case of renewable energy production on privately owned land does an observable land value exist that could be plausibly influenced by the presence of renewable energy assets. Privately owned land always has a value because it has, by definition, at least one economic use.[15] The value of all private land is captured in the national accounts and markets should be able to “price in” its value for renewable energy

---

[14] Note that the argument here pertains to large-scale exploitation of geothermal resources and not to their small-scale use for heating/cooling purposes in residential- or commercial-building ground-source geothermal systems. The property rights to this energy likely do accrue to the land owner. Though here again it seems unlikely that the value of the land on which the building is sited will rise simply because the owner decides to install a ground-source geothermal system. Land below essentially any building can be used as a source of heat/cooling, so neither differential rent nor scarcity rent could be expected to arise.

[15] Even private land that is not actively used in any kind of production process nearly always has an economic use as a store of value for its owner. An exception to this might be very remote areas of land held privately for the purposes of ecological preservation. The economic value of such areas, even as a store of value, may be zero. For the present purposes, such areas can be ignored.

production (notwithstanding the issues associated with property rights and market equilibria just noted).[16]

Publicly owned land is different, especially public land that is found in its “natural” state (*e.g.*, forests, rivers or deserts) and has no practical economic use (for example, because of remoteness or lack of any plausible economic use). Such land is not considered an asset in the context of the national accounts, as no value can be observed for it. The argument that renewable energy asset values will be captured in land values is not plausible, then, for production that occurs on public land with no other economic use. This includes essentially all rivers used for hydroelectricity production and any public lands used exclusively for solar, wind or geothermal production. In the absence of renewable energy production, these areas have no economic value. In such cases, the SEEA-CF notes “the value of the land will, in theory, be equal to the net present value of the future income stream [from the renewable energy production]” (SEEA-CF ¶5.229). This recognition that land used only for renewable energy production is equal in value to the value of the renewable energy resources themselves[17] is simply another way of stating that such land has no economic value unto itself; all its value arises from its use to produce renewable energy.

Why the value that arises from renewable energy production on otherwise valueless land should be attributed to the land rather than to the renewable energy assets themselves is not clear and the SEEA-CF offers no explicit justification. It is the equivalent of attributing the value of standing timber resources to the land on which the trees grow and not to the trees themselves, something the SEEA-CF recommends against. The SEEA-CF recommends instead that timber resources (in fact, all natural resources other than renewable energy) be recognized as assets in and of themselves. Thus, the approach suggested for renewable energy assets would seem inconsistent with the main thrust of the SEEA-CF’s arguments regarding natural resource valuation.[18] This issue is of considerable practical importance, since renewable energy production is increasingly sited on land that has no alternative economic use. Large solar energy farms (utility-scale projects), which account for most of the growth in the world’s installed capacity (IEA, 2017), can be tens of square kilometres in size and tend to be built in inhospitable areas such as deserts. If the SEEA-CF renewable energy resource recommendations were followed, the value of the renewable energy resources captured by these large farms would be attributed to land in the national accounts.[19] If the main SEEA-CF

---

[16] An interesting case (not discussed in the SEEA-CF) is that of speculation in land with no obvious economic value other than renewable energy production. It may be the case that private entrepreneurs, anticipating future growth in demand for solar or wind energy, will purchase large tracts of public land in remote areas with high potential for renewable energy production but no other apparent economic value (such as deserts). The value of such land would, in principle, appear in the national accounts. The extent of such speculation is unknown, but it seems unlikely to be widespread given the large areas in question (renewable energy farms in remote areas can be tens of kilometres squared in size). Governments may be reluctant to sell off large areas of public land to speculators unless plans for a renewable energy farm have already been put in place and approved, in which case the land would likely be sold to the firm developing the farm rather than to a speculator and it would be quickly brought into production rather than lying “fallow” waiting for a farm to be proposed.

[17] The valuation of natural resource assets by measuring the present value of the future rent they generate is the standard approach in the SEEA-CF. It is recommended for the valuing of fossil fuel, mineral, timber and other natural resource assets.

[18] Section 5.8.4 of the SEEA-CF discusses valuation of timber resources. There the asset of economic significance is considered the timber itself and not the land on which the trees grow, though it is recognized that timber rent may include a small share that should be attributed to the land on which the timber stands. The SEEA-CF recommends that this share be estimated and deducted for the purpose of deriving the estimate of resource rent on timber resources. It does not, however, recommend that the entire timber rent be considered to arise from the land asset, as it does in the case of renewable energy resources.

[19] It is worth noting that the value of such inhospitable land for solar energy production might, in fact, be zero according to standard economic theory, as the opportunity cost of its use for solar farms may be zero.

approach to valuing natural resources were followed instead, they would be attributed to a separate solar energy asset (with, perhaps, a small amount attributed to the land asset, as discussed further in Section 4.1.2).

A final concern with the SEEA-CF's argument around renewable energy assets comes in the case of off-shore production, such as the off-shore wind farms that are of growing importance.[20] As with most publicly owned territory, no economic value is attributed to off-shore areas in the national accounts and, therefore, the value of off-shore renewable energy production cannot be captured in the value of a country's off-shore territory. Recognizing this, the SEEA-CF states that "by convention, the value of income streams from [off-shore] sources are attributed to the value of land" (SEEA-CF ¶5.231). Again, it is unclear why this should be the case. If it is the case, the question of which land the value of off-shore energy resources should be assigned to arises. As noted above, the approach elsewhere in the SEEA-CF suggests the opposite treatment of off-shore resources: assigning their value to the resources themselves and recording the resources as distinct assets in the national accounts. This is what the SEEA-CF recommends be done for timber and other renewable resources, as well as for all non-renewable resources.

2.2 Summary

To summarize, the SNA provides limited guidance as to the treatment of renewable energy resources as assets. The SEEA-CF offers considerably more guidance, arguing that solar, wind, geothermal and hydroelectric energy asset values are captured in the value of the associated land. While having some *prima facie* appeal, this argument appears implausible in many instances. The conditions in which the value of such assets could be expected to be reflected in observed land values are limited to the production of solar and wind energy only and that only on land that is 1) privately owned; 2) has a positive economic value for something other than solar/wind energy production; and 3) is located where renewable energy markets could be assumed to be in long-run equilibrium. We believe such instances are likely few in number and that the values involved are not large in comparison to the overall value of renewable energy resources. In many countries, solar and wind energy markets are nascent and rapidly evolving, and, so, do not yet in our view approach the long-run equilibria in which private land values could be reasonably expected to accurately reflect the potential for renewable energy production, a view supported by our review of recent empirical literature. Even in countries with long histories of renewable energy production, it is not clear that the SEEA-CF approach is always appropriate; for example, it would not apply to the 32% (and growing) of Denmark's wind energy capacity that was installed off-shore in 2016 nor would it apply to the massive, utility-scale solar farms rapidly developing in remote regions of China and elsewhere.

With respect to the most important renewable energy resource today, hydroelectric power, the SEEA-CF's argument does not seem appropriate at all. Hydroelectric dams and generating stations are almost exclusively built on publicly owned rivers that have no measured value as economic assets. There is, thus, no possibility that the value of hydroelectric resources could be captured in any recorded value of these public waterbodies. The SEEA-CF's recommendation that the public waterbodies be given a value equal to calculated value of the hydroelectric resources themselves (SEEA-CF ¶5.491) is inconsistent with its recommended approach to valuation of other natural resource assets and it implies that the hydro resources have value unto themselves.

---

[20] Denmark, for example, saw its share of off-shore wind power capacity increase from just 2% of total capacity in 2000 to 32% in 2016 (Danish Energy Agency, 2018).

For their part, geothermal resources are publicly owned in most countries, with property rights separate from the land found above them. There is no reason, given this, to expect the value of the land above the resources to be positively influenced by their presence (and the opposite is plausible). Even in the United States, where sub-soil asset property rights vest by default with land owners, many land parcels have had their associated sub-soil resource rights severed and, therefore, land values may not change even if geothermal resources were discovered.

Given the above, the application of the SEEA-CF's approach to the valuation of renewable energy resources risks missing much of the value of these increasingly important resources. For example, none of the value of the 56% of Canada's total electricity generating capacity that was accounted for by hydroelectric resources in 2016[21] would be captured in any existing land (or water) value on Canada's national balance sheet accounts. The only way for this value to be included in Canada's national accounts would be to be explicitly calculate it as the present value of the future stream of rent from the resource. The SEEA-CF acknowledges this, but argues that this calculated value should be considered part of the value of water and not of the hydroelectric resource itself, a treatment that is out of line with its approach to other natural resource assets.

---

[21] Statistics Canada, Table 25-10-0022-01, *Installed plants, annual generating capacity by type of electricity generation.* Available here.

3 Options considered

In this section, we first discuss define “renewable energy resources” and “renewable energy assets” in concrete terms and then present our recommended approach to the inclusion of renewable energy assets in the revised SNA. We then discuss two approaches to the valuation of these assets; our recommended approach and an alternative that may be appropriate in instances where energy markets are far from equilibrium.

3.1 The nature of renewable energy assets

It is important to be clear as to what “renewable energy resources” are and how they are related to the topic of interest here, renewable energy assets. In keeping with the renewable energy specifications of the United Nations Framework Classification for Resources (UNFC; United Nations Economic Commission for Europe, 2020), it is taken that renewable energy resources comprise the cumulative quantities of kinetic, heat or radiative energy recoverable from in moving water (hydro and ocean energy), moving air (wind energy), hot underground and surface rock and water (geothermal resources) and incident solar radiation (solar resources). The physical unit of measure for these resources is the joule in the SI system (other units that could be used include BTUs, tonnes of oil equivalent or watt-hours).

Not all renewable energy resources qualify as economic assets however. In further keeping with the general definition of an asset, only those renewable energy resources that are viable for use in economic production under prevailing technological and economic conditions qualify as assets. These resources correspond to those that would be classified to the UNFC category “commercial projects”. More specifically, these are the renewable energy resources that provide inputs into renewable energy production facilities where extraction and sale is economic on the basis of current market conditions and realistic assumptions of future market conditions; all necessary approvals/contracts have been confirmed or there are reasonable expectations that all such approvals/contracts will be obtained within a reasonable timeframe; economic viability is not affected by short-term adverse market conditions provided that longer-term forecasts remain positive; extraction is currently taking place; or, implementation of the development project is underway; or, sufficiently detailed studies have been completed to demonstrate the feasibility of extraction by implementing a development project.

The stock of renewable energy assets in a country at a given point in time is, then, the cumulative quantity of renewable energy resources “harvestable” by the commercial renewable energy projects in existence at the time. The UNFC recommends limiting the quantification of renewable energy resource stocks to by considering lifetimes for existing commercial projects. Lifetimes can be determined from the design basis of the facilities or based on industry practice/benchmarks. The fact that renewable energy assets can be characterized in physical terms permits use of the standard accounting concept of “price times quantity” as the basis for valuing the assets, where their price is the rent that arises during their use in a production process.

Given the above, it is clear that a remote river with no hydroelectric generation facilities on it, nor any under such facilities construction, is not a renewable energy asset. Nor is an air current in which no wind turbine currently stands (or is imminently being installed) or a ray of incident solar radiation that does not fall on an existing or imminent energy capturing device such as a photovoltaic cell. This is consistent with the treatment of other natural resource assets in the SNA and SEEA-CF. For example, the SNA and SEEA-CF recognize timber in a forest (another renewable resource) as an asset only in instances where that timber may be commercially logged at a profit under existing technological and economic conditions. Remote forests with no potential for logging do not qualify as assets. Similar criteria are applied to defining other renewable and non-renewable natural resources as assets in the SNA and SEEA-CF.

3.2 Recommended approach to renewable energy resources as assets

We recommend that renewable energy resources that meet the definition for classification as "commercial projects" in the UNFC be recognized as a new category of non-produced, non-financial assets in the revised SNA. This would require the addition of a new natural resource category to the SNA asset classification and, to avoid confusion with existing assets, renaming the current category for non-renewable energy resources. The SEEA-CF asset classification should be revised to maintain its alignment with the revised SNA. The existing natural resource asset classifications of the SNA and the SEEA-CF are shown in Table 1. Table 2 presents the proposed revised classifications, with the new asset categories shown in green and the renamed asset categories in red.

Table 1 – Existing SNA and SEEA-CF natural resource asset classifications

SNA	SEEA-CF
Land	*Mineral and energy resources*
Mineral and energy reserves	*Land*
Non-cultivated biological resources	*Soil resources*
Water resources	*Timber resources*
Other natural resources - *Radio spectra* - *Other*	*Aquatic resources*
	Other biological resources
	Water resources

Table 2 – Proposed revised SNA and SEEA-CF natural resource asset classifications

SNA	SEEA-CF
Land	*Mineral resources*
Mineral reserves	*Non-renewable energy resources*
Non-renewable energy resources	*Renewable energy resources*
Renewable energy resources	*Land*
Non-cultivated biological resources	*Soil resources*
Water resources	*Timber resources*
Other natural resources - *Radio spectra* - *Other*	*Aquatic resources*
	Other biological resources
	Water resources

Note: New asset categories are shown in green and renamed categories are shown in red.

The specific renewable energy resources that should be recognized in the revised SNA/SEEA-CF classifications of natural resource assets are shown in Table 3.

Table 3 – Renewable energy resources recommended for recognition as assets in the revised SNA/SEEA-CF

Renewable energy resources
Water energy resources
River water energy resources
Tidal energy resources
Wave energy resources
Solar energy resources
Wind energy resources
Geothermal energy resources
Other renewable energy resources

The approach recommended ensures consistency in the treatment of all natural resource assets in the SNA, including renewable energy resources. It also reflects the fact that the value of renewable energy resources is already large and is likely to grow substantially in the future. Inclusion of renewable energy assets within the SNA's asset boundary will help ensure alignment between the value of the economy's productive base reflected in the capital account and the income earned from that base in the production account. Renewable energy resources have become too important as productive assets to be excluded from capital accounts.

A potential disadvantage of our approach is that it could lead to double counting of the value of some renewable energy resources on national balance sheets, as we acknowledge there may be instances where (as argued in the SEEA-CF) the price of land assets already measured in the national account may be influenced by the possibility (or reality) of using the land for renewable energy production. Adding values for renewable energy assets on top of these existing land values could lead to double counting; for example, both the increase in value of a farmer's land from installation of a wind turbine and the asset value of the associated wind energy production could be captured. There are valid reasons to believe any such double counting would be minimal however.

Firstly, as argued in Section 2, the share of the total value of renewable energy assets that might be captured in existing land values on national balance sheets is likely small. It would, for example, miss the value of hydroelectric resources – the most important renewable energy resource globally. On top of this, geothermal and much of solar and wind energy resources would not be captured.

Secondly, double counting could be largely avoided in practice by national accountants in their land valuation methods. Since transactions in bare land are relatively rare (the majority of land transactions include both land and related produced assets, such as buildings, orchards, roads and industrial equipment), there is little empirical evidence to use in directly valuing land itself. As a result, values are frequently based on indirect estimates using either land/structure value ratios or as a residual (Eurostat and OECD, 2015). In both approaches, care is taken to exclude the value of all assets associated with the land in arriving at the value of land itself. In the case of land used for renewable energy production, the value of the wind turbines, solar panel arrays and other renewable energy equipment would be deducted in arriving at the land residual. In addition, national accountants would also deduct an estimate of the value of the associated renewable energy resources. Thus, if wind turbines were known to be operating on private farmland in country X, national accountants would estimate the asset value of the wind energy resource and deduct this from the value in arriving at the value of the farmland.

Thirdly, as discussed in more detail in Section 4.1.2, a case can be made that any increase in land values due to the presence of renewable energy production is, in fact, properly capturing the value of the characteristics of the land that make it valuable as a site for such production but that there is an additional value that arises (and is captured by other factors of production) due to the characteristics of the renewable energy resources themselves. In this case, there would be no double counting.

With regard to recording the ownership of renewable energy assets on sectored national balance sheets, we recommend the approach advocated in the SNA guidance note prepared by van de Ven and de Haan (see the discussion earlier in Section 2.1.2). In this approach, ownership of natural resource assets is partitioned between governments and resource companies according to the economic benefit each receives from their use. In the case of renewable energy assets, where governments do not today generally extract royalty payments for their use (solar/wind assets), the entire asset value would be attributed to the business sector following this approach. This seems appropriate to us, as it reflects the fact that many (though not all) governments operate today as though it is necessary to relinquish their benefits from solar/wind energy assets to encourage renewable energy companies to take on the risk of exploiting the resources. Whether governments will forego exertion of ownership rights over these assets indefinitely is a matter we address further below (see Section 5.1.2 and Appendix 2).

3.3 Recommended valuation approach

3.3.1 The residual value method

If renewable energy resources are to be included as assets in the revised SNA, an approach is required to their valuation**. For this, we recommend in most instances the approach adopted in the SEEA-CF (and SNA) for other natural resource assets; that is, valuation *via* the residual value method (SNA ¶20.47; SEEA-CF ¶5.94-¶5.125).** In the residual value method (RVM), the value of a natural resource asset is calculated as the present value of the future stream of rent attributable to its use in economic production. Rent itself is estimated as the difference (residual) between the annual revenues earned from sale of the resource and the annual cost of its production, including normal returns to both labour (wages) and entrepreneurship (return on produced capital) as well as an estimate of the consumption of produced capital. Any specific subsidies received by renewable electricity producers must be deducted from the value of sales and any specific taxes must be added.[22]

We argue that the RVM, while not without concerns from theoretical and practical points of view (which we take up in sections 4 and 5), is the best option for the valuation of renewable energy resources in the SNA in most instances. We acknowledge that the method relies on an assumption of renewable energy markets approximating long-run competitive equilibrium[23] and that markets in many countries – especially in the developing world – do not meet this criterion (as discussed in Section 2.1.4.1). However, data from the OECD suggest there has been considerable movement toward competitiveness in renewable energy markets since deregulation of electricity markets began in the 1990s, at least in developed countries (see Section 4.1.3 for further discussion). While market distortions from subsidization of renewable

---

[22] Specific subsidies and taxes are those directly related to the production of renewable energy. For example, a concessionary loan received by a solar electricity producer to finance purchase of solar panels would be considered a specific subsidy. A subsidy received for the purpose of employing workers of a specific type (those from disadvantaged populations, for example) would not. Regarding taxes, specific taxes would include any royalties or other fees paid on energy production. Normal taxes paid on corporate profits are excluded.

[23] Where energy markets are not in equilibrium, rent cannot be accurately measured as the difference between revenues and costs due to distortions in energy prices.

energy production and consumption remain, we nonetheless recommend the RVM for the valuation of renewable energy resources. It is the recommended approach in both the SNA and the SEEA-CF for other natural resource assets and it is widely applied in country practice[24] and by the World Bank (2011, 2018 and 2021) and UNEP (2012, 2014; Managi and Kumar, 2018) in their valuation of other natural resources, such as timber, mineral, fish and fossil fuel resources. The suitability of the RVM for renewable energy resource valuation has been testing for 15 pilot countries by the World Bank (Smith et al., 2021) and found to yield results that are plausible and coherent with broader economic trends in prices, energy demand and technological evolution. We discuss the theoretical and practical concerns with use of the RVM further in sections 4 and 5.

3.3.2 An alternative to RVM: The least-cost alternative method

An alternative to the RVM exists when the economic conditions required for that method to apply do not exist (as would have been the case in essentially all countries in the past when government intervention in electricity markets was broad and deep and as is likely still the case today in countries where market deregulation has not advanced significantly). This approach – known as the least-cost alternative method – rests on the principle that the rent on a given asset can be identified by evaluating the difference in cost when using the asset in production compared to its least-cost alternative. In the context of renewable energy, the method has been most often examined in the estimation of the rent on hydroelectric resources. It was used with considerable sophistication, for example, in two early studies of hydroelectric rents in Canada, as discussed in Appendix 4. We explore it briefly below.

The advantage of the least-cost alternative method is that it requires no information on the value of sales of the resource. Only information on costs of production is needed. In instances where revenue data are unreliable because of market distortions (especially subsidies), this is helpful, as correcting revenue data for market imperfections is complex. Cost data, on the other hand, are relatively easily corrected, since the inputs used in one activity are frequently used in others. For example, wages paid in highly regulated industries (like electric power in the 1980s), which may be inflated well above market rates, can be adjusted using labour rates in unregulated industries.

The disadvantage of the method is its complexity. Applied in full, the method requires modelling of two hypothetical scenarios, one in which the activity takes place using the asset of interest ,with cost data adjusted to eliminate distortions caused by market interventions, and a second scenario in which the activity takes place with the least-cost alternative asset (also with all cost data corrected). For any real-world activity, this is a significant modelling exercise. As Young and Loomis (2014; p. 213) note, “the analyst who undertakes to estimate the alternative cost of electricity generation ‘from scratch’ faces a major task.”

Another potential disadvantage of the method is that it may result in an estimate of what renewable energy rent *should* be, rather than what rent *is*. This is because, in its full application, the approach compares hypothetical least costs of energy production with and without the renewable source. If actual costs are far from least costs – because, for example, the electric power system is highly regulated and/or poorly managed – the hypothetical rent may be quite different from actual rent. This shortcoming can be avoided by applying the method in a more limited way, comparing actual costs against hypothetical costs.

Simple applications of the least-cost alternative method have been used to achieve “back-of-the envelope” calculations of renewable energy resource rents. Typically, observed market prices of

---

[24] See the review of empirical studies in Appendix 4.

electricity are compared against the cost of generation from a renewable energy project. For example, the average cost of importing electricity from a neighboring jurisdiction offers a straightforward way of evaluating the least-cost alternative in the case of hydroelectric production (Gillen and Wen, 2000; Hreinsson, 2008a; Hreinsson, 2008b; Wandji, 2018). This approach avoids the need to model the hypothetical alternative in detail but has the drawback that the “alternative” cost employed is in fact partly determined by the supply of renewable energy. It is this endogeneity that more complex counterfactual modelling seeks to overcome. In practice, the relative economic importance of the renewable energy assets being valued (that is, their price-making power) may serve as a yardstick to judge whether back-of-the envelope approaches are valid or whether more complexity is called for. For example, the simple approach of adopting imports as the least-cost alternative might be justified for a small renewable energy sector in a country that imports sizeable quantities of electricity from a regional market.

Though we recommend the RVM in most instances, we acknowledge that the least-cost alternative method is worthy of consideration in cases where subsidies remain significant and markets are likely still far from long-term equilibrium (mainly for solar and wind energy assets).

4 Recommended approach – conceptual issues

4.1 Resource rent arising from renewable energy assets

The nature of economic rent has always been of central interest to economists. Perhaps because of its fundamental role in economic theory, particularly its relation to theories of value, no consensus view has developed (Fine, 1982). All rent concepts share a focus on the benefits accruing to a factor of production over and above what is required to maintain that factor in the productive process, though they highlight different circumstances by which these payments come about. A review of basic rent concepts is provided in Appendix 5.

Within the SNA, rent is defined (SNA ¶7.109 and ¶7.154) as “the income receivable by the owner of a natural resource (the lessor or landlord) for the putting the natural resource at the disposal of another institutional unit (a lessee or tenant) for use of the natural resource in production.” The SNA explicitly considers that “two particular cases of resource rent are considered, rent on land and rent on subsoil resources. Resource rent on other natural resources follows the pattern laid out by these two instances.” (SNA ¶7.154). Where recorded payments arise from a combination of rent and other sources, for example land hire, the SNA stipulates a majority allocation rule, classifying the payment as rent or "other sources" based on whichever is the greater share (SNA ¶7.155-¶7.158). The definition of assets is specifically considered with regards to the treatment of rent on subsoil assets, with ownership recognized to “[depend] upon the way in which property rights are defined by law and also on international agreements” and a variety of payment structures being acceptable (SNA ¶7.159 and ¶7.160).

4.1.1 Rent and renewable energy assets

The evolving nature of renewable energy resource markets is essential to any analysis of the rent accruing to the resources. Not all renewable energy markets can be considered to be in long-run competitive equilibrium, especially not those in the rapidly emerging areas of solar and wind energy. This has implications for the nature and level of rent and its distribution among factors of production. For example, Ricardian/differential and scarcity/absolute rents are based upon the supposition of market equilibrium. Where markets are not in equilibrium such rents cannot exist, strictly speaking. By contrast Marshallian quasi-rents are features of markets that are not in long-run equilibrium.

An additional challenge is that the inexhaustible nature of renewable energy resources poses challenges to theories of value and thus to theories of rent.[25] This is most obvious for wind and solar resources, which are globally available. Scarcity and differential rents arise locally, however, as a given site can only be used for solar/wind production by one economic unit at a time and because the resources themselves are variable in quality (wind currents are not the same everywhere and the intensity of the sun varies with latitude). Scarcity may also be arbitrarily imposed; for example, *via* legislation granting excludable rights to generate and sell energy from these sources. As noted in Section 5.1.2, governments may choose to do this in the future, as they have done in the case of the radio spectrum.

---

[25] A related measurement problem arises when the supply of resources is increasing over time (or total expenditures are growing): a declining cost share of the resource is equated with declining productivity in growth accounting, producing a biased view of the contribution to economic growth over time. Santos *et al.* (2016) explore this issue with regards to structural changes in the energy supply in Portugal.

4.1.1.1 Hydroelectric resource rent

Hydropower is an ancient technology and factor markets can reasonably be assumed to be in something close to long-run competitive equilibrium in countries where electricity markets have been deregulated. Marked heterogeneity and scarcity amongst sites for hydro power implies that hydro projects should earn both Ricardian and scarcity rents. Where equilibrium can reasonably be assumed, quasi-rents should not exist. In countries where electricity prices remain regulated and where hydroelectric power utilities remain publicly owned, the assumption of market equilibrium likely does not hold. Ricardian and scarcity rents will still arise, though they will be captured by electricity consumers rather than by the owner of the resource (government) and their measurement is made more difficult.[26]

4.1.1.2 Geothermal resource rent

Rights to subsoil resources, including geothermal resources, are generally recognized (and mostly assumed by governments) and markets often exist in which such rights are traded and priced. As with all underground resources, geothermal resources are both heterogeneously distributed and scarce.[27] The technology for geothermal power production is relatively well-established. Under these circumstances, both Ricardian and scarcity rents should accrue assuming market equilibrium. In the absence of market equilibrium, quasi-rents should arise.

4.1.1.3 Solar and wind resource rent

Wind and solar energy are rapidly emerging technologies. Though the sun and the wind are not scarce in any meaningful sense, different locations have a greater or lesser access to them due to latitude, inherent differences in wind currents and physical features of the surface. In long-run equilibrium, more productive (sunnier, windier or closer-to-market) sites should therefore earn Ricardian rents only. In the short-run, opportunities for quasi-rents exist.

4.1.2 Is renewable energy asset rent really land rent?

Implicit in the SEEA-CF argument that renewable energy asset values should be captured in land values is the idea that the rent associated with these resources is, in fact, attributable to features of the land and not to features of the resources themselves. The position taken here is that this is not entirely so in any case and not so at all in most cases. That land characteristics have nothing to do with renewable energy resource rent seems uncontestable in cases where land plays no meaningful role in the production process. This would be the case for geothermal resources, hydro resources, ocean resources and off-shore wind resources. This leaves only on-shore solar and wind energy resources as possible cases where rents could arise due to the characteristics of land rather than to the characteristics of the resources themselves.

In considering the cases of on-shore solar and wind energy production, it is worth repeating the points made in our summary of Section 2. The conditions in which the value of solar and wind energy assets could be expected to be reflected in observed land values are limited to production occurring on land that is 1) privately owned; 2) has a positive economic value for something other than solar/wind energy production; and 3) is located where renewable energy markets could be assumed to be in long-run equilibrium. As noted, we believe such instances are likely few in number and that the values involved are not large in comparison to the overall

---

[26] Note that this is one reason to recommend the least-cost alternative approach rather than the RVM for the valuation of hydroelectric resources in regulated markets.

[27] An exception to this is so-called “enhanced geothermal systems”, in which extremely deep (> 5000 m) wells are drilled to access the hot rock that exists essentially uniformly across the planet at that depth. Development of these resources, which obviously have considerable potential, is just beginning.

value of renewable energy assets. Nevertheless, it is plausible under certain conditions that private land used for on-shore solar and wind energy production could increase in value due to such production. To the extent this is the case, four possible interpretations of the increased land value exist:

1) the increased land value reflects *all* the rent that arises due to the renewable energy production *and* this rent arises due only to characteristics of the *land*
2) the increased land value reflects *all* the rent that arises due to the renewable energy production *but* this rent actually arises due to characteristics of the *renewable energy resource* the land provides access to
3) the increased land value reflects *all* the rent that arises due to the renewable energy production *but* this rent actually arises due to characteristics of *both* the *renewable energy resource* and the *land*
4) the increased value reflects *some* of the rent that arises due to the renewable energy production, *and* this portion of rent arises due to characteristics of the land, *but* there is an *additional amount* of rent that arises due to the characteristics of the *renewable energy resource* and that is captured by other factors of production.

We discuss each of these possible interpretations in turn.

We argue that the first interpretation (i.e., that increased land values reflect *all* the rent that arises due to renewable energy production *and* that all this rent arises because of *land characteristics*) is implausible. While it may be so that all the rent arising due to renewable energy production is captured in increased land values, the notion that is only the characteristics of the land that generate this rent does not seem reasonable. Climatic factors having nothing to do with land influence the kinetic and radiative energy available at any given place at any given time, so land characteristics alone cannot be the source of all rent.

The second interpretation also seems implausible. Again, it may be so that the increased land value reflects all the rent that arises, but it is not reasonable to argue that all this rent arises due to characteristics of the renewable energy resource (e.g., wind speed/direction; solar irradiance/angle). This would be to deny the importance of, say, the aspect of one piece of land versus another in terms of its suitability for permitting the capture of wind or the sun's rays.

Both the third and fourth interpretations seem plausible. It seems reasonable to suggest that the characteristics of both the land *and* the renewable energy resource play a role in the emergence of rent. Both scarcity rent (the number of sites suitable for capturing renewable energy is limited) and differential rent (not all renewable energy resources are of the same quality) should arise. We would note that the interpretation of the source of the rent as joint between the land and the resource itself is akin to what the SEEA-CF refers to as a composite asset (¶5.300 to ¶5.310). For example, timber stocks and the land on which they grow are considered a composite asset in the SEEA-CF and the rent arising in timber harvesting is seen to be due to each of them.[28] It is worth noting that, according to the SEEA-CF (¶5.379), in most instances the share of timber rent attributable to forestland is likely small, especially where the land in question has no economic alternative.

---

[28] Interestingly, the SEEA-CF also notes that land on which renewable energy production takes place can have the nature of a composite asset (¶5.310). However, in the SEEA-CF definition of this asset, its composite nature arises because land used for renewable energy production may also be used for other production purposes (say, farming). So, the "composite" arises because of two or more uses of the land asset and not, as in our interpretation, because of the combination of the land asset with a renewable energy resource.

Whether all the rent that arises due to renewable energy production will be captured in increased land values (interpretation 3) or whether there is an additional portion arising that would be captured by other factors of production (interpretation 4) is an open question. If, as we contend above, there are characteristics of renewable energy resources that are entirely independent of land, then theory would suggest interpretation 4 is correct (there will be "additional" rent arising due to the characteristics of the resource). If this were the case, empirical analysis should reveal "excess" asset value above and beyond any observed increase in land values. Carrying out such analysis, which is beyond the scope of this guidance note, would be of interest as an empirical test of which interpretation is correct.

If interpretation 4 is correct (which we think is most likely the case), the accounting is simplified. Any increased *land* value arising due to the renewable energy production should be attributed to land on the balance sheet. The additional asset value of the renewable energy resource itself, which should be estimated using the RVM[29], should be attributed to the renewable energy asset on the balance sheet.

If interpretation 3 is correct, then a means may be required to split the increased land value between land assets and renewable energy assets on the balance sheet. However, it may be that the values involved will be small enough to ignore. As argued earlier (Section 2.1.4.3), most of the growth in solar and wind power generation is occurring in large utility-scale facilities on public land. Thus, the value of renewable energy assets exploited on private land may be small enough to ignore and permit to be recorded as land value on balance sheets.

Before leaving this topic, it is again worth noting that the above discussion applies only to the relatively small portion of renewable energy production that takes place on private land with another meaningful economic use. In all other cases, our recommended accounting approach is straightforward: measure the asset value using the RVM and attribute that value to the renewable energy asset on the balance sheet. Thus, even if there may be some complications for national accountants in adding renewable energy assets to balance sheets, the effect of these complications on the overall quality of the estimates can be expected to be minor.

4.1.3 The residual value method and its applicability to renewable energy assets

As noted in the preceding section, for the residual value method (RVM) to have theoretical validity, electricity markets must be competitive and in something close to long-run equilibrium. If factors are present in markets that distort either the revenues earned from the sale of renewable electricity or the costs of its production, or both, then rent so calculated cannot be relied upon to reflect the true marginal value of the resource. For much of the world, until relatively recently, such distortions were commonplace in electricity markets. Historically, these markets were dominated by large, publicly owned utilities that operated in highly regulated markets. Until at least the 1980s, electricity prices were kept artificially low by governments through a combination of direct subsidies to consumers and monopoly power for producers. Public utilities were permitted to borrow at preferential rates, were not held to account by shareholders for normal levels of profit and could assume that governments them would bail them out of financial difficulties. As a result, both the revenues earned from the sale of electricity and the costs of its production were distorted from their long-run competitive equilibrium values.

---

[29] In applying the RVM in this case, the value of the private land used in the renewable energy production would have to be accounted for in the RVM calculation (as an additional cost against revenue).

Electricity market reform has been going on around the world to varying degrees since the 1980s. Its focus has been separation of transmission and generation, breaking up monopolies, privatization and reduction of subsidies and tariffs (Hyland, 2015; Jamasb *et al*., 2015).

The OECD's Product Market Regulation (PMR) indicators measure the competitiveness of a number of markets, including electricity and natural gas. In compiling the PMR indicators, the OECD considers several factors, including market entry barriers, public ownership, vertical integration and retail price regulation. Based on this, a measure from 0 to 6 is calculated for all OECD and several non-OECD countries, with 0 reflecting the most competitive markets and 6 the least. In 2018, the average PMR value for electricity markets for OECD countries was 1.63, with a range from 0 (United Kingdom) to 2.89 (South Korea); the equivalent figures for natural gas markets were 1.65, 0 (United Kingdom) and 4.63 (Switzerland). These results suggest, perhaps surprisingly given electricity's notoriety as a highly subsidized commodity, that electricity markets are more broadly competitive than natural gas markets today in OECD countries. The results for the non-OECD countries considered (2.93 for electricity and 2.60 for natural gas on average)[30] suggest that electricity markets are slightly less competitive than natural gas markets in these countries and that both markets are less competitive than those in OECD countries.

Taking a more qualitative approach, a World Bank review (Jamasb, *et al*. 2015) considered the state of electricity market reform in developing countries. It found that many developing countries have undertaken electricity market reform, but the progress varies between countries and most remain in transition. Reforms were found to have improved the efficiency and productivity in the electricity sector, though the gains may not always benefit energy consumers. Independent regulatory bodies and strict regulation, which do not exist everywhere, are necessary to ensure efficiency gains do not benefit only producers and governments.

These results suggest that the results of electricity market reform have been at least partly successful in most countries and considerably so in developed countries. Given this, it would seem reasonable to suggest – the concerns raised earlier in Section 2.1.4.1 above notwithstanding – that application of the RVM to estimation of renewable electricity rents would be appropriate today for countries well advanced in electricity market deregulation. Its application to hydroelectric resources would seem particularly appropriate, since those markets have long histories. Its application to the valuation of geothermal, solar and wind energy resources may be less justified since these markets are generally less well developed. Heavy subsidization of solar and wind energy, especially, is more the norm than the exception, even in developed countries. The Netherlands, a country with a long history of wind energy production, for example, has only recently seen development of its (and the world's) first subsidy free wind-energy project (Radowitz, 2019). At the end of 2017, 113 countries had feed-in-tariff (FIT) programs of some kind to support renewable energy generation. However, there has been a shift toward more competitive support policies, with 29 countries holding capacity auctions in 2017 (REN21, 2018). See Section 5.1.2 for further discussion of subsidies.

At the same time, the nature of government support for solar and wind energy is different than it was in the electricity market's past. For one, solar and wind energy producers in many countries today operate in the context of broadly deregulated and competitive electricity markets, where consumers face prices that reflect marginal costs of production. Even publicly owned utilities are generally expected to operate with profit maximization in mind in many countries today. Producers, moreover, are more likely to be private companies than large public utilities lacking profit motives. Today's solar and wind energy producers do not benefit greatly from preferential

---

[30] Argentina, Brazil, Kazakhstan and South Africa.

borrowing rates[31], must keep an eye on long-run shareholder returns and cannot accumulate unsustainable levels of debt, as public utilities once did. Thus, the distortions of both revenues *and* costs that would have made use of the RVM inappropriate in the past are becoming of less concern over time.

---

[31] Though concessionary financing is available to renewable producers, its use accounted for a “near-negligible” share of total renewable energy finance in the period 2013-2016 (IRENA, 2018).

5 Recommended approach – Practical issues

Below we discuss some of the practical considerations in applying the RVM. Additional information regarding data needs and potential data sources associated with the method is provided in the data template laid out in Appendix 6.

5.1 Estimating revenues and costs of production

5.1.1 Revenues, intermediate inputs, labour and produced capital

Estimates are required for the cost of intermediate inputs, labour and produced capital used in the production process. For large-scale renewable energy production, data on revenues, intermediate costs and labour costs should be available from national surveys of the utility industry.

Produced capital costs are more complex, as several types of data are required: 1) an estimate of the value of the produced capital employed in the renewable electricity process; 2) an estimate of the rate of return to that produced capital and 3) an estimate of the rate of depreciation of the capital. If the value of wind energy rent is being estimated, for example, an estimate of the total replacement value of the wind turbines and any other produced capital used by wind energy producers is needed, as well as estimates of the rates of return and depreciation for that capital are required. If sectoral capital stock data are available from the national accounts, the required estimate of the value of produced capital may be available there. If not, the figure will have to be compiled using data available from other sources; for example, corporate reports of renewable energy companies. For the rate of return, the SEEA-CF recommends using an economy-wide figure based on government bond rates where these exist (SEEA-CF ¶5.144). The data necessary to estimate such a rate of return should be available from the national accounts so long as an economy-wide estimate of capital stock is compiled. For the rate of depreciation, if an estimate is not available from the national accounts it will have to be obtained elsewhere. The rate of depreciation may be quite different from one renewable energy type to another. Hydroelectricity generation equipment, for example, can be very long lived (with dams and turbines lasting 50 years or more). Solar and wind electricity equipment might depreciate more quickly, since these technologies are still in their relative youth and developing rapidly.

5.1.2 Subsidies and taxes

Applying the RVM requires data on subsidies paid to and taxes paid by producers of renewable energy. Subsidies are identified in the SNA as either “subsidies on products” or “subsidies on production”. The former are paid to producers directly on the sales of their products, such as a premium on solar or wind electricity paid through a FIT program. The latter are paid in relation to the production process, such as a subsidy paid on capital acquisition *via* a concessionary loan. The value of each must be estimated and subtracted from the value of renewable electricity sales[32] in arriving at an estimate of resource rent *via* the RVM. While fossil fuels are heavily subsidized globally, it is important to note that national statistical offices generally do not adjust

---

[32] Note that sales are to be valued *including* any subsidies on products. Thus, if a FIT is in place for a given producer, its electricity output should be valued at the rate paid through the tariff and not at the prevailing market price for electricity. The difference between the tariff rate and the market rate is the value of the product subsidy that must subsequently be deducted in the rent calculation.

estimates of fossil fuel resource rent for these subsidies when applying the RVM to non-renewable energy resource valuation.

A complementary approach worth considering would involve applying the notion of social resource rent promoted by Statistics Netherlands. In calculating social resource rent, the value of subsidies received by producers using renewable energy resources is not deducted from revenues in the calculation. As a result, social resource rents are typically positive even when rent as normally calculated is negative. **It is not recommended that social resource rent be used as the central estimate of rent for renewable energy resources in the SNA, as this would introduce conceptual inconsistency into the capital accounts. However, consideration could be given to presenting social rents as an addendum item alongside normally calculated rents.** Subsidies received for energy production from renewable sources may be seen as an expression of public support for the production of energy without direct carbon dioxide emissions. This notion is discussed further in Appendix 4.

The subsidies discussed above are both “explicit”, where payments are made directly to producers in relation to specific aspects of their activities. Subsidies can also be implicit; for example, support provided to producers by government organizations whose function is to import equipment and then sell its at lower prices domestically (SNA ¶7.101). In principle both explicit and implicit subsidies are important and should be taken into consideration in the RVM.

Subsidies to energy producers are not the only form of government support to the renewable energy industry today. In countries where the equipment used to generate renewable energy is manufactured (solar panels and wind turbines, for example), it is also common for governments to subsidize the manufacturers. Depending on the impact of these subsidies on manufacturing firms’ behaviour, it may be that this subsidization impacts the cost structure of renewable energy producers. If, for example, wind turbine manufacturers sell turbines at prices below what their competitive market price would be in the absence of subsidization, wind energy companies face relatively lower capital costs than other firms, distorting their financial incentives.

Determining what a wind turbine would be worth in a fully competitive market is clearly not straightforward. From one perspective, it would be reasonable to expect manufacturers to take advantage of their subsidies to sell at lower prices than they would have to otherwise. On the other hand, firms may be price-takers and understand that subsidies are often temporary. Thus in competitive markets, and over the long run, market forces will tend to push manufacturers toward charging fair market value. The ability of firms to set prices is limited given the highly traded nature of modern manufactured goods. Furthermore, international trade laws explicitly prohibit countries from using subsidies to undercut their foreign competitors (Text Box 1).

Text Box 1 – World Trade Organization rules and solar energy subsidies

The dispute mechanism of the World Trade Organization (WTO) has been used to challenge renewable energy subsidies supporting develop local manufacturing capacity. In a dispute over the Government of Ontario’s (Canada) FIT program, the WTO’s Appellate Body condemned the program’s local-content requirements, though not the program as a whole (De Beivre, Poletti, and Espa, 2016).

China is the largest manufacturer of both wind turbines and solar panels (Zhang *et al.*, 2013; Bougette and Chalier, 2013). Renewable energy manufacturing in China has historically been supported with a number of subsidy programs, including financial support for research and development; import tax exemptions for equipment and parts necessary for the manufacture process; and loans and credit provided by state banks. China also had a local content requirement until 2009, when the program was cancelled due to scrutiny from the WTO (Zhang *et al.*, 2013). In 2013, the EU placed anti-dumping duties on solar panels produced in China as a response to Chinese subsidies and pressure from European manufacturers. The United States also imposed protective measures. While the EU also had renewable energy subsidies, its programs were designed to decrease the price paid for renewable electricity by consumers rather than to support manufacturers (Bougette and Chalier, 2017). The anti-dumping measures were removed in 2018, as the European Commission felt that the support measures in China had decreased and import prices were coming into line with world prices (Blenkinsop, 2018)

Subsidies to the renewable energy industry are not the only ones offered by governments. Many industries across the economy, including agriculture, forestry and mining through manufacturing, transportation and construction benefit from various kinds and degrees of support in most countries. Cost structures in many industries may therefore be distorted away from their long-run competitive equilibrium positions. According to the International Energy Agency (IEA, no date), direct fossil fuel subsides worldwide alone amounted to about $US400 billion in 2018. The OECD reports that agricultural subsidies in its member countries came to $US317 billion on average from 2015 to 2017. Global subsidies for renewable energy, in contrast, amounted to $US150 billion in 2015 according to the IEA. Clearly, though large, government support of the renewable energy industry is not the largest category of subsidies in absolute terms.

Given the above, there does not seem to be a case for including manufacturing subsidies for solar and wind energy equipment among those considered in the valuation of renewable energy resources. Market forces will tend to ensure that renewable energy producers pay fair market value for their equipment and these subsidies are not especially large in the global context. Cost structures of renewable energy producers are not likely to be any more distorted by manufacturing subsidies than are the structures of any capital-intensive sector of the economy, including fossil fuels, mining, forestry and non-renewable electricity production. **Thus, it is recommended that only subsidies on renewable energy products (for example, FIT on solar and wind electricity) and on renewable energy production (for example, concessionary loans for capital acquisition) be considered in the valuation of renewable energy resources.**

Turning briefly to taxes, the RVM requires that specific taxes paid by producers of renewable energy be added to the value of sales in the estimation of rent. Specific taxes would include any royalties paid on renewable energy production, as well as other fees to the extent they are clearly related to energy production and not to general business operations; a fee paid for a wind farm operator's license would be considered a specific tax, while a normal business licence fee that would be paid by any operating entity would not.

Royalties, which are common in the cases of fossil fuels, minerals and timber, are not generally collected by governments on renewable energy production, with the exception of hydroelectricity (Pineau *et al.*, 2017), where this is widespread. Governments today are mainly interested in supporting nascent geothermal, solar and wind industries – and regularly do so in the form of subsidies – so there is no broad collection of royalties on these resources. This is changing however; for example, in the United Kingdom, the Queen and the Treasury have recently asserted her right to collect royalties on off-shore wind production (Ambrose, 2021). In Canada, the province of British Columbia charges royalties based on revenue for wind power development on public lands. The province of Ontario uses a competitive bidding process for wind power developments on public land (Ingelson, 2018).

As discussed further in Appendix 2, collection of royalties on renewable energy production over and above hydropower may increase in the future as these industries mature, subsidies are reduced and governments begin to view the resources as public assets from which rent can, and should, be captured through royalties and other payments. **We recommend that no special effort be made to measure the few specific taxes that may be paid on geothermal,**

solar and wind resources today. As a research issue, consideration may be given to how these payments might evolve in the future and what that might mean for future patterns of rent (see Section 5.1.5.3). For hydroelectric resources, we recommend that royalties and other specific taxes paid on production be accounted for in the calculation of rent.

5.1.3 The costs of intermittency – Grid integration costs of variable renewable energy resources

Other than hydroelectric resources, which have been around for decades and are well integrated into existing national energy systems, renewable electricity sources are relative newcomers in these systems. They are also, at least in the case of solar and wind resources, quite different from existing system components. The nature of traditional electricity generation technologies is such that they can 1) operate nearly continually; 2) vary their level of output according to demand; 3) be easily integrated with one another in a national grid. This is true of fossil fuel and nuclear generation, largely true of hydroelectric generation and also true of geothermal generation where it exists. Solar and wind – or variable renewable energy (VRE) – resources are different.

Due to their nature, VRE resources are not as predictable as other sources of electricity. Put simply, the sun does not always shine and the wind does not always blow. “Capacity credit” is the term used in the renewable energy industry to reflect the contribution of VRE resources to overall electrical system security. It can be estimated by determining the capacity of conventional plants displaced by solar and wind resources while maintaining the same degree of system security; that is, an unchanged probability of failure to meet the reliability criteria for the system. Alternatively, it is estimated by determining the additional load that the system can carry when wind power is added while maintaining the same reliability level (European Wind Energy Association, 2010).

Reliability is not the only issue in integrating VRE resources into existing electricity systems. Upgrades may be needed to national transmission and distribution grids as well. In order to connect remote production sites, such as offshore or desert wind farms, new trunk powerlines may be needed. To take advantage of internationally distributed production sites to “smooth” production and increase system security, cross-border transmission lines will be required (European Wind Energy Association, 2010).

Under conditions of long-term competitive equilibrium, in which renewable and non-renewable electricity sources are fully integrated into the same national system, the reliability and grid connection costs of the various sources would be factored into the prices of their outputs. Rent on solar and wind resources would therefore reflect the lower reliability of wind and solar and any higher costs associated with their transmission *vis à vis* other sources.

It is clear, however, that solar and wind energy resource markets are not in long-term competitive equilibrium, especially not in developing countries. However, as argued above, in many developed countries they operate in an industry that has moved toward equilibrium in recent decades (Text Box 2). Moreover, VRE resources remain relatively small players in what is a massive global electricity market. At low levels of market penetration, VRE grid integration costs can be expected to be modest (European Wind Energy Association, 2010). The International Energy Agency (IEA, 2018) describes four stages of VRE deployment. Only in the third phase, when VRE resources represent from 10-25% of electricity generation, do significant grid integration challenges emerge. Only a few countries were considered to be at Phase 3 or higher as of 2018.[33]

Text Box 2 - Progress on eliminating vertical integration in electricity production and distribution

One of the main issues preventing electricity markets from achieving long-term competitive equilibrium in the past was vertical integration of electricity production and transmission/distribution. Large public utilities not only owned and operated all the generating capacity, but they did the same for the powerlines and other infrastructure necessary to get electricity from the generating station to consumers. Eliminating the monopoly power imparted to these massive, integrated companies has been a major effort of market reforms. The OECD's PMR indicators (see description in Section 4.1.3) consider vertical integration in the electricity industry on a scale of 0 (complete integration) to 6 (complete separation of ownership). Between 2000 and 2018, the OECD average for the vertical integration indicator dropped from 5.19 to 2.3, suggesting considerable progress toward independence among producers and transmitters/distributors of electricity, even if work remains to separate them entirely.

As noted above (Section 4.1.3), the theoretical applicability of the RVM to renewable energy resources is less than ideal due to distortions in renewable energy markets. Failure to internalize the full costs of VRE grid integration would certainly be among them and could be considered an implicit subsidy. It is not clear that this particular distortion, among the others, deserves special treatment however. We would, therefore, **not recommend that VRE grid integration costs be considered when estimating renewable energy resource rents**.

5.1.4 Smoothing of historical rents

Due to variations in energy commodity prices, it is possible for the costs and, especially, revenues associated with the production from renewable energy resources to vary substantially from period to period. Such variations can result in significant changes in the rent attributable to the resources and, therefore, to their asset values. The result is that the renewable energy asset values recorded on balance sheets can be quite volatile. Such volatility is not, in and of itself, a bad thing, as it reflects real changes in the value of the resource. Information on such changes may be useful to policymakers, as it reveals the need to plan for unevenness in the economic flows, such as taxes and royalties, associated with exploitation of the resource. For this reason, national accountants may wish to simply leave such variations alone and have them appear on balance sheets. On the other hand, there may be value in statistically smoothing such variations, as they may not reflect the long-term potential of the resources to generate economic flows. National accountants may thus wish to smooth variations in asset values by, for example, using five-year moving averages of costs and revenues in the estimation of rent. The position taken here is that either approach is valid. This is a statistical choice based on user needs that should be made by individual countries during implementation. This approach is consistent with the position taken on smoothing in the SEEA-CF (¶5.199).

5.1.5 Estimating revenues and costs in the future

No matter what method is used to determine renewable energy resource rent (RVM, least-cost alternative or something else), the need to estimate future revenues and costs cannot be avoided. This is because the final step in estimating the value of the resource as an economic

---

[33] Phase 3 (10-25% VRE generation): Italy, the United Kingdom, Greece, Spain, Portugal, Germany and parts of the United States and Japan; Phase 4 (>25% VRE generation): Ireland and Denmark.

asset is to calculate the net present value (NPV) of a stream of annual rent flows over the lifetime of the resource.[34]

The SEEA-CF recommends that "in the absence of…information on expected future price changes…estimates of [future] resource rent should be set based on current estimates of resource rent, thus assuming no price changes beyond the general level of inflation" (SEEA-CF ¶5.133). This is the approach already adopted by most statistical offices and other agencies involved in the valuation of natural resource assets. In the case of the natural resource assets that have been valued to date – mainly those that are bought and sold in long-standing, relative stable and predictable markets (fossil fuels, minerals and timber) – the assumption of constant future rents is defensible. It likely is as well for hydroelectric resources, which are well established economically and technologically.[35] In the cases of the rapidly evolving markets for geothermal, solar and wind energy, however, it is not. The state of play in these markets in terms of the costs of technologies (solar panels, for example), the prices for electricity (including the possibility of widespread carbon pricing in the future) and uncertainty around the future of subsidies is simply too fluid to make an assumption of constant rent realistic.

This means that research will be required to determine reasonable future trajectories for, on the one hand, revenues from renewable production and, on the other, the cost of that production.

5.1.5.1 Future revenues

Revenues are a function of the quantities of renewable energy produced and the price renewable energy commands in the market. A general starting point for production forecasts is the International Energy Agency's annual *World Energy Outlook*, which provides multi-decade projections of most variables of importance for energy markets, though without a great deal of regional or temporal detail. The 2016 edition of the report contains a special focus on renewable energy resources and the 2018 edition does so for electricity in general.

Regarding prices, there is an overwhelming amount of information available on possible future trajectories (Weron and Zator, 2014). Thus, the problem is not finding a price forecast but choosing among the various alternatives available (see, for example, Joint Research Centre, 2018 and IEA, no date). In general, any model of the energy sector will include a future price path, though the researchers may not make the path available in their results. The paths are "endogenous" to the models and typically what users are interested in is the outcome – how much does each sector grow or, in today's world, what changes will result in global carbon levels. Thus, the modelling literature may not be a good source of information regarding future electricity prices. A useful strategy may be to partner with the International Energy Agency or another agency involved in large-scale energy modelling to obtain price forecasts. Private corporations like Shell and British Petroleum also have energy models that may be sources of information.

---

[34] Economic theory provides the rationale for this: the value of any asset is assumed to be equal to the discounted present value of the stream of benefits it will provide its owner over its useful lifetime. In most instances, this value is determined through transactions in assets between buyers and seller in the marketplace; the values of both bulldozers and laptop computers are determined this way. In the instance of natural resources, markets are either very thin (few transactions) or absent entirely. Thus, national accountants must estimate the value of these resources indirectly by calculating the net present value of their lifetime benefits, which is taken to be the stream of rent they generate over their lifetimes.

[35] It should be noted, however, that the assumption of constant future rents has the effect of embedding the volatility of resource commodity prices into natural asset valuations. Research into alternative versions of the NPV calculation to deal with such volatility has been undertaken by the United Nations Expert Advisory Group on National Accounts (2014).

A simple approach to projecting future prices may be to assume they will be equal to long-term averages of historical prices (Advisory Expert Group on National Accounts, 2016).

5.1.5.2 Future costs

In terms of future production costs, a promising source of both data and methods is research into the "levelized cost of electricity" (LCOE). LCOE is widely used to compare the cost-effectiveness of competing technologies and guide investment decisions (Branker *et al.* 2011). It reports the NPV of production costs (both capital and operating) on a per-unit-output basis ($/kWh) and can include various capital depreciation profiles. This, in principle, provides all that is needed in the RVM in terms of cost inputs. The advantage of looking to this literature for data and methods is that the area is both active and mainstream. The International Energy Agency, for example, presents estimates of LCOE in its publications. Use of LCOE estimates from an agency like the International Energy Agency would lend credibility to renewable energy resource valuation. One concern with LCOE values is that they underestimate the cost of VRE resources because they do not consider capacity credits.

5.1.5.3 Future subsidies and taxes

Regarding subsidies, which can affect both the revenue and cost side of renewable energy production, the Netherlands recently announced the world's first subsidy-free wind project. It appears that China, the world's largest solar electricity producer, is moving toward some subsidy-free projects as well (Reuters, 2019). Researchers are already reporting solar and wind energy LCOE values – in the absence of subsidies – that are competitive with traditional fossil fuel and nuclear electricity (Lazard, 2018). The International Renewable Energy Association (IRENA and CPI, 2018) argues that "electricity from renewables will soon be consistently cheaper than from most fossil fuels. By 2020, all the renewable power generation technologies that are now in commercial use are expected to fall within the fossil fuel-fired cost range, with most at the lower end or undercutting fossil fuels." Thus, though renewable energy rents will continue to be impacted by subsidies for some time to come, subsidies will likely diminish – or even disappear – over the kind of lifetimes recommended for NPV calculations for renewable energy resources. Given this, projecting the future path of subsidies in valuing renewable energy may be as simple as assuming a linear decline from their current level to some diminished level (or zero) over a reasonable time horizon. A potential source of data is the International Institute for Sustainable Development's Global Subsidies Initiative (GSI), which has data for renewable energy subsidies by technology type, though only in Europe. The GSI data are, in turn, based on data from the Council of European Regulators (CEER, 2013). The GSI also provides data for some non-European countries; for example, China and India.

Consideration must also be given to future patterns of specific taxes on renewable energy resources. Though royalties and other such taxes are negligible today on geothermal, solar and wind (but not on hydroelectric) resources, they may not remain so forever. A reasonable guide to how geothermal, solar and wind resources may be treated in the future would be the treatment rent from other natural resources is given by governments. Evidence from Statistics Canada's national balance sheet[36] – the only one in the world to apportion the value of natural resource assets between the government and corporate sectors – suggests that Canadian governments collect about 25% of rent on fossil fuel, mineral and timber resources. An approach to incorporating future royalty payments on geothermal, solar and wind resources might be, then, to assume a gradual ramping up of royalties from zero to 25% over the same time horizon over which subsidies are assumed to diminish.

---

[36] Statistics Canada, Table 36-10-0580-01, *National Balance Sheet Accounts*. Available here.

5.1.5.4 Resource life

In terms of choosing the “lifetime” for renewable energy resources, standard practice in accounting for renewable natural resources would suggest the use of a very long (50 year[37]) lifetime in the NPV calculation. Given the uncertainties around revenues and costs, it may be more appropriate to use a finite lifetime in the NPV calculation for renewable energy resources; a 25-year horizon would be reasonable for resources with highly uncertain future revenues and costs like solar and wind electricity. This is long enough to meaningfully capture the value of the asset while minimizing the impact of any uncertainties in the rent estimate on the asset value. It is also approximately equal to the expected lifespan of renewable energy generation equipment, after which equipment may be “repowered” (for example, replacement of the generators or blades in a wind turbine). Thus, use of a 25-year horizon may eliminate the need to factor repowering costs into revenue and cost projections. A longer time horizon (50 years) could be used in the case of hydroelectric resources, for which more stable future costs and revenues can be assumed.

We recommend that sensitivity analysis be conducted to see which of the above variables has the greatest impact on estimated renewable energy asset values. Effort should then be devoted to developing models to project those variables with the greatest impact as accurately as possible. Other variables can be projected using simpler models.

---

[37] Use of lifetimes beyond 50 years in NPV calculations has little effect on the resulting values, since the effect of discounting is to greatly reduce the present value of rent flows in the distant future.

References

Ambrose, J. 2021. “Queen’s property manager and Treasury to get windfarm windfall of nearly £9bn” *The Guardian* (online edition), 8 February 2021. https://www.theguardian.com/business/2021/feb/08/queens-treasury-windfarm-bp-offshore-seabed-rights

Bernard, J.T., Bridges, G.E., and A. Scott. 1982. “An evaluation of potential Canadian hydro electric rents.” Resources Paper No. 78. Vancouver: University of British Columbia.

Bidwell, D. 2016. “The Effects of Information on Public Attitudes Toward Renewable Energy.” Environment and Behaviour48(6): 743-768.

Black, A., 2004. “Financial payback on California residential solar electric systems”, *Solar Energy*, Volume 77, Issue 4. https://www.sciencedirect.com/science/article/pii/S0038092X04000325

Blenkinsop. 2018. “EU ends trade controls on Chinese solar panels.” Reuters. Retrieved August 31, 2018. https://www.reuters.com/article/us-eu-china-trade/eu-ends-trade-controls-on-chinese-solar-panels-idUSKCN1LG1QM

Borenstein, S. 2011. “The private and public economics of renewable electricity generation.” Working paper 17695, National Bureau of Economic Research. https://www.nber.org/papers/w17695 .

Bougette, P. and C. Charlier. 2017. “Anti-dumping and Feed-in Tariffs as Good as Buddies? Modeling the EU-China Solar Panel Dispute.” GREDEG Working Paper no. 2017-17. https://ideas.repec.org/p/gre/wpaper/2017-17.html

Boungnong, C. and D. Phonekeo. 2012. “Economic Rent from Hydropower Development in the Case of Lao PDR.” *GMSARN International Journal 6.2*: 35-44.

Branker, K., Pathak, M.J.M., and J.M. Pearce. 2011. “A Review of Solar Photovoltaic Levelized Cost of Electricity.” *Renewable & Sustainable Energy Reviews* 15: 4470-4482.

Cadogan-Cowper, A. and P. Comisari. 2009. Recording land in the national balance sheet. Information paper for the London Group Meeting, Wiesbaden, 30 November-4 December 2009. https://unstats.un.org/unsd/envaccounting/londongroup/meeting15/LG15_11_1a.pdf

CEER (Council of European Energy Regulators). 2013. S*tatus Review of Renewable and Energy Efficiency Support Schemes in Europe*. 52 pages.

Da Silva., E.A. 2018. “Absolute Rent”. In Macmillan Publishers Ltd (eds). *The New Palgrave Dictionary of Economics*. London: Palgrave Macmillan.

De Beivre, D., Poletti, A. and Espa, I. 2016. “Actual and potential WTO disputes on subsidies for fossil and renewable energy.” Paper for the international conference *Global Public Goods, Global Commons and Democracy: An Interdisciplinary Perspective.* KU Leuven. https://ghum.kuleuven.be/ggs/events/2016/international-conference-global-commons-global-public-goods-and-global-democracy-leuven/de-bievre-espa-poletti-actual-and-potential-wto.pdf

Danish Energy Agency. 2018. “Energy Statistics 2016”. https://ens.dk/sites/ens.dk/files/Statistik/energy_statistics_2016.pdf .

Dastrup, S. Joshua S. Graff-Zivin, Dora L. Costa and Matthew E. Kahn. 2012. “Understanding the Solar Home Price Premium: Electricity Generation and “Green” Social Status”. *European Economic Review*, Volume 56, Issue 5. https://www.sciencedirect.com/science/article/pii/S0014292112000244

Diamond, K.E. 2015. “Wake Effects, Wind Rights, and Wind Turbines: Why Science, Constitutional Rights, and Public Policy Issues Play a Crucial Role.” *William & Mary Environmental Law and Policy Review* 40(3): 813-847. https://scholarship.law.wm.edu/cgi/viewcontent.cgi?article=1658&context=wmelpr

Diamond, K.E. and E.J. Crivella. 2011. “Wind Turbine Wakes, Wake Effect Impacts, and Wind Leases: Using Solar Access Laws as the Model for Capitalizing on Wind Rights During the Evolution of Wind Policy Standards.” *Duke Environmental Law & Policy Forum* 22: 195-244.

Enevoldsen, P. and D. Sovacool. 2016. “Examining the Social Acceptance of Wind Energy: Practical Guidelines for Onshore Wind Project Development in France.” *Renewable & Sustainable Energy Reviews* 53: 178-184

European Commission. 2017. “Citizen support for climate action”. *Energy, Climate change, Environment.* https://ec.europa.eu/clima/citizens/support_en .

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations and World Bank. 2009. *System of National Accounts 2008.* Washington, DC: World Bank. Retrieved from http://documents.worldbank.org/curated/en/417501468164641001/System-of-national-accounts-2008

Eurostat and OECD. 2015. “Eurostat-OECD compilation guide on land estimation. Luxembourg: Publications Office of the European Union. https://ec.europa.eu/eurostat/documents/3859598/6893405/KS-GQ-14-012-EN-N.pdf

European Wind Energy Association. 2010. “Powering Europe: wind Energy and the electricity grid.” http://www.ewea.org/grids2010/fileadmin/documents/reports/grids_report.pdf

Fine, B. 1982. “Royalty and Rent”. *Land Economics* 58(3): 338-350.

Gillen, D. and J-F. Wen. 2000. “Taxing Hydroelectricity in Ontario.” *Canadian Public Policy 26(1)*: 35-49.

Haan, Peter and Martin Simmler. 2018. “Wind electricity subsidies — A windfall for landowners? Evidence from a feed-in tariff in Germany”. *Journal of Public Economics*, Volume 159. https://www.sciencedirect.com/science/article/pii/S0047272718300112

Hartwick, J.M. and N.D. Olewiler. 1999. *The Economic of Natural Resource Use*. 2nd Edition. Reading, Mass.:Addison-Wesley.

Hoen, B. R. Wiser, M. Thayer and P. Cappers. 2012 "Do PV systems increase residential selling prices? If so, how can practitioners estimate this increase?," *2012 38th IEEE Photovoltaic Specialists Conference*.

Hoen, B. Sandra Adomatis, Thomas Jackson, Joshua Graff-Zivin, Mark Thayer, Geoffrey T. Klise and Ryan Wiser. 2017. “Multi-state residential transaction estimates of solar photovoltaic system premiums.” *Renewable Energy Focus*, Volumes 19–20. https://www.sciencedirect.com/science/article/pii/S1755008416304537

Hreinsson, E.B. 2008a. "Renewable Energy Resources in Iceland – Environmental Policy and Economic Value." *Nordic Conference on Production and Use of Renewable Energy.* Vaasa, Finland.

Hreinsson, E.B. 2008b. "The Economic Rent in Hydro and Geothermal Resources in Iceland with Reference to International Energy Markets and Resource Cost Structure." *Working Group on European Electricity Infrastructure.* Paper 08GM0965.

Hreinsson, E.B, Jonassson, K. and G.G. Petursson. 2013. "Discounted value of economic rent in hydro and geothermal expansion planning in Iceland." 48th International Universities Power Engineering Conference (UPEC).

Hyland, M. 2015. "Restructuring European electricity markets: A Panel data analysis." *ESRI Working Paper No. 504.* Dublin: The Economic and Social Research Institute (ESRI).

IEA (International Energy Agency). 2017. "Renewables 2017: Analysis and Forecasts to 2022". https://www.oecd-ilibrary.org/energy/renewables-2017_re_mar-2017-en

IEA (International Energy Agency). 2018. System Integration of Renewables: An Update on Best Practice. https://www.iea.org/publications/insights/insightpublications/SystemIntegrationofRenewables.pdf

IEA (International Energy Agency). No date. Fossil-fuel subsidies (webpage). https://www.iea.org/weo/energysubsidies/

IPCC (Intergovernmental Panel on Climate Change). 2011. *Renewable Energy Sources and Climate Change Mitigation.* O. Edenhofer, R.P Madruga and Y. Sokona (Eds). New York: Cambridge University Press. https://www.ipcc.ch/site/assets/uploads/2018/03/SRREN_FD_SPM_final-1.pdf

Ingelson, A. 2018. "Wind Energy Development on Public Lands in Alberta: A Missed Opportunity". *University of Calgary Faculty of Law Blog. https://ablawg.ca/2018/06/14/wind-energy-development-on-public-lands-in-alberta-a-missed-opportunity/comment-page-1/*

IRENA (International Renewable Energy Agency). 2017. Electricity Storage and Renewables: Costs and Markets to 2030. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2017/Oct/IRENA_Electricity_Storage_Costs_2017.pdf

IRENA (International Renewable Energy Agency) and CPI (Climate Policy Initiative). 2018. Global Landscape of Renewable Energy Finance. Abu Dhabi: International Renewable Energy Agency. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2018/Jan/IRENA_Global_landscape_RE_finance_2018.pdf

Jamasb, T. Nepal, R. And G.R. Timilisina. 2015. "A Quarter Century Effort Yet to Come of Age." *Policy Research Working Paper 7730.* Washington DC.: World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/22211/A0quarter0cent0developing0countries.pdf?sequence=1

Jilani, S.A. 2015. "Spectrum Allocation Methods: Studying Allocation through Auctions." *Journal of Economics, Business and Management* 3(7): 742-745.

Kabir, E., Kumar, P., Kumar, S., Adelodun, A.A., and K. Kim.2018. "Solar Energy: Potential and Future Prospects." *Renewable and Sustainable Energy Reviews* 82:894-900.

Lai, Mei-Chun, Pei-Ing Wu, Je-Liang Liou, Yi Chen and Hanhui Chen. 2019. "The impact of promoting renewable energy in Taiwan — How much hail is added to snow in farmland prices? *Journal of Cleaner Production*, Volume 241. https://www.sciencedirect.com/science/article/pii/S095965261933389X

Lan, H. Z. Gou and L. Yang. 2020. "House price premium associated with residential solar photovoltaics and the effect from feed-in tariffs: A case study of Southport in Queensland, Australia." *Renewable Energy*, Volume 161. https://www.sciencedirect.com/science/article/pii/S0960148120311617

Landis, J.B. 2019. "Sunny and Share: Balancing Airspace Entitlement Rights Between Solar Energy Adopters and Their Neighbours." *Vanderbilt Law Review* 72(3): 1075-1114.

Lazard. 2018. "Levelized Cost of Energy Analysis." https://www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

Lee, Brian, Hung-Hao Chang and Szu-Yung Wang. 2021 "Solar power promotion plans, energy market liberalization, and farmland prices – Empirical evidence from Taiwan". *Energy Economics*, Volume 99. https://www.sciencedirect.com/science/article/pii/S0140988321002231

Lehn, F. and E. Bahrs, 2018a. "Analysis of factors influencing standard farmland values with regard to stronger interventions in the German farmland market". *Land Use Policy*, Volume 73, https://www.sciencedirect.com/science/article/pii/S0264837717305987

Lehn, F., and E. Bahrs. 2018b. "Quantile regression of German standard farmland values: Do the impacts of determinants vary across the conditional distribution?" Journal of Agricultural and Applied Economics, Volume 50. https://doi.org/10.1017/aae.2018.8

Levine, A. L. and Young, K. R. 2018. "Efforts to streamline permitting of geothermal projects in the United States." *Rocky Mountain Mineral Law Foundation Journal* 55(1).

Limbu, T.R. and R.M. Shrestha. 2004. "Evaluation of Economic Rent of Hydropower: A Case of Nepal." *Australasian Universities Power Engineering Conference.* Brisbane.

Ma, Chunbo, Maksym Polyakov and Ram Pandit. 2015. "Capitalisation of residential solar photovoltaic systems in Western Australia." Australian Journal of Agricultural and Resource Economics, Vol. 60. https://onlinelibrary.wiley.com/doi/10.1111/1467-8489.12126

Malinowski, M., Leon, J.I. and H. Abu-Rub. 2017. "Solar Photovoltaic and Thermal Energy Systems: Current Technology and Future Trends." *Proceedings of the IEEE* 105(11). https://ieeexplore.ieee.org/abstract/document/7914744

Managi, S. & Kumar, P. (Eds.). (2018). *Inclusive Wealth Report 2018*. London: Routledge. Retrieved from https://www.taylorfrancis.com/books/e/9781351002073

Myrna, O., M. Odening and M. Ritter. 2019. "The Influence of Wind Energy and Biogas on Farmland Prices". *Land*, Volume 8, Number 19. https://doi.org/10.3390/land8010019

Nykvist, B., and M. Nillson. 2015. Rapidly falling costs of battery packs for electric vehicles. *Nature Climate Change*, 5: 329-332.

OECD, United Nations, European Union, The World Bank and Food and Agriculture Organization of the United Nations. 2014. *System of Environmental Economic Accounting 2012: Experimental Ecosystems Accounting.* New York: UN. https://doi.org/10.1787/9789210562850-en.

Pew Research Center. 2018. *Majorities See Government Efforts to Protect the Environment as Insufficient.* “Strong public support for more solar and wind power”. https://www.pewinternet.org/2018/05/14/majorities-see-government-efforts-to-protect-the-environment-as-insufficient/ps-05-10-18_report-07/ .

Pineau, P-O., Tranchecoste, L., and Y. Vega-Cardenas. 2017. “Hydropower royalties: A comparative analysis of major producing countries (China, Brazil, Canada, and the United States).” *Water* 9(287).

Qiu, Y., D. Wang and J. Wang. 2017. “Soak up the sun: Impact of solar energy systems on residential home values in Arizona.” *Energy Economics*, Volume 66. https://www.sciencedirect.com/science/article/pii/S0140988317302384

Radowitz, B. 2019. “Vestas exec: Nordics show how all countries will become subsidy-free.” *Wind Europe Conference and Exhibition. https://windeurope.org/confex2019/files/media-and-press/Recharge-Day-one.pdf*

Rai, K. and B. Van Campen. 2015. “Geothermal policy and regulation: cases from Chile, Kenya, New Zealand and the Philippines.” IRENA.

REN21. 2018. Renewables 2018: Global Status Report. Paris: REN21 Secretariat. http://www.ren21.net/gsr-2018/

Reuters. 2019. “China to give Priority to subsidy-free renewable projects in new plan.” April 12, 2019. https://uk.reuters.com/article/us-china-renewables-subsidy/china-to-give-priority-to-subsidy-free-renewable-projects-in-new-plan-idUKKCN1RO1HG

Rothman, M. 2000 “Measuring and Apportioning Rents from Hydroelectric Power Developments.” *World Bank Discussion Paper no. 419*. Washington DC: World Bank. https://elibrary.worldbank.org/doi/abs/10.1596/0-8213-4798-5

Santos, J., Domingos, T., Sousa, T., and M. St. Aubyn. 2016. “Does a small cost share reflect a negligible role for energy in economic production?” MPRA Paper No. 70850 (working paper). https://mpra.ub.uni-muenchen.de/70850/.

Sardaro, Ruggiero, Nicola Faccilongo and Luigi Roselli. 2019. “Wind farms, farmland occupation and compensation: Evidence from landowners’ preferences through a stated choice survey in Italy”. *Energy Policy*, Vol. 133. https://ideas.repec.org/a/eee/enepol/v133y2019ics030142151930463x.html

Seifert, S, Kahle, C. and Huttel, S. 2020. “Price Dispersion in Farmland Markets: What Is the Role of Asymmetric Information?” *Amer. J. Agr. Econ.,* Volume 103. https://onlinelibrary.wiley.com/doi/full/10.1111/ajae.12153

Shrestha, R. M. and A.M.A.K Abeygunawardana. 2000. “Evaluation of economic rent of hydro power projects.” *Energy Policy 37*: 1886-1897.

Sinner, J. and J. Scherzer. 2007. “The Public Interest in Resource Rent.” *New Zealand Journal of Environmental Law* 11: 279-295.

Smith, E. 2007. “Wind Energy: Siting Controversies and Rights in Wind.” *Environmental & Energy Law & Policy Journal.*

Smith, R. A. Ilas, J. Gustavo Inon, and G. Peszko. 2021. “Renewable Energy: Unaccounted Wealth of Nations.” In *Changing Wealth of Nations 2021*. Washington: The World Bank. https://openknowledge.worldbank.org/bitstream/handle/10986/36400/9781464815904_ch14.pdf?sequence=19&isAllowed=y

Statistics Canada, 2015, “Natural resource wealth statistics in the National Balance Sheet Accounts”, in *Latest Developments in the Canadian Economic Accounts*, Catalogue No. 13-605-x, Ottawa: Statistics Canada. https://www150.statcan.gc.ca/n1/en/pub/13-605-x/2015009/article/14239-eng.pdf?st=w5qiZ4fb

Statistics Netherlands. 2011. “Environmental Accounts of the Netherlands 2010.” The Hague: Statistics Netherlands. https://www.wavespartnership.org/sites/waves/files/images/Netherlands%20env%20accts%202010.pdf

Statistics New Zealand. no date. “Energy Monetary Stock Account 1987-2001”*.* http://unstats.un.org/unsd/envaccounting/ceea/archive/Energy/EnergyMonetaryStockAccount_NewZealand.PDF

UK Office for National Statistics (UK ONS). 2016. “UK natural capital: monetary estimates, 2016.” *Statistical Bulletin.https://www.ons.gov.uk/economy/environmentalaccounts/bulletins/uknaturalcapital/monetaryestimates2016*

UK Office for National Statistics (UK ONS). 2019. “Scottish natural capital: ecosystem Service Accounts, 2019.” *Experimental Statistics. https://www.ons.gov.uk/releases/scottishnaturalcapitalecosystemserviceaccounts*

United Nations Economic Commission for Europe (UNECE). 2020. *United Nations Framework Classification for Resources – Update 2019.* ECE Energy Series No. 61. Geneva: United Nations Economic Commission for Europe. https://unece.org/fileadmin/DAM/energy/se/pdfs/UNFC/publ/UNFC_ES61_Update_2019.pdf

United Nations, European Union, Food and Agriculture Organization of the United Nations, International Monetary Fund, Organization for Economic Co-operation and Development and World Bank. 2014. *System of Environmental-Economic Accounting 2012 - Central Framework.* New York: United Nations. https://unstats.un.org/unsd/envaccounting/SEEA-CFRev/SEEA-CF_CF_Final_en.pdf

UNU–IHDP & UNEP. (2012). *Inclusive Wealth Report 2012 – Measuring progress toward sustainability*. Cambridge: Cambridge University Press. Retrieved from http://www.unep.org/pdf/IWR_2012.pdf

UNU–IHDP & UNEP. (2014). *Inclusive Wealth Report 2014 – Measuring progress toward sustainability*. Cambridge: Cambridge University Press. Retrieved from http://mgiep.unesco.org/wp-content/ uploads/2014/12/IWR2014-WEB.pdf

Van Campen., B. 2015. “Comparison of Geothermal regulation between Chile, Philippines and New Zealand.” Melbourne: Proceedings World Geothermal Congress.

Wandji, Y.F. and S.C. Bhattacharyya. 2018. “Evaluation of economic rent from hydroelectric power developments: Evidence from Cameroon.” *The Energy and Development Journal. https://dora.dmu.ac.uk/handle/2086/14494*

Wee, S. 2016. "The effect of residential solar photovoltaic systems on home value: A case study of Hawai'i." *Renewable Energy*, Volume 91. https://www.sciencedirect.com/science/article/pii/S0960148116300593

Wessel, R.H. 1967. "A Note on Economic Rent." *The American Economic Review* 57(5): 1221-1226.

Weron, R. and M. Zator. 2014. "Revisiting the relationship between spot and future prices in the Nord Pool electricity market." *Energy Economics* 44: 178-190.

Winters, M. S. and Cawvey, M. 2015. "Governance obstacles to geothermal energy development in Indonesia." *Journal of Current Southeast Asian Affairs* 34(1): 27-56.

World Bank. 2011. *The Changing Wealth of Nations: Measuring Sustainable Development in the New Millennium.* Washington, DC: World Bank. http://documents.worldbank.org/curated/en/630181468339656734/The-changing-wealth-of-nations-measuring-sustainable-development-in-the-new-millennium

World Bank. 2018. *The Changing Wealth of Nations: Building a Sustainable Future.* Washington, DC: World Bank. http://documents.worldbank.org/curated/en/727941517825869310/The-changing-wealth-of-nations-2018-building-a-sustainable-future

Young, R.A. and J.B. Loomis. 2014. *Determining the Economic Value of Water: Concepts and Methods.* New York: Routledge.

Zhang, S. Andrews-Speed, P. Zhao, X. and He, Y. 2013. "Interactions between renewable energy policy and renewable energy industrial policy: A critical analysis of China's policy approach to renewable energies." *Energy Policy* 62: 342-353.

Zuker, Richard C. and Glenn P. Jenkins. 1984. "Blue Gold: Hydro-Electric Rent in Canada." Development Discussion Papers 1984-01, JDI Programs.

Appendix 1 – Renewable energy assets in physical terms

Geothermal energy

Geothermal energy is derived from heat stored in rock, steam and water found deep in the earth. Enormous quantities of heat are found in the earth's core (mantle) due to trapping of the heat created at the time of the planet's formation (primordial heat) and through on-going decay of radioactive elements in the mantle. This heat radiates outward from the mantle to the crust, where it is accessible for human use. Geothermal energy extracted from the crust can be used directly for heating water that can then be used for heating buildings or domestic hot water or for electrical generation in cases where temperatures are high enough to create the steam required to run an electric turbine (Natural Resources Canada, 2012).

Hydroelectric energy

Hydroelectric energy is driven by the flow of water from high elevations on continents back to the ocean. Mountainous areas, or rivers originating in mountainous areas, have the greatest potential hydroelectric resources. Hydroelectric power plants vary in size, based on the characteristics of the site. Reservoirs and dams are often designed for multiple uses, including flood control, water supply, waterway navigation and recreation and agricultural irrigation.

Hydropower plants can be classified by type:

- **Run-of-river** - Power generation is driven primarily by the normal flow of the river, although there may be some capacity for short-term storage. Generation is dependent on precipitation and runoff and may vary substantially day-to-day and between seasons. Run-of-river plants may be located downstream from reservoir-type plants.
- **Storage hydropower** - Hydropower projects with dams create reservoirs to store water for later use. The type of reservoir depends on the characteristics of the site. Often reservoirs are created by flooding river valleys. High altitude lakes in mountainous areas are another common type and often maintain the characteristics of the original lake.
- **In-stream** - In-stream production, an emerging technology, functions similarly to run-of-river by making use of existing water control infrastructure through the installation of small turbines (IPCC, 2011).

Solar energy

The electromagnetic radiation emitted by the sun, or solar irradiance, can be harvested for use directly as heat or for conversion into electricity by means of, for example, photovoltaic cells. Solar irradiance varies over the surface of the earth, with the highest levels at the equator. The quantity of solar energy reaching any given point on the earth's surface is impacted by atmospheric characteristics; including cloud cover, aerosols, water vapor and other trace gases in the atmosphere (IPCC, 2011).

Passive solar energy technologies have been used for millennia to capture the sun's energy without use of mechanical or electrical equipment. Examples include orientating windows toward the sun to warm buildings, drying of fish and evaporating seawater to collect salt. Active solar technologies convert solar energy to heat or electricity through the use of mechanical or electrical equipment and have only been in use since the late 1800s (Kabir *et al*., 2018). Examples include pumped solar water heating systems for swimming pools or domestic hot water, the aforementioned photovoltaic cells for electricity production and “thermal concentration” systems that use lenses or mirrors to focus solar energy and heat a fluid to power a steam turbine (Malinowski, Leon and Abu-Rub, 2017).

Wind energy

Wind energy is driven in the first instance by the sun and by the earth’s rotation. Some solar radiation is converted into kinetic energy in the form of moving air molecules (wind) due to differences in solar radiation received at high and low latitudes. The earth’s rotation also contributes to the movement of air through the Coriolis effect. Winds are impacted by geographic features and are unevenly distributed over the face of the planet.

Wind energy has long been converted to mechanical power through the use of windmills. These have served to pump water, grind grain, power saw mills and other uses. Wind energy continues to be important for pumping water in remote areas.

Commercial conversion of wind energy to electricity began in the 1970s. The majority of wind turbines have been sited on land, but off-shore wind is growing in importance. Wind turbines convert the kinetic energy of the wind into mechanical energy and then to electrical energy. Taller turbines are typically able to produce more energy, as wind speed increases with height above the ground (IPCC, 2011).

Appendix 2 – Will governments assert property rights to solar and wind resources?

A relevant question is whether governments in the future will cede solar and wind property rights to private entities just because an entity happens to own the land that underlies the sun and wind. A plausible case can be made that such resources are public – as no private entity had anything to do with their creation – and, therefore, that any economic benefits arising from their use should flow to the government on behalf of all citizens. Governments may one day choose to realize those benefits – even if they mainly do not today – through legislation asserting public property rights. Indeed, some have already begun to do so in a limited way. In Canada, for example, the province of British Columbia charges royalties based on revenue for wind power development on public lands. The province of Ontario uses a competitive bidding process for wind power developments on public land (Ingelson, 2018).

Another reason governments may eventually exercise property rights over solar and wind resources is the clear and long-standing practice of doing so in the case of the most important renewable energy resource worldwide today, hydroelectric resources. Governments in many countries ensure that the economic benefits of hydroelectric resources flow to citizens by controlling the resources through publicly owned hydro utilities. This allows them to sell hydroelectricity at prices below competitive market rates, effectively distributing resource rent to consumers.[38] Even in countries with privatized electricity systems, governments charge royalties on the use of water in hydroelectricity production in an effort to capture some of the associated rent (Pineau *et al.*, 2017).

The similarly clear and long-standing government practice of capturing rent on fossil fuel and mineral exploitation provides another reason why rent capture on renewable energy resources may be taken more seriously by governments in the future. Certainly, in the case of geothermal resources, which share much in common with other sub-soil resources, it seems likely that governments will eventually apply the kind of royalty schemes already applied to fossil fuels and minerals. Indeed, some already do. That more will eventually do so seems all the more likely since governments in most countries claim the rights to geothermal resources (see Appendix 3).

There is recent precedent in the case of the radio spectrum for governments introducing policy to begin capturing rent on a natural resource that was previously considered free. The spectrum shares much in common solar and wind resources: all are intangible, associated in some way with the atmosphere and difficult for any unit other than a government to assert property rights over. Governments have regulated access to the spectrum since the early 1900s. However, the economic value of the spectrum was not realized until the 1990s, when governments began to allocate spectrum to cellular telephone operators through competitive auctions. Spectrum auctions from 1994 to 1996 in the United States netted the government nearly $20 billion dollars (Jilani, 2015). Governments realized at that point that the spectrum was a public asset with substantial value. They may well eventually see the same to be true of solar and wind resources. It would be relatively simple for them to assert, as they did with the spectrum, their rights to the ownership of sun and wind energy within their jurisdictions.

Moreover, as growth in solar, wind and other renewables gradually permits a shift away from fossil fuels, governments in fossil fuel-producing jurisdictions may have little choice but to begin capturing rent on renewable energy. They may face substantial and unaffordable declines in

---

[38] Of course, some of these consumers are corporations, so not all the economic benefits end up flowing directly to households.

revenues otherwise. In the Netherlands, for example, an average 6.6% of national government revenues came from corporate payments of natural gas royalties from 2003 to 2016.[39] Over that same period, the country's natural gas reserves declined by nearly 50% in physical terms. This physical depletion coupled with economic pressures on the fossil fuel sector in general mean that the Dutch government cannot count on substantial revenues from its natural gas resources forever. [40] Given this, it is reasonable to suggest the government may, at some point, decide to collect royalties on its growing wind power resources.

---

[39] Author's calculations based on data from the Netherlands' Central Bureau of Statistics.

[40] In addition to the general economic pressures on the fossil fuel industry, the Dutch government is also facing public demands to end natural gas extraction in the North Sea's Groningen Field due to earthquakes caused by settling of the sea bed in the area of extraction (Oil Change International, 2018). The government has committed to ending production in the field by 2030 as a result (van den Berg, 2018).

Appendix 3 – Geothermal property rights in major producing countries

The globally installed capacity of geothermal power was 12.8 GW by the end of 2017, with the United States owning the largest share (2.5 MW). Other major producers include the Philippines, Indonesia and New Zealand, all found along the Pacific Ring of Fire. Turkey, Italy and Iceland are the largest producers in Europe and Kenya is the only significant producer in Africa (REN21, 2018).

In many countries, geothermal resources are owned by the state; this includes the Philippines, Indonesia, Kenya, and Chile. The Philippines collects royalty payments of up to 1.5 percent of gross energy earnings, with the proceeds being split 60:40 between national and local governments (Van Campen, 2015). Past geothermal development in Indonesia was primarily pursued by the state oil and gas company, but a competitive bidding process for exploitation permits has been implemented (Winters and Cawvey, 2015). Development of geothermal resources in Kenya has also been primarily pursued by state companies, although the licensing process is open to private companies (Van Campen, 2015). Chile opened South America's first geothermal plant only in 2017 (REN21, 2018), but as home to about 10 percent of the world's volcanoes, the country has large untapped potential. Chile enacted a geothermal law in 2000 to allow private companies to explore and exploit resources in the country (Rai and Van Campen, 2015).

Ownership of geothermal resources in New Zealand is contentious. As with mineral and water resources, geothermal resources are held separately from land. However, many geothermal resources are subject to ownership claims by Maori peoples. In practice, geothermal resources are regulated by the Resource Management Act and overseen by regional governments (Van Campen, 2015).

Geothermal ownership in the United States varies by jurisdiction. On federal lands, geothermal resources are treated as mineral rights and are held by the government. Some states, including California, also treat geothermal resources as minerals and separate the rights to them from land. Other states, particularly arid Midwestern states, treat geothermal resources as water resources, subject to permitting by state authorities. Yet others, such as Maryland and Oregon, have hybrid systems that regulate geothermal resources as either mineral or water resources, depending on the temperature and depth of the resource (Levine and Young, 2018).

Ownership of geothermal resources in Iceland is attached to land. Geothermal resources on public land are property of the state. Exploration and exploitation of resources requires a permit from the National Energy Authority, regardless of where the resource is located (Orkustfnun, no date.)

Appendix 4 – Empirical studies of renewable energy asset values

Though hydroelectric resources account for more of the installed global capacity of renewable electricity resources than all other sources combined (IEA, 2017), few efforts have been made at measuring their value. Writing in 2000, Rothman noted that "very little has been written…on how to measure economic rent from hydroelectric development." Only a handful of empirical studies having been published in the peer reviewed or grey literatures in the time since (Wen and Gillen, 2000; Limbu and Shrestha, 2004; Hreinsson, 2008a; Hreinsson, 2008b; Statistics Netherlands, 2011; Boungnong and Phonekeo, 2012; UK Office for National Statistics, 2016; Statistics New Zealand, 2017; Wandji and Bhattcharyya, 2018). The more relevant of these studies are reviewed briefly below.

Two major studies of the value of Canadian hydroelectric resources were undertaken in the 1980s (Bernard, Bridges and Scott, 1982 and Zuker and Jenkins, 1984). This was a time when Canada's electricity markets were dominated by large, publicly owned utilities producing and selling power in highly regulated markets. Given this, it is not surprising that neither set of researchers concluded that the RVM was suitable. Both the price at which electricity was sold in Canada at the time and the cost structures of the public utilities that produced it were subject to substantial government intervention. Instead, both studies adopted the least-cost alternative approach (see Section 3.2). Bernard, Bridges and Scott compared actual capital and operating costs of hydroelectricity resources against those of the least-cost mix of coal, heavy oil, natural gas and nuclear generation needed to replace them; non-hydroelectric portions of the existing system were not remodelled. Load duration curves were used to determine the cheapest method of replacing hydroelectric resources for different types of load (base, intermediate and peak). Attempts were made to calculate differences in transmission costs for hydroelectric versus other resources given the need for hydroelectricity to be transmitted over long distances. Transformation, distribution and administration costs were assumed to be the same. Zuker and Jenkins's approach was similar, though rather than modelling just the replacement of hydroelectric resources with the least-cost alternative, they compared the overall cost of Canada's existing electricity system (including hydro) with the cost of a completely remodelled, least-cost system based on coal, heavy oil, natural gas and nuclear resources.

Gillen and Wen (2000) proposed a method for estimating hydroelectric resource rent in the Canadian province of Ontario (which has substantial hydroelectric resources) using the cost of electricity imports as the least-cost alternative. Their interest was to assess whether the provincial government's water charges collected from hydroelectric energy producers were an effective mechanism for rent capture. They found that rents in 1995 were $CDN1.3 billion, ten times as much as the province collected in water charges. This led them to conclude that the province substantially under-taxed hydroelectric rent.

As an aside, Gillen and Wen's rent estimates suggest that Ontario's hydroelectric assets were worth about $CDN29 billion in 1995, or about $CDN 45 billion in current dollars.[41] The province's hydro assets have grown by something like 15% since 1995, suggesting a value of around $CDN 50 billion for its current assets. Given that Ontario is currently home to about 11% of Canada's hydroelectric assets, this would suggest a very rough value of $CDN 500 billion ($US380 billion) for the country's existing hydroelectric assets. This figure is larger than

---

[41] Assuming a 3.8% discount rate and a 50-year lifetime for the resource.

Statistics Canada's 2017 estimated value of any natural asset other than land.[42] While Gillen and Wen's estimates are to be used with caution[43], they do illustrate the importance of a complete accounting of the wealth associated with natural resources in revealing Canada's true national wealth. The same would be true of other countries, such as China, Brazil and the United States, with large hydroelectric energy resources.

Statistics Netherlands (2011, p. 138), noting that when national balance sheets "are restricted only to non-renewable energy resources…serious underestimation of a country's available energy resources" is possible, undertook a study of the value of the Netherlands' wind energy resources using the RVM. This method was chosen because "like any other natural resource, renewable energy resources provide capital services to their owner and their remuneration [resource rent] should be an element in the gross operating surplus of the energy producer" (p. 139). Given this, the RVM should reveal the value of the wind energy rent. A nominal discount rate of 6% was applied and the resource was assumed to be available into the infinite future. An interesting feature of the study is development of what the authors call a "social resource rent", which they define as resource rent normally calculated (or market-based resource rent) as per the RVM but without the adjustment for specific subsidies on production. The intuition behind the social resource rent is that it reflects the value of the resource taking societal preferences (in the form of subsidies) into account. The "social preferences" referred to here are those of the public for emissions-free energy generation, as expressed through political support for government subsidies to carbon-free wind energy. The authors find that, while market-based resource rent on wind energy resources was negative in every year from 1990-2010 (implying a zero economic value for the resource), social rent is consistently positive after 2004. Valued using social rent, Dutch wind energy resources were estimated to be worth more than 5 billion euros in 2010 – a substantial sum, but still only 3% of the estimated value of the Netherlands' natural gas resources in that year.

The United Kingdom Office for National Statistics has prepared two different estimates of the value of the United Kingdom's renewable energy resources, one (UK ONS, 2016) for hydroelectric and wind energy resources for the whole of the United Kingdom and the other for all renewable resources[44] but just for Scotland (UK ONS, 2019). Both studies use the RVM. Data on revenues and costs for the UK-wide study were sourced from annual corporate reports. Due to data limitations, no account was taken of subsidies provided to the industry. This, the authors recognize, means the estimated asset values are likely overstated. The combined value of hydroelectric and wind energy resources (assuming a 3% to 3.5% discount[45] rate over 50 years) was 54.5 billion UK pounds in 2014. The Scottish study estimated renewable energy resource "rent" by assuming it was equal to the renewable share of the electricity generation industry's gross value added.[46] The authors acknowledge that this is not a valid estimate of rent

---

[42] The natural resource assets currently included on Canada's national balance sheet are fossil fuels, minerals, timber and land (commercial, residential and agricultural). Statistics Canada, Table 38-10-0006-01, *Value of selected natural resource reserves*. Available here.

[43] Gillen and Wen note that their rent estimates are similar to those found by Zuker and Jenkins but considerably more than Bernard, Bridges and Scott's value.

[44] Hydroelectric, solar, wind, tidal, wave, landfill/sewage gas and other bioenergy resources.

[45] A 3.5% discount rate is applied during the first 30 years in the net present value calculation and a 3% discount rate thereafter up to 50 years.

[46] Differential levelized costs of production between conventional and renewable electricity generation, weighted by the physical quantities of electricity generated from different sources, were applied to total electric power generation gross value added to estimate the gross value added of electricity from renewable sources.

but use it in any case in the RVM to calculate an “asset value” for Scottish renewable energy resources, which they give as about 24 billion UK pounds (2017 prices) for the year 2015.[47]

---

[47] The RVM calculation uses a 100-year asset life with a 3.5% discount rate during the first 30 years, a 3% discount rate thereafter up to 75 years and a 2.5% rate after 75 years.

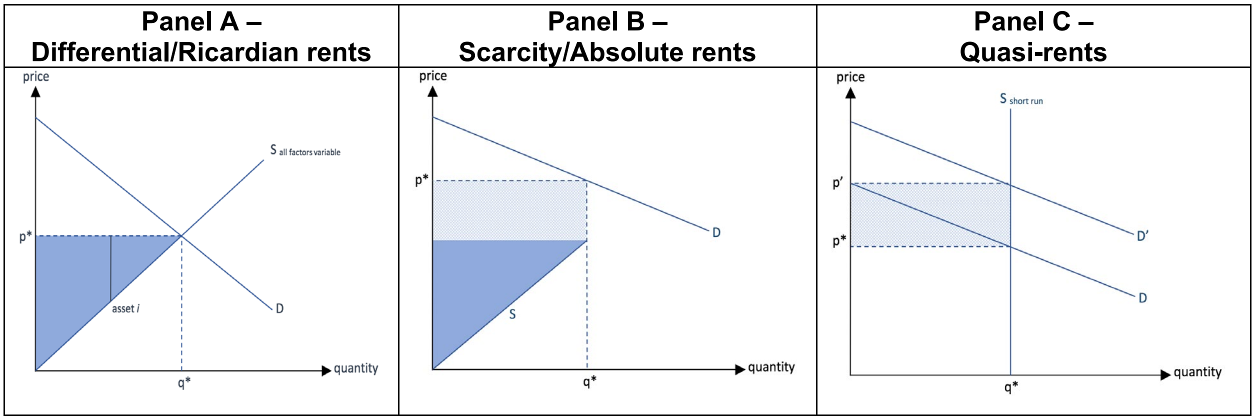
Appendix 5 – Major rent concepts in economic theory and their applicability to renewable energy resources

Rent concepts can be roughly categorized as follows (Sinner and Scherzer, 2007):

- **Ricardian/differential rents -** Rents that accrue to the more productive factors of production in homogenous input markets. In equilibrium, the price at which the least-productive firm is willing to produce clears the market; all firms with marginal costs below this price earn Ricardian (also called "differential") rents (Hartwick and Olewiler, 1999). Classical economists (for example, von Thünen) recognized that location of a resource could be the source of Ricardian rents.
- **Scarcity/absolute rents** – Rents that arise when demand exceeds supply in the long run. Since supply cannot be increased either for natural (fixed physical stock) or arbitrary (regulated entry barriers) reasons, "limits on the supply of a resource allow producers to charge prices greater than their marginal cost" (Rothman, 2000, p. 4). Such "scarcity" rents are also known as "absolute" rents within Marxian economics (da Silva, 2018).
- **Marshallian short-run/quasi rents** – Rents that arise in the short-run; that is, in the absence of a stable long-run equilibrium. Quasi-rents arise when demand exceeds supply at a fixed point in time and are dissipated as the prospect of rent capture encourages more entrants to the market.

In all cases, the fundamental source of rent is scarcity. Thus, Wessel (1967, p. 1222) considers that Ricardian rent is "in essence" the same as scarcity rent, as it is the scarcity of more-productive factors that allows them to earn differential rents. If scarcity is not permanent, Marshall's "quasi-rents" emerge until long-run equilibrium is reached. Figure 1 summarizes the various concepts.

Figure 1 – Rent concepts



Renewable energy resources can generate several types of rents. Differential or Ricardian rents (shaded area in Panel A) arise from productivity differences between producers. The intersection of market demand and supply determines the equilibrium price and quantity (p* and q*), which is also the price at which the least-productive asset will produce. The i^{th} asset earns rent equal to the difference between market price and its marginal cost of production (which lies on the market supply curve). Scarcity or absolute rents (light shaded area in Panel B) arise from demand exceeding supply in the long run. Here, supply cannot exceed q*, but market demand bids the price to p*. All assets earn scarcity rents. As before, more productive assets also earn differential rents. Finally, quasi-rents (shaded area in Panel C) are rents that arise in the short-term only. In the short term, the supply of assets is fixed at q*, with demand curve D and equilibrium price and quantity p* and q*. Suppose demand shifts outward to D', bidding price up to p'.

Assets then earn a form of scarcity rent, which persists until demand falls or more producers enter the market (not shown).

Appendix 6 – Data/methodology template for renewable energy asset valuation

Renewable energy resource	**Recommended approach to rent estimation**	**Expected pattern of future rents**	**Assumed resource lifetime**	**Data requirements**		
				Revenues	**Costs**	**Specific subsidies and taxes**
Geothermal	Residual value method in countries where electricity markets can be assumed to be close to long-term competitive equilibrium Least-cost alternative method can be considered for countries where electricity markets remain distorted by government intervention	Variable – depends on future revenues and costs	25 years	Electricity price per kWh in base year; projections of annual electricity prices over resource lifetime Electricity production (kWh) in base year; projections of annual electricity production over resource lifetime	Cost of materials and supplies in base year; projections of annual costs over resource lifetime[1] Labour costs in base year; projections of annual costs over resource lifetime[1] Value of fixed capital used in production in base year;[2] projections of annual fixed capital stocks over resource lifetime	Value of subsidies paid on products (such as FIT) in base year; projections of product subsidies over resource lifetime Value of subsidies paid on production (such as concessionary loans) in base year; projections of production subsidies over resource lifetime Value of royalties and other specific taxes (such as generator operating licenses) in base year; projections of specific taxes over resource lifetime
Hydro electric	See geothermal	Constant	50 years	Electricity price per kWh in base year Electricity production (kWh) in base year	Cost of materials and supplies in base year Labour costs in base year Value of fixed capital used in production in base year[2]	Value of subsidies paid on products (such as FIT) in base year Value of subsidies paid on production (such as concessionary loans) in base year Value of royalties and other specific taxes (such as generator operating licenses) in base year
Solar	See geothermal					
Wind	See geothermal					

Notes:
1. A reasonable simplifying assumption may be constant costs over the resource lifetime for materials/supplies and labour.
2. Fixed capital stocks include all assets used in renewable electricity generation, including wells and heat-exchange equipment (geothermal), dams (hydroelectric), panel arrays (solar), turbines (wind) and generating equipment (all).