The **CHANGING WEALTH** *of* **NATIONS**

2024

TECHNICAL REPORT

Methods and Data

WORLD BANK GROUP

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1 Introduction

This document describes the concepts, methods and data sources used in the estimation of comprehensive wealth by the World Bank in *The Changing Wealth of Nations 2024* (CWON 2024). Building on the foundation laid in previous work by the World Bank, including *Expanding the Measure of Wealth* (1997), *Where is the Wealth of Nations?* (2005), *The Changing Wealth of Nations* (2011), *The Changing Wealth of Nations* (2018) and *The Changing Wealth of Nations* (2021), the data and methods described in this document represent the latest developments of the World Bank's approach. Though many aspects of the approach remain the same as in previous work, CWON 2024 adopts a number of innovations in key areas related to the measurement of assets in real terms, estimation of natural resource rent, estimation of human capital and others.

A nation's wealth consists of a diverse portfolio of assets, which together form the productive base of the national economy. These assets include (assets marked with an asterisk were added to the database for the 2024 edition):

- *Produced capital*: machinery and equipment; buildings; intangible assets such as intellectual property; and urban land.
- *Non-renewable natural capital*: fossil fuels (oil, gas, coal); and minerals and metals (bauxite, cobalt*, copper, gold, iron ore, lead, lithium*, molybdenum*, nickel, phosphate rock, silver, tin, and zinc).
- *Renewable natural capital*: agricultural land (cropland and pastureland); forests (timber; non-wood forest ecosystem services, including recreation, fishing, and hunting; non-wood forest products; and water services, reported by protected area status); mangroves (shoreline protection services); marine capture fisheries (including commercial and artisanal fisheries), and renewable energy* (hydropower).
- *Human capital*: the value of skills, experience, and effort by the working population over their lifetime by gender (male and female).
- *Net foreign assets*: the sum of a country's external assets and liabilities, such as foreign direct investment and reserve assets.

Before delving into the specifics, it is important to outline a few key methodological concepts and assumptions that apply broadly to both renewable and nonrenewable natural capital. The general principle of asset valuation is that an asset's value should reflect the discounted sum of net benefits it is expected to generate over its lifetime. For natural capital, these net benefits are represented by resource rents—the difference between the total value of production (or revenues) and the total cost of production, including the cost of produced capital used in resource exploitation.

To calculate the net present value of renewable and nonrenewable natural capital, a consistent discount rate of 4 percent is applied across all resources and years, as was the case in previous wealth reports. The valuation period for renewable natural capital is capped at 100 years, in line with the methodology adopted by the UK Office for National Statistics (ONS), which is considered a standard in natural capital accounting. This 100-year time horizon provides a balanced approach, offering a long-term perspective necessary for sustainable resource management, while minimizing the risk of overestimating future benefits that may not materialize beyond this period. Meanwhile, the lifetime of nonrenewable natural capital is determined directly based on reserves and projected extraction paths.

2 Aggregate Comprehensive Wealth

Aggregate comprehensive wealth – that is, the sum of the values of each of the assets in a given nation's comprehensive wealth portfolio – is compiled in both nominal and "real" terms in CWON. Compilation in nominal terms is straightforward. Nominal aggregate comprehensive wealth is simply the sum of each of the assets measured in nominal terms themselves. Measuring aggregate real comprehensive wealth, or comprehensive wealth adjusted to eliminate the influence of price changes, is more complicated. Doing so requires a decision on the approach to use in taking price effects out.

Past practice in CWON was to compile aggregate real comprehensive wealth estimates by deflating the nominal value of each asset (produced, human, natural and financial) in the comprehensive wealth portfolio using a GDP implicit price index (GDP-IPI) and then adding the deflated asset values together. Implicit this approach was the view that *future consumption possibilities* are what must be sustained to ensure well-being in the future (Diewert, Inklaar and Gu, 2023). Deflation via the GPD-IPI treated all assets in the comprehensive wealth portfolio as fungible stores of value readily converted to money to be spent on goods and services. While this approach cohered with the work of many leading theoreticians of wealth accounting (Arrow et al. (2013), Dasgupta, (2014)), it was, in fact, not aligned with the explicit understanding of sustainability taken in previous CWON reports. Previous reports were clear that "a nation's income is *generated* by its [comprehensive] wealth" (CWON, 2021, p. 25; emphasis added). This view places the emphasis in comprehensive wealth accounting squarely on the sustainability of *production* (since production is the source of income) rather than on the sustainability of *consumption*. Thus, there was in previous editions an inconsistency between the implicit view of sustainability embedded in the approach to deflation and the explicit view of it found in the discussion and analysis.

For this reason, a decision was made for CWON 2024 to shift away from deflation using the GDP-IPI in favor of an approach that recognizes the importance of all assets as inputs to production processes. This approach rests on construction of an index in which the physical quantities - or "volumes" - of the various assets comprising comprehensive wealth are aggregated together using their nominal values as weights. Such a volume index aligns with the notion that what matters for sustainability is not preserving assets as stores of value but, rather, preserving them as physical entities that, when combined with one another in production processes, yield the goods and services that are, themselves, the object of consumption.

Another shortcoming of the past approach of using the GDP-IPI for deflation is worth noting. This is that the GDP-IPI was not well suited to deflating comprehensive wealth estimates because it does not necessarily reflect trends in the prices faced by consumers. Since, as noted, comprehensive wealth accounts deflated using the GDP-IPI are implicitly focused on measuring the sustainability of consumption, a deflator that reflected the prices faced by consumers was what was needed. The GDP-IPI fails in this regard because the goods and services comprising GDP can differ markedly from the goods and services consumed by individuals. A country with an economy dependent on exports of fossil fuels, for example, will experience quite different price trends in its production activities than in its consumption activities. The former will be dominated by international prices of bulk oil, gas and coal while the latter will be dominated by the prices of consumer goods and services, many of which may be imported when the domestic economy is focused on fossil fuel production. Since consumers purchase no bulk oil, gas or coal, the prices of these commodities will have no direct impact on the prices they face. Likewise, the prices of consumer products will have a limited impact on the value (or price) of GDP as measured by the GDP-IPI, when few of them are produced domestically as in a petro-economy.

The consumer price index (CPI) would have been a better choice than the GDP-IPI, as it more fully reflects the prices faced by consumers and it is those prices that are most relevant when thinking about the sustainability of consumption opportunities. It was not used in the past, however, because of data limitations. While the GDP-IPI is readily available for most countries and years thanks to the widespread efforts of national statistical offices to measure GDP in both nominal and real terms (the GDP-IPI is simply the ratio between these estimates). The same is not true for the CPI, however, for which significant gaps are found in terms of both geographical and temporal coverage.

As noted, the move to a volume index for CWON 2024 addressed an inconsistency in previous editions, where the approach to deflation was not aligned conceptually with the view of sustainability. This raises the question, "Why change the approach to deflation rather than the view of sustainability?" The answer is that a focus on the sustainability of production rather than consumption fits best with the broad conception of wealth that underpins comprehensive wealth accounting. When wealth is thought of not in the abstract terms that often underpin economic theory, but in the concrete terms demanded when forests, water and minerals - not to mention the people that make up the workforce - are understood as forms of wealth, it becomes clear that a conception of assets merely as fungible stores of value is not fully adequate. This can be illustrated with some simple examples. First, thinking of human capital, it is clear that the knowledge, skills and capacities of individuals are not things that can be packaged up and sold off to the highest bidder. These aspects of human capital are inherent to the individuals who possess them. The benefits of possessing human capital can, thus, only be realized when those who possess it choose to offer (or rent) it to others temporarily in return for wages as part of an employment arrangement, or, alternatively, use it themselves in carrying out their own production activities. Either way, the human capital remains embedded in, and inseparable from, the person. It cannot simply be liquidated all at once in return for a lump-sum payment.

Similarly, much natural capital - especially ecosystem assets that are not bought and sold in the market - has value only as an input into a production process (here we need to be clear that "production" includes production of non-market goods and services like flood control and recreational opportunities). Countries cannot dig up ecosystems and sell them to their neighbors. The same is true of many forms of produced capital, even if produced capital has come to be thought of in a highly stylized form in much of economics. A specialized piece of equipment used to, say, extract oil from deep underground may have value only in the process of producing oil. Its worth as a pure store of value may well be close to zero. The same is true of many other types of produced assets, many of which are useful only when employed in production processes and are not readily transferable to others.

The only asset within the comprehensive wealth portfolio that is best thought of as a pure store of value is financial capital. Most financial assets are relatively liquid and can be converted to cash in the short term. Even here, though, some assets are not always readily convertible. Ownership stakes in foreign corporations, for example, can certainly be sold but not always quickly.

The choice to move to a volume index for CWON 2024 meant that a specific index had to be chosen among the many possibilities (IMF, 2017). A commonly used index is the Fisher Index, after the economist Irving Fisher (Fisher himself referred to it as the "ideal index", but it has come to be so associated with him that it now bears his name). Many national statistical offices use the Fisher Index to express changes in price or volume and it has many desirable theoretical properties (Diewert, 1976). It has drawbacks in practice however. Notably, a complex formula is required to derive the contribution of each element of the index to the overall growth in the index (Chevalier, 2003). An index that avoids this complexity and shares many of the same theoretical qualities as the Fisher Index is the Törnqvist Index, after the Bank of Finland statistician who first proposed it (Bank of Finland, 1936). It is the Törnqvist index that was adopted for use in compiling real comprehensive wealth estimates for CWON 2024. Its implementation is summarized below.

2.1 Generic Törnqvist volume index methodology

As noted, for CWON 2024, a Törnqvist volume index with 2019 as the base year was used to compute "real" asset values. We place "real" in quotation marks because, strictly speaking, we are not measuring real asset values, at least, not as that term is commonly understood in statistics.[1] Rather, we are measuring price-weighted volumes of assets and then expressing those volumes in monetary terms using so-called "chained prices". The methods used to do so are explained below, covering volume indexes for individual assets (e.g., timber – Section 2.2.1), for individual capital types (e.g., human capital – sections 2.2.2 to 2.2.6) and for aggregate comprehensive wealth (Section 2.2.7). We start with a generic presentation of the formula for the Törnqvist volume index, however, as it will be convenient to refer back to this in presenting the implementation of the volume index for specific assets.

The Törnqvist volume index for a given set of assets $\{1, 2, \dots, k\}$ is a weighted geometric mean[2] of the so-called "quantity relative" of each asset included in the index – that is, the ratio of the quantity (or volume) of the asset in the current time period and its volume in the previous period – weighted by the arithmetic average of the shares of the asset in the total nominal value of all k assets in the current period and the previous period. The generic formula to compute the Törnqvist volume index is as follows.[3]

[1] "Real" values (sometimes referred to as "constant price" values) are values that have had the effect of price inflation removed from them. They differ from volume estimates in that real values may still include the impact of holding gains on asset values.
[2] A geometric mean of a set of values is the n^{th} root of the product of the values, where n is the number of values in the set.
[3] Country notation is suppressed for the sake of clarity in presentation.

$$Törn_t = \prod_{a=1}^{k} \left(\frac{q_{a,t}}{q_{a,t-1}}\right)^{\theta_{a,t}} = \prod_{a=1}^{k} \left(\frac{q_{a,t}}{q_{a,t-1}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]}$$

$$= \left(\frac{q_{1,t}}{q_{1,t-1}}\right)^{\frac{1}{2}[s_{1,t}+s_{1,t-1}]} * \left(\frac{q_{2,t}}{q_{2,t-1}}\right)^{\frac{1}{2}[s_{2,t}+s_{2,t-1}]} * \dots * \left(\frac{q_{k,t}}{q_{k,t-1}}\right)^{\frac{1}{2}[s_{k,t}+s_{k,t-1}]}$$

$$= \left(\frac{q_{1,t}}{q_{1,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{1,t}^n}{w_t^n}+\frac{w_{1,t-1}^n}{w_{t-1}^n}\right]} * \left(\frac{q_{2,t}}{q_{2,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{2,t}^n}{w_t^n}+\frac{w_{2,t-1}^n}{w_{t-1}^n}\right]} * \dots * \left(\frac{q_{k,t}}{q_{k,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{k,t}^n}{w_t^n}+\frac{w_{k,t-1}^n}{w_{t-1}^n}\right]}$$

where:

- $q_{a,t}$ is the volume of asset a in year t
- $q_{a,t-1}$ is the volume of asset a in year $t-1$
- $s_{a,t}$ is the share of asset a in in the nominal value of all assets $\{1, 2, \dots, k\}$ included in the index in year t, defined as $s_{a,t} = \frac{w_{a,t}^n}{w_t^n}$
- $s_{a,t-1}$ is the share of asset a in in the nominal value of all assets $\{1, 2, \dots, k\}$ included in the index in year $t-1$, defined as $s_{a,t-1} = \frac{w_{a,t-1}^n}{w_{t-1}^n}$
- w_t^n is the nominal value of all assets $\{1, 2, \dots, k\}$ included in the index in year t, defined as $w_t^n = \sum_{a=1}^{k} w_{a,t}^n$ where $w_{a,t}^n$is the nominal value of asset a in year t
- w_{t-1}^n is the nominal value of all assets $\{1, 2, \dots, k\}$ included in the index in year $t-1$, defined as $w_{t-1}^n = \sum_{a=1}^{k} w_{a,t-1}^n$ where $w_{a,t-1}^n$is the nominal value of asset a in year $t-1$
- $\theta_{a,t}$ is the weight of asset a in year t, which is the arithmetic average of the shares of asset a in the nominal value of all assets $\{1, 2, \dots, k\}$ included in the index in period t and $t-1$, defined as $\theta_{a,t} = \frac{1}{2}\left[s_{a,t} + s_{a,t-1}\right] = \frac{1}{2}\left[\frac{w_{a,t}^n}{w_t^n} + \frac{w_{a,t-1}^n}{w_{t-1}^n}\right]$

It is important that the meaning of the term "volume" as used above is clear. Volume should be understood to be a physical quantity (or a proxy for a quantity) of a given asset. As an example, the volume of timber assets is measured in hectares and the volume of oil assets is measured in barrels. The purpose of the volume index is to permit the volumes of disparate assets to be added together although they are measured in different units. This is accomplished by weighting the "quantity relatives" of each asset by their value shares, as described above, rendering them unitless and, therefore, commensurable.

2.1.1 Chaining the Törnqvist volume index

To make the Törnqvist volume index easier to interpret, it is chained together to make a time series by selecting a base year (2019 in the case of CWON 2024) and then expressing other years in terms relative to the base year, as follows.

For the base year (by), the chained Törnqvist volume index is normalized to 100:

$$Törn\_chained_{by} = 100$$

For all the years *before* the base year, that is for $t < by$, the chained Törnqvist volume index is computed as:

$$Törn\_chained_{t<by} = \frac{Törn\_chained_{t+1}}{Törn_{t+1}}$$

For all the years *after* the base year, that is for $t > by$, it is computed as:

$$Törn\_chained_{t>by} = Törn\_chained_{t-1} * Törn_t$$

2.1.2 Expressing the chained Törnqvist volume index in monetary terms

To further ease interpretation of the index, it is customary to express the time series of chained volume index numbers in monetary terms, which are referred to in CWON as real asset values and expressed in "chained 2019 prices". To do this, the chained Törnqvist volume index value in each year is multiplied by the aggregate nominal value of all assets included in the index in the base year (2019 in the case of CWON 2024), with the real asset value (w^r) in the base year set equal to the nominal asset (w^n) value. This proceeds as follows.

For the base year (by) compute:

$$w^r_{by} = w^n_{by}$$

For all the years *before* the base year, that is for $t < by$, compute:

$$w^r_{t<by} = Törn\_chained_t * \frac{w^n_{by}}{100} = \frac{Törn_{chained_{t+1}}}{Törn_{t+1}} * \frac{w^n_{by}}{100}$$

For all the years *after* the base year, that is for $t > by$, compute:

$$w^r_{t>by} = Törn\_chained_t * \frac{w^n_{by}}{100} = Törn\_chained_{t-1} * Törn_t \frac{w^n_{by}}{100}$$

2.2 Methodology for Törnqvist volume indexes in CWON

Having presented the generic methodology for a Törnqvist volume index in the preceding section, we now turn to the compilation of the specific volume indexes required for CWON. These indexes cover the period 1995-2020 and, depending on the index in question, include anywhere from one to eighteen assets. It should be noted that the indexes for the different asset types cannot simply be added together to arrive at aggregate real comprehensive wealth; rather, aggregate real comprehensive wealth is calculated as its own chained Törnqvist volume index in which the volumes are represented by the chained Törnqvist volume indexes for the individual asset types in the CWON accounts and their weights are the nominal values of each asset types (see Section 2.2.7 for details). This is unlike the previous editions of CWON when the real values of assets, which were derived by applying price indexes to nominal asset values, could simply be added together to compile the overall wealth estimate.

2.2.1 Törnqvist volume index for an individual asset

The compilation of a Törnqvist volume index for an individual asset (for example, timber) is trivial but is presented here for completeness. First, an unchained Törnqvist volume index for the single asset is compiled:

$$Törn_t^a = \frac{q_{a,t}}{q_{a,t-1}}$$

where:

- $q_{a,t}$ is the volume of asset a in year t.

Because there is just a single asset in the index, there is no weighting applied to the quantity relatives. Effectively, the weight for the single asset is unity.

Once the unchained index time series is compiled as above, it is then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2.

2.2.2 Törnqvist volume index for produced capital

Produced capital in CWON 2024 comprises residential and non-residential buildings; machinery (including computers, communication equipment and other machinery); transportation equipment; and other assets (including software, other intellectual property products and cultivated assets) plus an estimate for the value of urban land. As explained further in Section 8, estimates of the value of machinery, transportation equipment and other assets are taken for most countries directly from the Penn World Tables (Feenstra et al., 2015)[4], while estimates of the value of urban land are taken to be a constant share (24 percent) of the value of produced capital in all countries following Kunte et al. (1998).[5]

An unchained Törnqvist volume index is first compiled to aggregate the estimated volume of produced capital from the Penn World Tables and the estimated volume (area) of urban land as follows:

[4] The Penn World Tables are a global, publicly available database of macroeconomic data compiled by researchers at the University of Groningen in the Netherlands to study economic growth, structural change, productivity and inequality.

[5] CWON 2024 is the final edition in which urban land will be considered a form of produced capital, as this classification is inconsistent with both the SEEA and the SNA. Beginning with the next edition, urban land will be classified as a type of natural capital. At the same time, an improved methodology for estimating the value of urban land will be implemented.

$$Törn_t^{pk} = \prod_{a=1}^{2}\left(\frac{q_{a,t}^{pk}}{q_{a,t-1}^{pk}}\right)^{\theta_{a,t}} = \prod_{a=1}^{2}\left(\frac{q_{a,t}^{pk}}{q_{a,t-1}^{pk}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]}$$

$$= \left(\frac{q_{PWT,t}}{q_{pwt,t-1}}\right)^{\frac{1}{2}[s_{PWT,t}+s_{PWT,t-1}]} * \left(\frac{q_{urban,t}}{q_{urban,t-1}}\right)^{\frac{1}{2}[s_{urban,t}+s_{urban,t-1}]} =$$

$$= \left(\frac{q_{PWT,t}}{q_{pwt,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{PWT,t}^{n}}{w_{pk,t}^{n}}+\frac{w_{PWT,t-1}^{n}}{w_{pk,t-1}^{n}}\right]} * \left(\frac{q_{urban,t}}{q_{urban,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{urban,t}^{n}}{w_{pk,t}^{n}}+\frac{w_{urban,t-1}^{n}}{w_{pk,t-1}^{n}}\right]}$$

where,

- $q_{PWT,t}$ is the real value of produced capital in year t from the Penn World Tables[6]
- $q_{urban,t}$ is the area of urban land (in hectares)[7]
- $w_{PWT,t}^{n}$ is the nominal value of produced capital in year t from the Penn World Tables
- $w_{urban,t}^{n}$ is the nominal value of urban land in year t (estimated as 24 percent of the value of $w_{PWT,t}^{n}$)
- $w_{pk,t}^{n}$ is the total nominal value of produced capital plus urban land in year t, $w_{PWT,t}^{n} + w_{urban,t}^{n}$

Once the unchained index time series for produced capital is compiled as above, it is then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2.

2.2.3 Törnqvist volume index for nonrenewable natural capital

Nonrenewable natural capital in CWON 2024 comprises sixteen assets in total: three fossil fuel assets (crude oil, natural gas, coal) and thirteen metals and minerals (bauxite, copper, gold, iron ore, lead, nickel, phosphate, silver, tin, zinc, cobalt, molybdenum, and lithium). An unchained Törnqvist volume index is first compiled to aggregate the estimated volumes of these individual assets into an overall index of nonrenewable natural capital as follows:

[6] Specifically, the variable "cn" from the Penn World Tables is used. See Section 8 for further details.
[7] Estimates on the area of urban land are made by combining land area data from the Centre for International Earth Science Information at Columbia University and population data from the United Nations (UN) Population Division's World Urbanization Prospects. See Section 8 for further details.

$$Törn_t^{nrk} = \prod_{a=1}^{16} \left(\frac{q_{a,t}^{nrk}}{q_{a,t-1}^{nrk}}\right)^{\theta_{a,t}} = \prod_{a=1}^{16} \left(\frac{q_{a,t}^{nrk}}{q_{a,t-1}^{nrk}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]}$$

$$= \left(\frac{q_{oil,t}}{q_{oil,t-1}}\right)^{\frac{1}{2}[s_{oil,t}+s_{oil,t-1}]} * \left(\frac{q_{gas,t}}{q_{gas,t-1}}\right)^{\frac{1}{2}[s_{gas,t}+s_{gas,t-1}]} * \left(\frac{q_{coal,t}}{q_{coal,t-1}}\right)^{\frac{1}{2}[s_{coal,t}+s_{coal,t-1}]}$$

$$* \left(\frac{q_{mineral1,t}}{q_{mineral1,t-1}}\right)^{\frac{1}{2}[s_{mineral1,t}+s_{mineral1,t-1}]} * \ldots$$

$$* \left(\frac{q_{mineral13,t}}{q_{mineral13,t-1}}\right)^{\frac{1}{2}[s_{mineral13,t}+s_{mineral13,t-1}]}$$

$$= \left(\frac{q_{oil,t}}{q_{oil,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{oil,t}^n}{w_{nrk,t}^n}+\frac{w_{oil,t-1}^n}{w_{nrk,t-1}^n}\right]} * \left(\frac{q_{gas,t}}{q_{gas,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{gas,t}^n}{w_{nrk,t}^n}+\frac{w_{gas,t-1}^n}{w_{nrk,t-1}^n}\right]}$$

$$* \left(\frac{q_{coal,t}}{q_{coal,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{coal,t}^n}{w_{nrk,t}^n}+\frac{w_{coal,t-1}^n}{w_{nrk,t-1}^n}\right]} * \left(\frac{q_{mineral1,t}}{q_{mineral1,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{mineral1,t}^n}{w_{nrk,t}^n}+\frac{w_{mineral1,t-1}^n}{w_{nrk,t-1}^n}\right]} * \ldots$$

$$* \left(\frac{q_{mineral13,t}}{q_{mineral13,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{mineral13,t}^n}{w_{nrk,t}^n}+\frac{w_{mineral13,t-1}^n}{w_{nrk,t-1}^n}\right]}$$

where,

- $q_{oil,t}$, $q_{gas,t}$, and $q_{coal,t}$ are, respectively, the quantities (proven reserves) of crude oil (barrels)[8], natural gas (terajoules), and coal[9] (tonnes) in year t
- $q_{minerala,t}$ is the quantity (proven reserves) of mineral or metal a { $a \in$ 1 (bauxite), 2 (cobalt), 3 (copper), 4 (gold), 5 (iron ore), 6 (lead), 7 (lithium), 8 (molybdenum), 9 (nickel), 10 (phosphate), 11 (silver), 12 (tin), 13 (zinc)} in year t
- $w_{oil,t}^n$, $w_{gas,t}^n$ and $w_{coal,t}^n$ are, respectively, the nominal values of crude oil, natural gas, and coal assets in year t
- $w_{minerala,t}^n$ is the nominal value of mineral or metal a { $a \in$ 1 (bauxite), 2 (cobalt), 3 (copper), 4 (gold), 5 (iron ore), 6 (lead), 7 (lithium), 8 (molybdenum), 9 (nickel), 10 (phosphate), 11 (silver), 12 (tin), 13 (zinc)} in year t
- $w_{nrk,t}^n$ is to the total nominal value of all nonrenewable natural resource assets in year t.

Once the unchained index time series for nonrenewable natural capital is compiled as above, it is then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2.

[8] Crude oil includes field condensate and natural gas liquids.
[9] Coal includes hard coal (includes thermal and metallurgical coal) and brown coal (lignite and sub-bituminous coal).

2.2.4 Törnqvist volume index for renewable natural capital

Renewable natural capital in CWON 2024 comprises eight assets in total: agricultural land, timber, three non-wood terrestrial forest ecosystem service assets (recreation, hunting and fishing; non-wood forest products, and water services), non-wood mangrove forest ecosystem service assets (shoreline protection services), marine fish stocks and renewable energy (hydropower). An unchained Törnqvist volume index is first compiled to aggregate the estimated volumes of these individual assets into an overall index of renewable natural capital as follows:

$$Törn_t^{rk} = \prod_{a=1}^{8}\left(\frac{q_{a,t}^{rk}}{q_{a,t-1}^{rk}}\right)^{\theta_{a,t}} = \prod_{a=1}^{8}\left(\frac{q_{a,t}^{rk}}{q_{a,t-1}^{rk}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]}$$

$$= \left(\frac{q_{agland,t}}{q_{agland,t-1}}\right)^{\frac{1}{2}[s_{agland,t}+s_{agland,t-1}]} * \left(\frac{q_{timber,t}}{q_{timber,t-1}}\right)^{\frac{1}{2}[s_{timber,t}+s_{timber,t-1}]}$$

$$* \left(\frac{q_{forestES1,t}}{q_{forestES1,t-1}}\right)^{\frac{1}{2}[s_{forestES1,t}+s_{forestES1,t-1}]} * \ldots$$

$$* \left(\frac{q_{forestES3,t}}{q_{forestES3,t-1}}\right)^{\frac{1}{2}[s_{forestES3,t}+s_{forestES3,t-1}]} * \left(\frac{q_{mangES,t}}{q_{mangESt-1}}\right)^{\frac{1}{2}[s_{mangES,t}+s_{mangES,t-1}]}$$

$$* \left(\frac{q_{fish,t}}{q_{fish,t-1}}\right)^{\frac{1}{2}[s_{fish,t}+s_{fish,t-1}]} * \left(\frac{q_{hydro,t}}{q_{hydro,t-1}}\right)^{\frac{1}{2}[s_{hydro,t}+s_{hydro,t-1}]}$$

$$= \left(\frac{q_{agland,t}}{q_{agland,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{agland,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{agland,t-1}^{n}}{w_{rk,t-1}^{n}}\right]} * \left(\frac{q_{timber,t}}{q_{timber,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{timber,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{timber,t-1}^{n}}{w_{rk,t-1}^{n}}\right]}$$

$$* \left(\frac{q_{forestES1,t}}{q_{forestES1,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{forestES1,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{forestES1,t-1}^{n}}{w_{rk,t-1}^{n}}\right]} * \ldots$$

$$* \left(\frac{q_{forestES3,t}}{q_{forestES3,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{forestES3,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{forestES3,t-1}^{n}}{w_{rk,t-1}^{n}}\right]}$$

$$* \left(\frac{q_{mangES,t}}{q_{mangESt-1}}\right)^{\frac{1}{2}\left[\frac{w_{mangES,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{mangES,t-1}^{n}}{w_{rk,t-1}^{n}}\right]} * \left(\frac{q_{fish,t}}{q_{fish,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{fish,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{fish,t-1}^{n}}{w_{rk,t-1}^{n}}\right]}$$

$$* \left(\frac{q_{hydro,t}}{q_{hydro,t-1}}\right)^{\frac{1}{2}\left[\frac{w_{hydro,t}^{n}}{w_{rk,t}^{n,}}+\frac{w_{hydro,t-1}^{n}}{w_{rk,t-1}^{n}}\right]}$$

where,

- $q_{agland,t}$ is the quantity (hectares) of agricultural land in year t
- $q_{timber,t}$ is the quantity (cubic metres) of timber in year t

- $q_{forestESa,t}$ is the quantity (hectares) of forestland associated with non-wood terrestrial forest ecosystem service asset a { $a \in 1$ (recreation, hunting and fishing), 2 (non-wood forest products), 3 (water services)} in year t
- $q_{mangES,t}$ is the quantity (hectares) of mangrove forest associated with non-wood mangrove forest ecosystem service assets land in year t
- $q_{fish,t}$ is the quantity (tonnes) of marine fish resources in year t
- $q_{hydro,t}$ is the quantity (gigawatt hours of electricity production) of hydroelectric resources in year t
- $w^n_{agland,t}$ is the nominal value of agriculture land assets in year t
- $w^n_{timber,t}$ is the nominal value of timber assets in year t
- $w^n_{timber,t}$ is the nominal value of timber assets in year t
- $w^n_{gas,t}$, $w^n_{coal,t}$ and $w^n_{coal,t}$ are, respectively, the nominal values of crude oil, natural gas, brown coal and hard coal assets in year t
- $w^n_{forestEAa,t}$ is the nominal value of non-wood terrestrial forest ecosystem service asset a { $a \in$ 1 (recreation, hunting and fishing), 2 (non-wood forest products), 3 (water services)} in year t
- $w^n_{fish,t}$ is the nominal value of marine fish assets in year t
- $w^n_{hydro,t}$ is the nominal value of hydroelectric resource assets in year t
- $w^n_{rk,t}$ is to the total nominal value of all renewable natural resource assets in year t.

Once the unchained index time series for renewable natural capital is compiled as above, it is then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2.

2.2.5 Törnqvist volume index for human capital

Human capital in CWON 2024 comprises four categories of workers: (male/employed; male/self-employed; female/employed; and female/self-employed). An unchained Törnqvist volume index is first compiled to aggregate the estimated volumes of these individual worker categories into an overall index of human capital as follows:

$$
\begin{aligned}
Törn^{hk}_t &= \prod_{a=1}^{4}\left(\frac{q^{hk}_{a,t}}{q^{hk}_{a,t-1}}\right)^{\theta_{a,t}} = \prod_{a=1}^{4}\left(\frac{q^{hk}_{a,t}}{q^{hk}_{a,t-1}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]} \\
&= \left(\frac{q_{khcat1,t}}{q_{hkcat1,t-1}}\right)^{\frac{1}{2}[s_{hkcat1,t}+s_{hkcat1,t-1}]} * \ldots * \left(\frac{q_{khcat4,t}}{q_{hkcat4,t-1}}\right)^{\frac{1}{2}[s_{hkcat4,t}+s_{hkcat4,t-1}]} \\
&= \left(\frac{q_{khcat1,t}}{q_{hkcat1,t-1}}\right)^{\frac{1}{2}\left[\frac{w^n_{hkcat1,t}}{w^n_{hk,t}}+\frac{w^n_{hkcat1,t-1}}{w^n_{hk,t-1}}\right]} * \ldots * \left(\frac{q_{khcat4,t}}{q_{hkcat4,t-1}}\right)^{\frac{1}{2}\left[\frac{w^n_{hkcat4,t}}{w^n_{hk,t}}+\frac{w^n_{hkcat4,t-1}}{w^n_{hk,t-1}}\right]}
\end{aligned}
$$

where,

- $q_{a,t}^{hk}$ is the number of workers in category a $\{a \in 1$ (male/employed) 2 (male/self-employed) 3 (female/employed), 4 (female/self-employed)$\}$ in year t, quality adjusted with PWT HC index
- $w_{hkcata,t}^{n}$ is the nominal value of human capital of workers in category a $\{a \in 1$ (male/employed) 2 (male/self-employed) 3 (female/employed), 4 (female/self-employed)$\}$ in year t
- $w_{hk,t}^{n}$ is the total nominal value of all human capital in year t.

Once the unchained index time series for human capital is compiled as above, it is then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2.

2.2.6 Real value of foreign financial assets and liabilities

Foreign financial assets are the only assets in CWON 2024 for which a volume index is not compiled. This is because financial assets serve as pure stores of value and are, therefore, appropriate deflated to real terms using a price index. Financial assets are also intangible and so not easily expressed in volume terms. Thus, the approach taken to their deflation in CWON is simply to apply the consumer price index (CPI_t) to deflate nominal assets values into real values. For reasons that will be made clear in Section 2.2.7 next, this is done separately for foreign financial *assets* and foreign financial *liabilities*, as follows:

$$w_{ffa,t}^{r} = \frac{w_{ffa,t}^{n}}{CPI_t}$$

$$w_{ffl,t}^{r} = \frac{w_{ffl,t}^{n}}{CPI_t}$$

where,

- $w_{ffa,t}^{n}$ is the nominal value of foreign financial assets in year t
- $w_{ffl,t}^{n}$ is the nominal value of foreign financial liabilities in year t.

2.2.7 Törnqvist volume index for aggregate comprehensive wealth

Aggregate comprehensive wealth in CWON 2024 comprises produced capital, nonrenewable natural capital, renewable natural capital, human capital and net foreign financial assets. To compile the real aggregate value of these assets an unchained index is first compiled for produced capital, nonrenewable natural capital, renewable natural capital, human capital and only foreign financial *assets.* It is necessary to exclude foreign financial *liabilities* from this index because, by definition, liabilities carry a negative sign and the form of the Törnqvist index is such that positive and negative values cannot be combined in the same index. Of course, foreign financial *liabilities* cannot simply be ignored, so a separate (single asset) index is compiled for them.

Compilation of the index for produced capital, nonrenewable natural capital, renewable natural capital, human capital and foreign financial *assets* proceeds as follows, with the volumes of these assets taken to be the chained index values calculated as in sections 2.2.2 to 2.2.6 above:

$$Törn_t^{pk,nrk,nk,hk,ffa} = \prod_{a=1}^{5}\left(\frac{q_{a,t}^{pk,nrk,nk,hk,ffa}}{q_{a,t-1}^{pk,nrk,nk,hk,ffa}}\right)^{\theta_{a,t}} = \prod_{a=1}^{5}\left(\frac{q_{a,t}^{pk,nrk,nk,hk,ffa}}{q_{a,t-1}^{pk,nrk,nk,hk,ffa}}\right)^{\frac{1}{2}[s_{a,t}+s_{a,t-1}]}$$

$$= \left(\frac{Törn\_chained_t^{pk}}{Törn\_chained_{t-1}^{pk}}\right)^{\frac{1}{2}[s_{pk,t}+s_{pk,t-1}]} * \left(\frac{Törn\_chained_t^{nrk}}{Törn\_chained_{t-1}^{nrk}}\right)^{\frac{1}{2}[s_{nrk,t}+s_{nrk,t-1}]}$$

$$* \left(\frac{Törn\_chained_t^{rk}}{Törn\_chained_{t-1}^{rk}}\right)^{\frac{1}{2}[s_{rk,t}+s_{rk,t-1}]} * \left(\frac{Törn\_chained_t^{hk}}{Törn\_chained_{t-1}^{hk}}\right)^{\frac{1}{2}[s_{hk,t}+s_{hk,t-1}]}$$

$$* \left(\frac{w_{ffa,t}^{r}}{w_{ffa,t-1}^{r}}\right)^{\frac{1}{2}[s_{ffa,t}+s_{ffa,t-1}]}$$

$$= \left(\frac{Törn\_chained_t^{pk}}{Törn\_chained_{t-1}^{pk}}\right)^{\frac{1}{2}\left[\frac{w_{pk,t}^{n}}{w_t^{n}}+\frac{w_{pk,t-1}^{n}}{w_{t-1}^{n}}\right]} * \left(\frac{Törn\_chained_t^{nrk}}{Törn\_chained_{t-1}^{nrk}}\right)^{\frac{1}{2}\left[\frac{w_{nrk,t}^{n}}{w_t^{n}}+\frac{w_{nrk,t-1}^{n}}{w_{t-1}^{n}}\right]}$$

$$* \left(\frac{Törn\_chained_t^{rk}}{Törn\_chained_{t-1}^{rk}}\right)^{\frac{1}{2}\left[\frac{w_{rk,t}^{n}}{w_t^{n}}+\frac{w_{rk,t-1}^{n}}{w_{t-1}^{n}}\right]}$$

$$* \left(\frac{Törn\_chained_t^{hk}}{Törn\_chained_{t-1}^{hk}}\right)^{\frac{1}{2}\left[\frac{w_{hk,t}^{n}}{w_t^{n}}+\frac{w_{hk,t-1}^{n}}{w_{t-1}^{n}}\right]} * \left(\frac{w_{ffa,t}^{r}}{w_{ffa,t-1}^{r}}\right)^{\frac{1}{2}\left[\frac{w_{ffa,t}^{n}}{w_t^{n}}+\frac{w_{ffa,t-1}^{n}}{w_{t-1}^{n}}\right]}$$

where,

- w_t^n is the total nominal value of produced capital, nonrenewable natural capital, renewable natural capital, human capital and foreign financial *assets* in year t

and all other variables are as defined previously.

Compilation of this single-asset index for foreign financial *liabilities* proceeds as follows:

$$Törn_t^{ffl} = \frac{w_{ffl,t}^{r}}{w_{ffl,t-1}^{r}}$$

where,

- $w_t^{r,ffl}$ is the real value of foreign financial liabilities in year t (estimated as in Section 2.2.6).

Once the two unchained index time series are compiled as above, they are then chained and expressed in monetary terms following the approach laid out in sections 2.1.1 and 2.1.2. In a final step, the monetary values of the two indexes are then added to arrive at the total real value of comprehensive wealth measured in chained 2019 prices. For the sake of clarity, the steps involved in this final step are shown in full detail below.

2.2.7.1 Chaining the indexes

For the base year (2019) compute:

$$Törn\_chained_{2019}^{pk,nrk,nk,hk,ffa} = 100$$

$$Törn\_chained_{2019}^{ffl} = 100$$

For all the years before the base year compute:

$$Törn\_chained_{t}^{pk,nrk,nk,hk,ffa} = \frac{Törn\_chained_{t+1}^{pk,nrk,nk,hk,ffa}}{Törn_{t+1}^{pk,nrk,nk,hk,ffa}}$$

$$Törn\_chained_{t}^{ffl} = \frac{Törn\_chained_{t+1}^{ffl}}{Törn_{t+1}^{ffl}}$$

For all the years after the base year compute:

$$Törn\_chained_{t}^{pk,nrk,nk,hk,ffa} = Törn\_chained_{t-1}^{pk,nrk,nk,hk,ffa} * Törn_{t}^{pk,nrk,nk,hk,ffa}$$

$$Törn\_chained_{t}^{ffl} = Törn\_chained_{t-1}^{ffl} * Törn_{t}^{ffl}$$

2.2.7.2 Expressing the chained indexes in monetary terms

Estimation of the real value of comprehensive wealth in chained prices including all assets and liabilities ($w_{cw,t}^{r}$) proceeds as follows. For the base year (2019) compute:

$$w_{cw,2019}^{r} = w_{pk,nrk,nk,hk,ffa,2019}^{n} + w_{ffl,2019}^{n}$$

For all the years *before* the base year (1995-2018 in the case of CWON 2024) compute:

$$\begin{aligned} w_{cw,t}^{r} &= (Törn\_chained_{t}^{pk,nrk,nk,hk,ffa} * \frac{w_{pk,nrk,nk,hk,ffa,2019}^{n}}{100}) + (Törn\_chained_{t}^{ffl} * \frac{w_{ffl,2019}^{n}}{100}) \\ &= (\frac{Törn\_chained_{t+1}^{pk,nrk,nk,hk,ffa}}{Törn_{t+1}^{pk,nrk,nk,hk,ffa}} * \frac{w_{pk,nrk,nk,hk,ffa,2019}^{n}}{100}) + (\frac{Törn\_chained_{t+1}^{ffl}}{Törn_{t+1}^{ffl}} \\ &* \frac{w_{ffl,2019}^{n}}{100}) \end{aligned}$$

For all the years *after* the base year (2020 in the case of CWON 2024) compute:

$$
\begin{aligned}
w_{cw,t}^{r} &= (Törn\_chained_{t}^{pk,nrk,nk,hk,ffa} * \frac{w_{pk,nrk,nk,hk,ffa,2019}^{n}}{100}) + (Törn\_chained_{t}^{ffl} * \frac{w_{ffl,2019}^{n}}{100}) \\
&= (Törn\_chained_{t-1}^{pk,nrk,nk,hk,ffa} * Törn_{t}^{pk,nrk,nk,hk,ffa} * \frac{w_{pk,nrk,nk,hk,ffa,2019}^{n}}{100}) \\
&+ (Törn\_chained_{t-1}^{ffl} * Törn_{t}^{ffl} * \frac{w_{ffl,2019}^{n}}{100})
\end{aligned}
$$

3 Non-renewable natural resources

The non-renewable natural resources valued in the CWON accounts include fossil fuels (oil, gas, and coal) and metals and minerals (bauxite, cobalt, copper, gold, iron ore, lead, lithium, molybdenum, nickel, phosphate, silver, tin and zinc).

3.1 Estimating non-renewable natural resource rent and asset value

Consistent with guidance in the SNA and SEEA-CF and with past CWON practice, the valuation of non-renewable energy and mineral resources in CWON 2024 rests on an approach where asset values are estimated as the net present value (NPV) of expected future resource rents. Resource rents, for their part, are estimated as the difference between the revenues realized from exploiting the resources and the costs of doing so (the so-called "residual value method", or RVM). This overall approach is referred to here as the NPV-RVM approach.

Not all non-renewable resources qualify as economic assets. In keeping with the general definition of an asset and with the guidance in the SNA and SEEA-CF, only non-renewable resources that are viable for extraction under prevailing technological and economic conditions are considered economic assets and included in the CWON non-renewable resource accounts. Thus, a remote oil, coal or mineral deposit with no infrastructure in place (or under construction) to extract the ore is not considered an economic asset. Only where the necessary equipment and infrastructure is in place to extract non-renewable resources and where those resources can be sold at a profit under prevailing price conditions does an asset exist. 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 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.

As noted above, CWON 2024 retains the RVM-NPV approach applied in previous reports but with some methodological improvements as discussed below. In the RVM-NPV, 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 (see **Text Box *1*** for further discussion of resource rent).

Text Box 1 - Concepts of resource rent

All resource 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. The 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 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).
- **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) considers that Ricardian rent is essentially 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.

The details of the NPV-RVM approach and data sources used in the valuation of non-renewable resources are laid out below. Equation 3.1 expresses the version of the RVM used to estimate rent for non-renewable resources in a given country and year t.

$$RR_{t,i}^{nrk} = TR_{t,i}^{nrk} - O\&M_{t,i}^{nrk} - (rK_{t,i}^{nrk} + \partial_i^{nrk}) \qquad (3.1)$$

where

i ∈ (oil, natural gas, coal, bauxite, cobalt, copper, gold, iron ore, lead, lithium, molybdenum, nickel, phosphate rock, silver, tin, zinc)

$RR_{t,i}^{nrk}$ = residual value estimate of resource rent for non-renewable asset i in year t in the country in question

$TR_{t,i}^{nrk}$ = total revenue from sales of non-renewable asset i in year t in the country in question, less any subsidies on production received plus any taxes on production paid

$O\&M_{t,i}^{nrk}$ = cost for labour, materials, fuel and other supplies to operate and maintain the produced assets used to extract non-renewable asset i in year t in the country in question

r = economy-wide average annual rate of return to produced capital in the country (a constant)

$K_{t,i}^{nrk}$ = total value of produced capital used to extract non-renewable asset i in year t in the country in question

∂_i^{nrk} = annual rate of depreciation of the produced capital used to extract non-renewable asset i in year t in the country in question.

In general, when estimating rent on natural resources like non-renewable resources it is recommended to exclude production subsidies received by producers when estimating revenues from resource sales. (SEEA-CF Section 5.4.5). Subsidies should be deducted as they increase net revenue from resource exploitation and, by consequence, increase resource rent derived via the residual value method. Since subsidies do not represent a return to the resource itself, they should be excluded from resource rent. In practice, data on subsidies paid to natural resource extraction companies are difficult to obtain. For this reason, subsidies remain as part of resource rent for all natural resource assets in CWON 2024.[10]

3.1.1 From rent to resource value

Non-renewables resources valued in the World Bank wealth accounts include fossil energy and mineral resources. Consistent with guidance in the SEEA-CF, the value of a nation's stock of a non-renewable resource is measured as the present value of the stream of expected rents that may be extracted from the resource until it is exhausted. This value, V_t, is given as:

(3.2)
$$V_t = \sum_{i=t}^{t+T-1} \frac{R_t}{(1+r)^{i-t}}$$

where R_t is rent in the current year[11]; r is the discount rate (assumed to be a constant 4 percent), and T is the lifetime of the resource. Rents in the current year are calculated as:

(3.3)
$$R_t = \pi_t q_t$$

where π_t denotes unit rents, equal to revenues less production costs including a 'normal' rate of return on fixed capital and the consumption of fixed capital (also called the user costs of capital); and q_t denoting the quantity of resource extracted. Rents are converted into constant US dollars at market rates using country-specific GDP deflators. The present value of rents from energy and mineral resources is estimated under the restrictive assumption that rents remain constant in future years.

3.2 Oil and natural gas

As noted, the value of a nation's stock of oil and natural gas is calculated as the present value of expected rents that could be obtained over the lifetime of the resource. Calculating the present value of future rents requires data for annual production, prices, production costs, and reserves. From existing reserves

[10] The value of subsidies could be interpreted as a "social" cost in the value of natural capital, to the extent that societies collectively agree through government policy to allocate resources to support or facilitate their exploitation.

[11] Previous CWON practice had been to smooth these rents using a lagged five-year moving average due to their volatility. This practice was applied unevenly across assets however, so it has been discontinued in CWON 2024. All rents for all assets are left unsmoothed in this edition.

and current rates of production, the time to exhaustion of the resource is assumed. Data sources and methods for estimating each of these elements are described below.

3.2.1 Oil and natural gas production

Table 1 indicates the data sources for the production of oil and natural gas.

Table 1: Data sources for production of oil and natural gas

Element	Data sources
Production of Oil and Natural Gas	• Rystad Energy, UCUBE (Upstream Database) • International Energy Agency (IEA), "World Energy Statistics", IEA World Energy Statistics and Balances database (link) • IEA, "World Conversion Factors", IEA World Energy Statistics and Balances database (link708M) • BP, Statistical Review of World Energy (link) • US Energy Information Administration, International Energy Statistics (link) • UN Statistics Division, UN Monthly Bulletin of Statistics (link)

The Rystad Energy UCUBE and IEA World Energy Statistics databases are subscription-based services. The BP, US EIA, and UN databases are free and publicly available. Slight differences exist between the data sources as to the scope of oil production. The IEA, BP, and US EIA data include crude oil, shale oil, oil sands, and lease condensates[12]. Rystad Energy and the UN MBS exclude lease condensates.

3.2.2 Oil and natural gas unit costs, prices, and unit rents

Unit rents are estimated using country-level averages of unit prices and production costs from the Rystad Energy UCUBE database, and, additionally, estimates of the user costs of capital. Using the terminology of Rystad Energy, unit prices are equal to unit revenues, which in the Rystad Energy database are the sum

[12] Lease condensates are additional liquids that are recovered and separated by field facilities at oil and natural gas wells. They may contain pentane and a variety of hydrocarbons, depending on their density. Denser condensates may be darker in color and appear similar to light crude oil. Lighter condensates contain more natural gas liquids, such as ethane, propane, and butane and may be more translucent in color. Lease condensates (crude oil with an API gravity of 45° or higher) accounted for roughly about 23 percent of oil production between January 2015 and April 2021 in the continental United States. US EIA, "Crude Oil and Lease Condensate Production by API Gravity", https://www.eia.gov/petroleum/data.cfm#crude (accessed September 20th, 2021).

of exploration expenditure, capital expenditures, exploration expenditure, operational expenditure, government take, and free cash flow in current US dollars per barrel (or barrel of oil equivalent for natural gas).[13] Unit costs equal operational expenditure plus the user costs of produced assets.

In previous editions of CWON, annual capital expenditure was used as a proxy for returns to capital in the non-renewable resource extraction industries (the $rK_{t,i}^{nrk}$ term in equation 3.1). The presumption was that over the long-run capital expenditure must, by definition, be no more than returns to capital, since entrepreneurs can invest, at most, what they earn off their investments in the long run. However, in the short run this constraint need not hold, as entrepreneurs are able to borrow money to increase investment in any given year (or years) over and above what it may be in the long run. Thus, the previous CWON approach of using annual capital expenditure data as a proxy for return on investment was liable to over- or under-estimate return on investment in any given year, depending on where the industry was at in its investment cycle. For this reason, CWON 2024 no longer uses annual capital expenditure to proxy return to capital for the oil and gas industry.[14] Rather, user costs in the oil and gas industry are constructed by estimating capital stocks for each oil or gas producing country (the $K_{t,i}^{nrk}$ from equation 3.1) and applying the economy-wide average annual rate of return to produced capital in the country (the r from equation 3.1).

Following the *Measuring Capital* Manual (OECD, 2009) approach, we estimate the initial capital stock at time 0 for each country using the following formula:

(3.4)
$$K_{0,\mathrm{O\&G}} = \frac{I_{0,\mathrm{O\&G}}}{r + d_{O\&G}}$$

where $K_{0,O\&G}$ is the initial capital stock for the oil and gas industry, $I_{0,O\&G}$, is oil and gas industry investment in year 0, r is a time-invariant economy-wide rate of return and $d_{O\&G}$ is a time-invariant depreciation factor (see below for details).

Time 0 for each country is the first year for which capital expenditure data is available for the oil and gas industry between 1970 and 2020. This is because the World Bank's underlying time series goes back to 1970 and because the longer the time series, the more reliable the capital stock estimate. If capital expenditure data is missing in between years for up to 10 years, the series is gap filled using linear interpolation.

[13] The Rystad model starts by estimating revenues using prices and production volumes. It then estimates these sub-categories from a variety of data sources including official reporting from companies and governments, ad-hoc published data, official institutions and in-house analysis. By construction, the sum of these economic categories will sum to total yearly revenue.

[14] Due to data limitations, this change has only been applied to the oil and gas industry in CWON 2024. When future improvements in data sources, the hope is that it can be expanded to other non-renewable resources in future editions.

After the initial capital stock estimate is calculated, the value of the capital stock in subsequent periods is estimated by adding annual capital expenditure and subtracting annual depreciation, as follows:

(3.5) $$K_{t,O\&G} = K_{t-1,O\&G} + I_{t,O\&G} - (K_{t-1,O\&G})d_{O\&G}$$

If there are gaps in the capital expenditure series longer than 10 years, the estimation procedure starts again estimating K_0, as the industry is assumed to have closed and restarted. As the capital stock estimate can be quite sensitive to the initial capital stock estimate, a symmetrical 5-year average around the initial capital expenditure observation is taken as the initial capex value, I_0 (e.g., if the capital expenditure time series begins in 1970, the average of the values for 1970 through 1974 is calculated and this figure is used as I_0 and year zero is taken as 1972).

For the parameter estimates, the depreciation rate is assumed to be 7.5 percent for high income countries and 8.5 percent for all other countries. The economy wide rate of return is estimated based on the country average between 1970 and 2022 of a gap-filled series of candidate economy-wide rates of return. The candidate variable in hierarchy-order used are: the long-run government bond rate, the real interest rate and the internal rate of return (source details and summary of use are in Table 2).

Table 2: Sources for the Economy-wide Rate of Return

Variable	Source	Share of Gap-filled Series
IMF, Govt Bond	IMF International Financial Statistics (link)	22.7
PWT, IRR	PWT 10.01 (link)	32.68
Real Interest Rate	World Bank (link) FR.INR.RINR	41.27
WB, Extrapolated	WB staff estimate	3.35
Total		100

With the capital stock series and parameters from depreciation and the economy-wide rate of return (as a proxy for the industry-specific rate of return), user costs are estimated as:

(3.6) $$User\ costs_{t,O\&G} = K_{t,O\&G}(r + d_{O\&G})$$

Table 3 below defines each of the price and cost components.

Table 3: Components of unit rents for oil and natural gas, as calculated using Rystad Energy data

Calculation of unit rents and rental rates for oil and natural gas **Unit rent = unit revenue – unit cost** **Unit cost = opex + user costs** **Rental rate = unit rent / unit revenue**	
Unit Cost Component	**Definition**
Opex	Costs necessary to maintain the operations of a well or asset, including transportation costs for delivering oil and gas from the production point to the point of pricing; SG&A costs, which cover administrative staff costs, office leases, stocks and stock option plans, and professional expenses (legal, consulting, insurance); and lease, fixed, and variable production costs
User costs of produced assets	The user costs of produced assets include the consumption of fixed capital (depreciation) and a 'normal' rate of return on fixed capital. Depreciation is best described as a loss in value, and therefore a deduction from income, of an asset as they age and/or are used in production (OECD, 2009). The 'normal' rate of return on fixed capital is the average or typical return one would expect from investments in produced assets. It can be conceptualized as the difference between the rental price of a capital good and its depreciation (OECD, 2009). To estimate both components, capital stocks are estimated using capital expenditure data from Rystad, which includes development costs related to facilities and drilling of wells, as well as other capital expenses such as the establishment of a facility, infrastructure, pre-drilling costs, drilling and development of wells, modifications to the facility and processing system (e.g. subsea infrastructure).
Unit Revenue	Unit revenue is determined by oil prices which depend on oil quality and total oil and gas prices, which depend on local markets or known contracts.

Sources: Rystad Energy (2015)

The country data from Rystad Energy on unit revenues and costs for oil and natural gas are used to calculate country-level rental rates for the entire series subject to data availability. For most countries there is country-level rent data to be used. If, however, there are gaps in the country rental rates of less than 10 years, these are filled using an index of regional rental rates. If gaps are more than 10 years, then regional average rental rates, weighted by production, are used, with negative unit rents set to zero before averaging. Due to volatility and large negative rents in data for Sub-Saharan Africa, the regional rental rate used for gapfilling is replaced with a simple average of rental rates for all other regions (excluding North America)[15].

3.2.3 Oil and natural gas reserves and time to depletion

Time to depletion of oil and natural gas is equivalent to the ratio of proved reserves to production. Proved reserves are those quantities of oil and natural gas that geological and engineering information indicates with reasonable certainty can be recovered profitably in the future from known reservoirs under existing economic and operating conditions. Data on proved reserves are available from BP and the US Energy Information Administration (Table 4).

Table 4: Data sources for proved reserves of oil and natural gas

Component	Data sources
Proved reserves of oil and natural gas	• BP, Statistical Review of World Energy (link) • US Energy Information Administration, International Energy Statistics (link)

The BP data on oil and gas reserves are drawn from a variety of official statistics and data provided by the OPEC Secretariat, Cedigaz, World Oil and the Oil & Gas Journal and an independent estimate of Russian oil reserves based on information in the public domain. The US EIA data on oil and gas reserves for the United States are drawn from agency estimates; US EIA data for other countries is drawn primarily from the *Oil & Gas Journal*, and the estimates for Kuwait and Saudi Arabia each include one-half of the reserves for the Neutral Zone. Oil reserves include field condensate and natural gas liquids (NGLs) as well as crude oil. They also include an estimate of Canadian oil sands 'under active development' as a proxy for proved reserves.

For the sake of consistency, where BP data are used for production, BP data are also used for reserves; where US EIA data on production are used, the US EIA data on reserves are used. If data from the same source are not available for both reserves and production, then the BP data on reserves are given priority. If data on reserves are missing for a particular country, then an estimate of the average reserves-production (R-P) ratio for that region is applied using the BP data. For years prior to 1980, reserves are back casted by regressing a time trend from the existing years of data.

[15] Unit rents may be negative particularly in the early stages of developing an oil or gas field, when significant capital expenditures must be made to bring the field into production. Rents may also be negative for more mature assets where producers receive additional subsidies or other forms of support to make production economical.

If there are gaps in the reserves series for a country that has reserves data at any other point in time, then these are gap filled forwards by deducting production, and gap-filled backwards by adding production. The backwards approach is likely to be more accurate, as it would include any past resource discoveries, as the forward filling approach is unable to account for any new discoveries that may have occurred without additional data.

Table 5: Oil Reserves Sources, 1995-2020

Source	Percent
BP	38.48
US EIA	57.38
WB staff, back cast	2.89
WB staff, gap filled	1.24
Total	100

Table 6: Gas Reserves Sources, 1995 - 2020

Source	Percent
BP	20.74
IEA	22.41
Rystad	1.59
US EIA	52.86
WB staff, back cast	0.89
WB staff, gap filled	1.51
Total	100

3.3 Coal

As with oil and natural gas, calculating the value of a nation's coal resources requires data on production, prices, costs, and reserves. Each of these elements is described below.

3.3.1 Coal production

As with oil and natural gas, data on coal production are obtained from a variety of sources (Table 7).

Table 7: Data sources for the production of coal

Element	Data sources
Production of coal	• International Energy Agency, World Energy Statistics (link) • US Energy Information Administration, International Energy Statistics (link)

	• UN Statistics Division, UN Monthly Bulletin of Statistics (link) • Energy Institute and BP, Statistical Review of World Energy (link)
Average net calorific value of coal production	• International Energy Agency, World Energy Statistics (link)

The primary data sources for coal production are the IEA's World Energy Statistics database and the Statistical Review of World Energy. These sources offer the most detailed estimates of production, broken down by specific coal grades.

Coal production is standardized based on heat content and is broken down into two general categories: ***hard coal*** and ***brown coal,*** which are aggregated into a single coal type for the final calculation. Hard coal is defined by the International Coal Classification of the Economic Commission of Europe as coal with a gross calorific value that is greater than 5,700 kcal/kg. Brown coal is all coal with a gross calorific value less than 5,700 kcal/kg (UN 1988). For countries with more detailed data from the IEA, hard coal production is further disaggregated into ***bituminous steam coal (including anthracite)*** and ***coking coal***. Steam coal is coal that is used primarily for generating electricity. The coal is fired in a boiler to heat water, producing steam that drives a turbine. Coking coal, or metallurgical coal, is hard coal with a low volatile matter content that is primarily used to make blast-furnace coke and foundry coke in the manufacture of steel. High-grade coking coal is produced by relatively few countries (just 5 countries accounted for about 80 percent of global production in 2020, China, India, Indonesia, Australia, and the United States). Thus, for countries with only data on total hard coal production, it is conservatively assumed that these countries only produce bituminous steam steal and not metallurgical coal. The IEA data cover more than two-thirds of all countries for coal production data are available from any source. The US EIA also provides disaggregated data on production of anthracite, bituminous, subbituminous, lignite, and metallurgical coal, but only for the most recent years. Subbituminous coal and lignite are taken as brown coal, and anthracite, bituminous, and metallurgical coal are taken as hard coal. For earlier years, data on coal production from the US EIA are reported only on a more aggregated basis for hard coal and brown coal. The more detailed breakdown in coal production by coal grade as a share of total coal production for the most recent years is assumed for these earlier years. The UN data are used only for gap-filling purposes because they report only aggregate hard and brown coal production.

In order to standardize coal production by heat content, IEA estimates of the average net calorific value (NCV) of coal production are used, as obtained from the World Energy Statistics database[16]. Where a country is missing IEA data on the average NCV of production for certain years, the earliest or latest value for that country is used to gap-fill missing observations. If a country is missing IEA data on average NCV of

[16] Note that the net calorific value (NCV) is slightly lower than the gross calorific value (GCV) for coal. The NCV subtracts the energy required to vaporize the moisture content in coal from the GCV.

production for all years, then a regional average is applied for that specific rank of coal. Global averages may be applied for regions where no countries have IEA data on average NCV of production.

3.3.2 Coal unit prices, costs, and unit rents

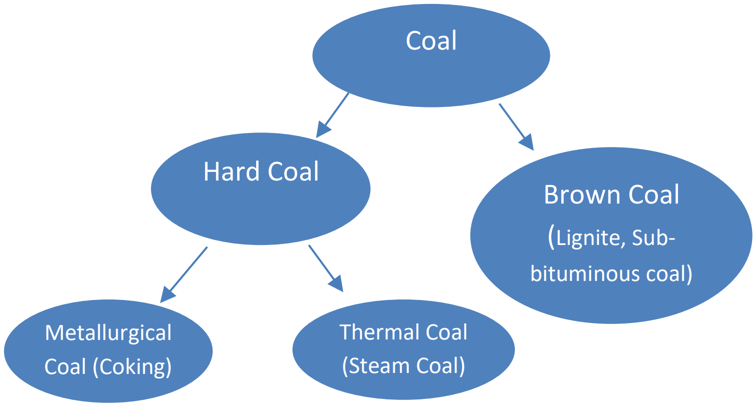
Data sources for unit production costs, user costs of capital and prices for coal are shown in Table 8.

Table 8: Data sources for coal prices and production costs

Element	Data sources
Unit production cost of coal	• Wood Mackenzie, Global Economic Model (GEM) database (link) • Case studies from various sources • World Bank, Manufactures Unit Value (MUV) Index, Global Economic Monitor Commodities database (link)
User costs of produced assets	• Estimated from Wood Mackenzie, Global Economic Model (GEM) database (link)
Unit price of coal	• World Bank, Global Economic Monitor Commodities database (link) • Government of Australia, Office of the Chief Economist, Department of Industry, Innovation and Science, "Resources and Energy Quarterly" (link) • IEA, *Coal Information* (Paris, OECD: various years)

The primary source of data for calculating unit production costs for coal is the Wood Mackenzie Global Economic Model (GEM) database. The GEM database is a subscription service that provides mine-level estimates of costs for around 1,300 mines in 15 countries: Australia, Botswana, Canada, Chile, China, Colombia, Indonesia, Mongolia, Mozambique, New Zealand, Russian Federation, South Africa, United States, Venezuela RB, and Vietnam. Together, these countries accounted for 85 percent of the world's hard coal production in 2014. The Wood Mackenzie data primarily cover the late 2000s and 2010s, although data for Australian mines stretch back to 1993. Production costs are estimated separately for mines producing ***thermal coal, metallurgical coal and brown coal (also known as lignite)***. Costs and prices for coal are normalized on the basis of energy content (USD per kcal), assuming the average NCV of production for thermal coal and metallurgical coal as reported by the IEA. Because the Wood Mackenzie data for thermal coal encompass bituminous steam coal as well as brown coal, the production cost per unit of energy (kcal) is assumed to be the same for both bituminous steam coal and brown coal. Metallurgical coal mainly includes coking coal.

Figure 1: Coal Type Classification



Because costs are reported at the mine level in the Wood Mackenzie GEM database, and some mines produce multiple grades of coal, only those mines that produce either thermal coal, coking or brown coal—but not multiple types—are included. Also, while Wood Mackenzie provide projections for production, costs, and prices for mines under development, for the calculation of rents, only mines that were producing coal in at least half of the years for which Wood Mackenzie has data for that country are included. Mines must currently be in production for the year in which they report cost data. These rules for inclusion in the sample used to calculate average production costs at the country level help ensure some consistency across time in the sample of mines per country and excludes assets still in the early start-up phase when large capital investments are needed to begin operations. Applying these rules restricts the total number of reporting assets to 217, including 95 mines for thermal coal, 65 for mines for metallurgical coal and 57 for brown coal. The number of assets per country for which production cost data are available from Wood Mackenzie is shown in Table 9. Costs are averaged at the country level by weighting costs for individual mines by total production.

Table 9: Number of mines in the Wood Mackenzie GEM database used to calculate production costs for thermal coal and metallurgical coal by country

Country	Thermal	Metallurgical	Brown
Australia	8	8	1
Canada	2	9	6
Chile	0	0	1
China	5	6	14
Colombia	4	1	3
Indonesia	3	0	7
Mongolia	0	2	5
New Zealand	1	1	0
Russian Federation	27	7	7
United States	8	30	13

Venezuela, RB	1	0	0
Vietnam	1	1	0
South Africa	31	0	0
Total	95	65	57

Note: Sample includes mines which are used to calculate production costs for at least one year per country

Production costs for additional countries and years not covered by the Wood Mackenzie database are gathered from academic articles, case studies, official statistics, industry reports, and other sources. These additional sources are listed in Table 10 below. These additional data sources include old studies from the 1980s, 1990s and a couple from the 2010s that had been used previously to estimate coal production costs for the World Bank's adjusted net savings (ANS) indicator.

Table 10: Additional sources of production cost estimates for coal

Thermal coal		
Country	**Years**	**Source**
Canada	1994	IEA (1995a)
China	1987	Doyle (1987)
Colombia	1994	IEA (1995a)
Czech Republic	1992-1994	IEA (1995a)
India	1988	Bhattacharya (1995)
India	2013	Greenpeace (2014)
Indonesia	1994	IEA (1995a)
Mexico	1989	World Bank (1989)
Poland	1991-1993	IEA (1995b)
Poland	2003	Kudelko, Kaminski, and Pekala (2007)
Poland	2014	Bukowski et al (2014); Ernst & Young (2014); assumes brown coal is 43 percent of thermal coal production and bituminous steam coal is 57 percent, using European average cost for brown coal
Russian Federation	1980, 1985, 1990	Tretyakova and Heinemeier (1986)
South Africa	1994	IEA (1995a)
United States	1994	IEA (1995a)
Metallurgical coal		
Country	**Years**	**Source**
Canada	1994	IEA (1995a)
India	1988	Bhattacharya (1995)
Poland	1994	IEA (1995b)
Poland	2003	Kudelko, Kaminski, and Pekala (2007)
South Africa	1994	IEA (1995a)

Data on production costs from the Wood Mackenzie database and additional data sources do not cover all countries and years for which data on coal production are available, so additional gap-filling and extrapolating is needed to construct complete time series.

For thermal coal, unit costs for Australian (1993-2014) and Indonesian (2000-2014) mines from the Wood Mackenzie database are averaged and then used as a nominal index to extrapolate cost trends for other countries and years. This is because the Australia and Indonesia data provide the best coverage and are generally consistent with trends in reference prices for thermal and metallurgical coal. For metallurgical coal, trends in nominal unit costs for Australian coal (1993-2014) are taken as a reference index for other countries. Note that the export unit value of Australian coal is often used in the industry as a benchmark for prices, so this method for extrapolating trends in unit costs has some precedent. For years prior to 1993, where data on unit production costs are not available from Wood Mackenzie, costs are extrapolated using the World Bank's Manufactures Unit Value (MUV) index. The MUV index was also used in previous versions of the World Bank's ANS and wealth accounts databases to extrapolate unit production costs for coal; however, the MUV index does a poor job of tracking price and cost trends for coal in the mid-2000s and early 2010s, during which time prices and costs for coal spiked and dropped quite dramatically. This is why the Australia-Indonesia index using the Wood Mackenzie data is preferred for years after 1993.

For the nominal cost index, price levels in 2000 = 100. Costs in earlier or later years are extrapolated as:

(3.7)
$$C_i = C_n * E_i \,/\, E_n$$

where C_i is the unit cost in the current year *i* being gap-filled (nominal terms); C_n is the cost in the base year *n* for which data are available from Wood Mackenzie or other sources; E_i is the index value in year *i*; and E_n is the index value in the base year.

Internal gaps exist for countries with new data for the 2000s and 2010s from Wood Mackenzie and old data from the 1980s and early 1990s. While the new data provides a more accurate basis for estimating production costs in recent years, it is assumed that the old data provide a more reliable basis for estimating production costs for the earlier years than simply extrapolating from the new data using the nominal cost index described above. For countries with both old and new cost data, cost estimates that are extrapolated for earlier years using the nominal index are rescaled to align with the original case studies. This rescaling is done by the following method. First, the nominal cost index is transformed logarithmically such that:

(3.8)
$$C_{index} = \ln C_n + \ln E_i - \ln E_n$$

where C_{index} is the ln of unit production costs in current year *i*, extrapolated according to the nominal cost index. For countries with both new and old data on production costs, the gap in the log-transformed unit production costs, ln(C_i), is then interpolated linearly such that:

(3.9)
$$C_{linear} = \ln C_n - (y_n - y_i)\left(\frac{\ln C_n - \ln C_0}{y_n - y_0}\right)$$

where C_{linear} is the ln of unit production costs in the current year *i*, interpolated linearly; C_n is the unit production cost in year *n*, the earliest year of new data from the Wood Mackenzie database or other source; C_0 is the unit production cost in year 0, the latest year of old data from the case studies used previously for the World Bank's ANS indicator; y_n is year *n*; y_0 is year 0; and y_i is year *i.* Finally, C_{index} and C_{linear} are combined:

(3.10)
$$\ln C_i = C_{index} - (C_{index} - C_{linear})\left(1 - \frac{y_i - y_0}{y_n - y_0}\right)$$

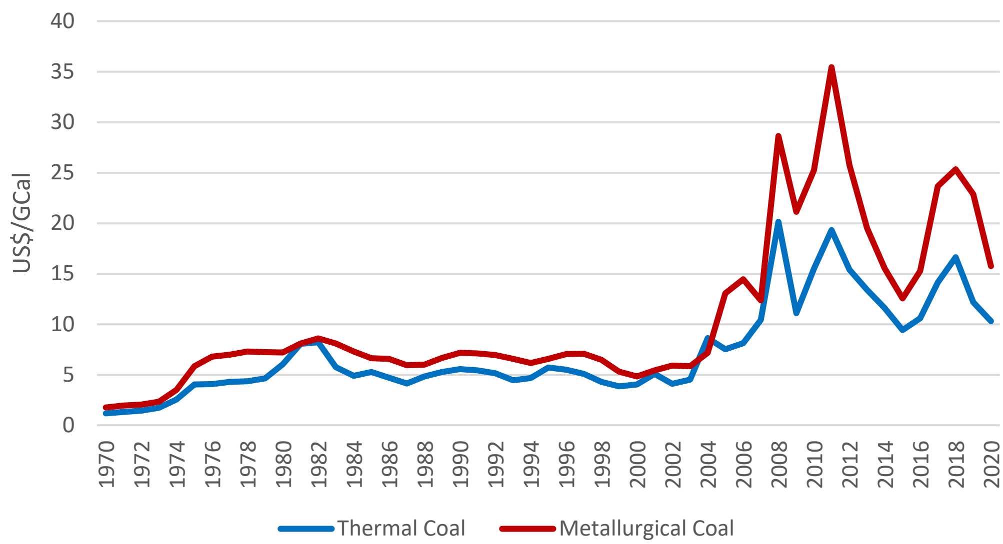
so that C_{index} and C_{linear} are weighted depending on how close the current year (y_i) is to the year at the beginning of the gap (y_0). This method of combining the interpolated production costs ensures that the interpolated costs match up smoothly with the cost study estimates.

Estimates for the user costs of capital (or produced assets) follow a similar approach as for oil and gas, with the same equations and parameters (see Section 3.2.2 above). The main difference is coal capital expenditure data is at the mine-level, rather than the country-level, and is estimated for the 3 different types of coal: thermal, metallurgical and brown coal.

If there are any internal gaps in user-costs series for countries with mine-level capital expenditure data, the same interpolation and extrapolation rules are followed as for the coal production costs, which are outlined above. After interpolation and extrapolation procedures are followed, regional and global average user-costs are estimated. For countries without user-cost data for any type of coal, the user-costs are gap-filled first with regional averages and then global averages if no regional data is available.
Estimates of unit prices for thermal coal are obtained from the World Bank's Global Economic Monitor Commodities database. Unit prices for thermal coal represent the average benchmark price for thermal coal exported from Australia, Colombia, and South Africa (FOB basis), standardized in terms of USD per kcal. This benchmark price is applied to all countries; differences in the quality of coal produced by individual countries are accounted for by standardizing prices according to energy content. The reference price per kcal is applied to both bituminous steam coal and brown coal.

Unit prices for metallurgical coal are pinned to the reference price for exports of Australian coking coal (FOB basis). Data on reference prices for Australian coking coal are obtained from various years of the IEA's *Coal Information* reports. Data for more recent years are obtained from quarterly reports by the Office of the Chief Economist, Department of Industry, Innovation and Science, Australian Government. Prices for metallurgical coal are standardized in terms of USD per kcal by assuming the average NCV for exports, using the conversion factors from the IEA World Energy Statistics database. Trends in the reference prices for metallurgical and thermal coal are illustrated in Figure 2 below.

Figure 2: Reference prices for thermal and metallurgical coal used in the estimation of coal rents



Note: Costs are normalized on the basis of energy content; 1 Gcal = 1 billion calories = 1 million kilocalories (kcal)

Country-level estimates of unit production costs and prices are used to estimate country-level rental rates for thermal, metallurgical and brown coal. If country-level estimates are not available, then country rental-rates are gap filled with regional average rental rates. Average rental rates are weighted by production. For regions lacking estimates of production costs (Middle East and North Africa), a simple world average of rental rates is applied. Where unit costs exceed prices, zero rents are assumed.

3.3.3 Coal reserves and time to depletion

Data on proved reserves of coal are taken from the sources listed in Table 11 below. Time to depletion of coal reserves is calculated as the ratio of reserves to production.

Table 11: Data sources for coal reserves

Element	Data sources
Proved reserves of coal	• US Energy Information Administration (US EIA), International Energy Statistics (link) • German Federal Institute for Geosciences and Natural Resources (BGR, 2020) • Energy Institute and BP, Statistical Review of World Energy (link)

The primary source of data on reserves is the US EIA International Energy Statistics database and the statistical review of world energy. The Statistical Review of World Energy was published by BP from 1952 until 2022 and is now managed by the Energy Institute. The review provides comprehensive data on global energy production, consumption, and emissions. The 2024 edition of the Statistical Review, now hosted by the Energy Institute, continues to be a key source for reliable and globally consistent energy data. The US EIA currently provides estimates of "recoverable reserves" of "hard coal" and "lignite" in 2021 (as of August, 2023). In the US EIA statistics, data on the United States are from US government sources; data for other countries are from the World Energy Council (WEC). The WEC defines "proved recoverable reserves" as "resources remaining in known coal deposits that have been shown to be accessible under current local economic and technological conditions"[17]. The US EIA notes that proved reserves as defined by the WEC are analogous to what the administration calls "measured" reserves; however, the US EIA data on proved reserves of coal for the United States also include "indicated" reserves. The data for measured and indicated reserves for the United States "have been combined prior to depletion adjustments and cannot be recaptured as *'measured alone'*"[18]. The US EIA's data for "lignite" reserves are equal to the WEC's data for both lignite and sub-bituminous coal; the EIA data for hard coal is equal to the WEC data for bituminous coal including anthracite. The EIA data on reserves are thus consistent with the definitions of hard and brown coal according to the International Coal Classification of the Economic Commission of Europe.

The German BGR provides estimates of reserves of "hard coal" and "lignite" coal for 2020 (as of September, 2023). In the BGR estimates, reserves are defined as "proven volumes of energy resources economically exploitable at today's prices and using today's technology" (BGR 2015: 160)[19]. The BGR definitions of hard coal and lignite differ from those used by the US EIA, WEC, IEA, and the International Coal Classification of the Economic Commission of Europe. Lignite is defined as "raw coal with an energy content (ash free) < 16,500 kj/kg," or about 3,900 kcal/kg. On the other hand, hard coal is any coal with an energy content of ≥ 16,500 kj/kg, or with a heating value above 3,900 kcal/kg. Because of this definitional discrepancy, the BGR data on reserves are only used for gap-filling purposes for countries without US EIA or WEC data. Also, in using the BGR data to calculate the time to exhaustion of coal reserves, estimates are only made for countries for which the BGR has data on both reserves and production.

[17] World Energy Council, "Energy Resources: Coal", https://www.worldenergy.org/data/resources/resource/coal/.

[18] US EIA, "International Statistics – Notes", http://www.eia.gov/cfapps/ipdbproject/docs/IPMNotes.html#c6.

[19] Note that while the WEC and BGR definitions of reserves are broadly consistent, the two institutions classify total resources differently. The WEC notes, "BGR's category 'resources' (using its own definition, which differs from WEC usage) amounts to around 82.9 billion tonnes of hard coal and 36.5 billion tonnes of lignite [for Germany]. These levels convey an indication of the enormous size of the additional amounts of coal 'in place', over and above the in-situ tonnages hosting the recoverable reserves" (WEC 2013). Because we are interested only in proven (or recoverable) reserves, the differences between how WEC and BGR categorize other resources (e.g., 2P and 3P) is not relevant here.

For countries without data on reserves, time to depletion is calculated using a simple average of the ratio of reserves to production for other countries in the region. An unweighted average is used because weighting would imply that the countries missing data are similar the world's major producers (e.g., R/P ratios for all East Asian countries are basically equivalent to those in China because China is the dominant producer in the region and accounts for about 55 percent of world coal production). Because there is no basis to judge the R/P ratios for missing countries, a simple unweighted average is better. Although this results in higher average R/P ratios, this suggests that countries with missing data are likely not extracting coal at the scale or rate of the major producers, which is logical.

The time to depletion that is calculated for the year in which data are available for both reserves and production (2014 for most countries) is assumed for all years. Also, as with other natural assets, the time to depletion for coal reserves is no longer capped at 25 years.

If there are gaps in the reserves series for a country that has reserves data at any other point in time, then these are gap filled forwards by deducting production, and gap-filled backwards by adding production. The backwards approach is likely to be more accurate, as it would include any past resource discoveries, as the forward filling approach is unable to account for any new discoveries that may have occurred without additional data.

3.4 Metals and minerals

Thirteen different metals and minerals are valued in the wealth accounts: bauxite, cobalt, copper, gold, iron ore, lead, lithium, molybdenum, nickel, phosphate rock, silver, tin, and zinc. Many of the same data sources and estimation methods are used for all metals and minerals in the wealth accounts. Because of this, the following section describes the data sources and methods for metals and minerals as a group.

3.4.1 Production of metals and minerals

Data sources for the production of metals and minerals are listed in Table 12. Table 13 provides specific product definitions for each metal and mineral commodity.

Production data come mainly from the US Geological Survey's (USGS) *Minerals Yearbook* and *Mineral Commodity Summaries*. Where data are missing in the USGS sources, data from the British Geological Survey (BGS) *World Mineral Statistics* archive may be used. In such cases, the following rules for gap-filling are applied. If USGS data are entirely missing for a country, the BGS data are used. If USGS data are available for some years but are missing for others, the BGS data may be used to fill missing values only if there is general consistency between the USGS and BGS data. This means that the average difference between USGS and BGS statistics is within ±25 percent for years where there is overlap between the two sources.

Table 12: Data sources for metals and minerals production

Element	Data sources
Production of metals and minerals	• US Geological Survey (USGS), Minerals Yearbook, Vol. I: Metals and Minerals, various years (link) • USGS, Mineral Commodity Summaries, various years (link) • British Geological Survey (BGS), World Mineral Statistics (link)

Table 13: Definitions for production of metals and minerals

Mineral	Definition for production statistics
Bauxite	Bauxite is "a naturally occurring, heterogeneous material composed primarily of one or more aluminum hydroxide minerals, plus various mixtures of silica, iron oxide, titania, aluminosilicate, and other impurities in minor or trace amounts" (1). BGS production statistics for bauxite may also include refractory bauxite for 1994 onwards. USGS statistics for Guinea, Guyana, and Jamaica are for the dry bauxite equivalent of crude ores.
Cobalt	USGS and BGS production statistics are report metric tons of contained mined cobalt. Most of the world's mined cobalt comes from the Democratic Republic of Congo (USGS, 2023).
Copper	USGS and BGS production statistics are for copper metal content, including the metal content from ores, concentrates, leaching, and electrowon copper.
Gold	USGS and BGS production statistics are for gold metal content. Data for some countries may include estimates of undocumented artisanal mining.
Iron ore	Iron ore production is reported by gross weight in both the USGS and BGS production statistics, where gross weight is the total for all iron products used in steelmaking. Data for some countries may include production of alternative iron sources such as nickeliferous iron ore, titaniferous magnetite beach sands, and manganiferous iron ore, and by-product ores.
Lead	USGS and BGS production statistics are for lead in concentrate, reported in terms of metal content. Data may include estimates of metal content of ores and of by-products from fluorspar and gold mining operations.
Lithium	USGS and BGS production statistics are for all lithium subcommodities produced at commercial scale.
Molybdenum	USGS and BGS production statistics are for mined Molybdenum concentrate.
Nickel	USGS and BGS production statistics for nickel are reported for metal content. USGS statistics may include laterite ore, sulfate, sulfide concentrate, and ferronickel. BGS statistics may also the metal content of sulfates and concentrates.

Phosphate rock	USGS and BGS production data for phosphate rock may include apatite. Data are reported by gross weight. BGS data may also include lime phosphates and phosphate dust. Although BGS reports data for guano as part of phosphate production, these numbers are excluded.
Silver	USGS and BGS production statistics are for silver metal content. Data for some countries may include estimates of undocumented artisanal mining.
Tin	USGS and BGS production statistics are for tin metal content. USGS data may include content of tin-tungsten concentrate and estimates of artisanal production.
Zinc	USGS and BGS production statistics are for metal content and may include ores as well as zinc content in both lead and zinc concentrates

Sources: (1) USGS, Mineral Commodity Summaries; (2) BGS World Mineral Statistics data archive

3.4.2 Mineral prices, costs, and unit rents

Unit rent of minerals is calculated at the mine level, using the S&P data for unit cost and the World Bank Global Economic Monitor (GEM) Commodities database (*"The Pink Sheet"*) for price. Lithium, molybdenum and cobalt do not have price data in the GEM, so realized price at the mine-level from S&P Global Market Intelligence is used. Analysis of the two data sources confirmed consistency between them, however the use of GEM prices makes gap filling easier, increases transparency for data users, and eases future annual updates for the team, especially if S&P data are not accessible annually. With high consistency between the two data sources, the benefits of using GEM prices outweighed any losses of information.

Lithium production and prices have been increasing globally and become of strategic importance due lithium-ion batteries. However, aggregating lithium production often in pure physical units is a challenge as there are several different grades and types with different lithium content and mining and refining processes (BGS, 2016). Therefore, to estimate rental rates averages across countries a unifying unit is required rather than a standard physical unit. S&P database for lithium economic data can be extracted in $ per lithium carbonate equivalent across four different lithium forms and compounds in the S&P database: lithium chloride, carbonate, hydroxide and concentrate. Prices and costs in these standardized units are then used to estimate rental rates.

For the purpose of calculating mineral rents, minerals fall into two categories based on availability of data from S&P Global Market Intelligence:

1. Minerals covered by USGS with coverage by S&P for at least some, but not all, countries (cobalt, copper, gold, lead, lithium, molybdenum, zinc, iron ore, nickel, silver)
    a. Countries covered by S&P:
        i. S&P mine level data used to calculate unit rent, averaged to national level
    b. Countries not covered by S&P:
        i. Regional average unit rent

ii. If regional average not available because S&P does not cover any country in the region, global average unit rent

2. Minerals covered by USGS but with no coverage by S&P (bauxite, tin, phosphate rock)

   For these minerals, we use a combination of current CWON unit rent estimates for the base year, and apply a new production cost index, replacing the old Manufactures Unit Value (MUV) index. The new cost index is derived from the change in average unit costs derived from the S&P data for the 7 minerals included in the first category above.

The derivation of unit rents is discussed in two parts, corresponding to the two categories of minerals: the seven minerals with data from S&P and the three not covered by S&P.

Part 1: Calculating Total National Rents Based on USGS Production Data and S&P Unit Rent

Total rents, $R_t^{M,N}$, for each mineral, M, in each country, N, are calculated as the product of the average unit rent, $\pi_t^{M,N}$, (derived in Part 2 and Part 3) and national production reported by USGS. USGS data for production and reserves are used instead of S&P data because S&P data are often not as complete as USGS data. By using the average national unit rent calculated from S&P data, we implicitly assume that S&P's 'missing' mineral output is produced at the same average unit cost and generates the same unit rent as the average for all S&P mines. This is discussed further in Part 2 and Part 3.

(3.11)
$$R_t^{M,N} = \pi_t^{M,N} q_t^{USGS,M,N}$$

where,

$R_t^{M,N}$= Total rent for mineral, M, in country, N, in year t

$\pi_t^{M,N}$ = average unit rent for mineral, M, in country, N, based on S&P data in year t and GEM prices

$q_t^{USGS,M,N}$ = Total production of mineral, M, in country, N, from USGS/BGS data in year t

Asset values, V_t, are then calculated using the following equation:

(3.12)
$$V_t = \sum_{i=t}^{t+T-1} \frac{R_t}{(1+r)^{i-t}}$$

where,

R_t is rent in year *t*

r is the discount rate (assumed to be a constant 4 percent), and

T is the lifetime of the resource.

Part 2: Unit Rent for Minerals Covered by S&P

S&P covers 10 of the 13 minerals included in the CWON database. For each of these minerals, CWON requires national average unit rents in every year, 1991 to 2020. Unit rent calculation is carried out in two steps, first calculating unit rent at mine level, then averaging for national unit rents. Further averaging of unit rents across regions and globally is done for those countries identified by USGS as producers but missing from the S&P database (see below for further details).

Step 1. Unit Rent at Mine Level for Each Mineral

Unit rent, π, is calculated at the mine level, using the S&P data for unit cost and the World Bank Global Economic Monitor (GEM) Commodities database ("The Pink Sheet") for price[20].

(3.13) $$\pi_{m,t}^{M,N} = \left(p_t^{GEM,M} - c_{m,t}^{M,N}\right)$$

where,

$\pi_{m,t}^{M,N}$ = equals unit rent for mineral, M, in country, N, from mine, m, in year, t

$p_t^{GEM,M}$ = equals average global unit price in the GEM database for a mineral, M, in year t

$c_{m,t}^{M,N} = \frac{OC_{m,t}^{M,N} + UC_{m,t}^{M,N}}{q_{m,t}^{SP,M,N}}$ unit cost is calculated from operating costs and user costs of capital as defined below and production in the S&P database

$OC_{m,t}^{M,N}$ = operating costs for mine, m, year, t, for mineral M, in country N. Operating costs are the sum of total minesite costs and transportation costs in the S&P database.

$UC_{m,t}^{M,N}$ = User costs of capital for mine, m, year, t, for mineral, M, country N, where user costs are estimated at the mine-level from capital expenditure and depreciation in the S&P database. The same approach for estimating user costs for oil and natural gas (see Section 3.2.2) is used for minerals, except that the depreciation of the capital stock over time uses S&P depreciation data rather than a fixed parameter.

$q_{m,t}^{SP,M,N}$ = Volume of production from S&P for mine, m, year, t, for mineral M, in country N

Step 2. Unit Rent at National Level for Each Mineral

Average national unit rent, $\pi_t^{M,N}$, is calculated by summing mine-level rent weighted by each mine's share of national production, as reported by S&P.

[20] Price is expressed as dollars per tonne/ton/metric ton for paid copper, and dollars/troy ounce for paid gold.

For each mineral, M = 1,…7:

(3.14) $$\pi_t^{M,N} = \sum_1^n \pi_{m,t}^{M,N} \times \frac{q_{m,t}^{SP,M,N}}{q_t^{SP,M,N}}$$

where,

total S&P production at national level, $q_t^{SP,M,N}$, is the sum of production across all mines, m=1…n:

(3.15) $$q_t^{SP,M,N} = \sum_1^n q_{m,t}^{SP,M,N}$$

Step 3. Unit Rent at Regional and Global Level

S&P has generally good country coverage, but it is not as complete as USGS; some countries are missing. Regional and global unit costs/rent are used for gap filling. For the missing countries, we assume the unit rent for a given mineral is similar to the average unit rent for producers of that mineral in countries that are covered by S&P. We apply the regional average unit rents for that mineral in the missing countries. The exception is lithium, where due to the variety of types and grade of lithium and global concentration of production (the majority currently produced as lithium concentrate in Australia, followed by Chile, China (USGS, 2018)), if national data is unavailable regional or global average rental rates are not used for gap-filling. This is because rental rates for different types of lithium are likely to be widely different and production data is only available by gross weight rather than an unified metric, such as the lithium carbonate equivalent (LCE).

Regional unit rents, $\pi_t^{M,Reg}$, are calculated as the weighted average of country unit rents with USGS production is used for country weights.

(3.16) $$\pi_t^{M,Reg} = \sum_1^n \pi_t^{M,N} \times \frac{q_t^{USGS,M,N}}{q_t^{USGS,M,Reg}}$$

where,

Total production at regional level is the sum of USGS production across all countries in the region, N=1…n:

(3.17) $$q_t^{USGS,M,Reg} = \sum_1^n q_t^{USGS,M,N}$$

For countries where there are no other producers in the region and a regional average cannot be calculated, a global average unit rent can be used. Calculating global averages is given by the following equations, noting that USGS production figures are used for weighting.

Global unit rents, $\pi_t^{M,G}$, are calculated as the weighted average of regional unit rents, with USGS production used for regional weights.

(3.18)
$$\pi_t^{M,G} = \sum_{1}^{m} \pi_t^{M,R} \times \frac{q_t^{USGS,M,Reg}}{q_t^{USGS,M,G}}$$

where,

Total production at global level, $q_t^{USGS,M,G}$, is the sum of USGS production across all regions, R=1…m:

(3.19)
$$q_t^{USGS,M,G} = \sum_{1}^{m} q_t^{USGS,M,N}$$

Negative rents and the calculation of national average rents

Commodity prices are notoriously volatile and, in some cases, a mine in full operation may generate negative rents if the price falls below the cost of production. A mine may continue to operate under such conditions in the expectation that prices will rise in the future. Following the treatment recommended in the SEEA-CF, negative rents are set to zero for the calculation of national unit rent.

Part 3: Unit Rent for Minerals Not Covered by S&P

S&P does not include information about three minerals in the CWON database: bauxite, tin, and phosphate rock. For these minerals, we propose a two-part approach:

1. *1991 base year unit cost*: continue using the 1991 base year unit cost estimated from case studies for earlier versions of CWON, but
2. *Updating unit cost for 1992-2020*: replace MUV to update the cost estimates with a cost index, CI_t^G , based on S&P global average production costs, $c_t^{M,G}$. The index measures the change in annual production costs as a share of price, averaged over 7 minerals at global level[21]. While this is far from ideal, it is an improvement over the MUV because the cost index is narrowly focused only on costs directly related to mining.

This cost index could be estimated in a manner similar to unit rents, by estimating costs at mine level and averaging across mines, countries, regions. A simpler method takes advantage of calculations already

[21] Copper, Gold, Iron Ore, Lead, Nickel, Silver, Zinc. Minerals added in CWON 2024 (cobalt, lithium and molybdenum) were not added to the cost index, on the basis that they would be unlikely to improve this approach of estimation.

carried out to estimate global average unit costs implicit in the global average unit rent calculation. Global unit cost for each mineral could be expressed as:

(3.20) $$c_t^{M,G} = \left(p_t^{GEM,M} - \pi_t^{M,G} \right)$$

Because unit prices and units of measurement are so different across the seven minerals, we look at how **cost as a share of price** changes over time for each mineral, then average this change across all minerals:

(3.21) $$s_t^{M,G} = \left(c_t^{M,G} \div p_t^{GEM,M} \right)$$

where, $s_t^{M,G}$ is the global average cost share of S&P mineral, M, in year t, 1991…2018.

The global cost index, *CI^G,* is calculated in two steps: first, a global cost index is calculated for each mineral, CI^M, then a simple, unweighted average of the change is taken across all minerals.

The cost index, *CI^M,* for each mineral, M, would simply be the change in cost from one year to the next, using the old CWON unit cost for 1991:

(3.22) $$CI_t^{M,G} = 1 + \left[\frac{(s_t^{M,G} - s_{t-1}^{M,G})}{s_{t-1}^{M,G}} \right] \quad \text{for t = 1992...2018}$$

The global average cost index, CI_t^G, is the simple, unweighted average of unit costs across the seven minerals in S&P:

(3.23) $$CI_t^G = \sum_1^7 CI_t^{M,G} \div 7$$

The unit cost for each of the three non-S&P minerals would be calculated as:

- 1991: use unit cost from older versions of CWON, $c_{1991}^{M,Old}$
- 1992 to 2020: apply the global cost index for each year to the previous year's unit cost:

(3.24) $$c_t^{M,G} = c_{t-1}^{M,G} \times CI_t^G$$

for t = 1992…2020 and

M = bauxite, tin, phosphate

Unit rent for these three minerals would then be $\pi_t^{M,G} = \left(p_t^{GEM,M} - c_t^{M,G} \right)$ and total rents calculated as in Part 1.

3.4.3 Mineral reserves and time to depletion

Years to exhaustion of the resource, *T*, are calculated given rates of current production and proven reserves. Data on reserves for all metals and minerals are from the USGS Minerals Yearbooks and Mineral Commodity Summaries, various years. USGS calculates reserves as that part of the reserve base which could be economically extracted or produced at the time of determination. The reserve base is defined as the in-place demonstrated (measured plus indicated) resource from which reserves are estimated. Reserves (and mine production) data for selected countries (the largest producers) were available from 1994 onwards.

If there are gaps in the reserves series for a country that has reserves data at any other point in time, then these are gap filled forwards by deducting production, and gap-filled backwards by adding production. The backwards approach is likely to be more accurate, as it would include any past resource discoveries, as the forward filling approach is unable to account for any new discoveries that may have occurred without additional data. For resources in countries for which production data are available but information on reserves is absent, regional or world averages for *T* are used.

3.5 Volumes of non-renewable resources

The volume estimates for non-renewable resources required for compilation of the Törnqvist volume indexes of non-renewable natural capital (see Section 2.2.3) and aggregate comprehensive wealth (see Section 2.2.7) are the reserve estimates described above in this chapter (see sections 3.2.3, 3.3.3 and 3.4.3 for details).

4 Forest Resources

The total value of forest resources as estimated for the World Bank wealth accounts includes the capitalized value of rents from timber, along with the value of non-timber forest ecosystem services. Data and methods for estimating the value of timber and non-timber services are described below.

4.1 Timber resources

The predominant economic use of forests has been as a source of timber. Timber resources are valued according to the present discounted value of rents from the production of roundwood over the expected lifetime of standing timber resources. This value, V_t, is given by the following equation:

(4.1) $$V_t = \sum_{i=t}^{t+T-1} \frac{R_t}{(1+r)^{i-t}}$$

where R_t is rent from timber in year *t*; *r* is the discount rate (assumed to be equal to 4 percent), and *T* is the lifetime of timber resources (capped at 100 years). Unlike metals and minerals, timber is a renewable resource, so *T* depends on the rate of timber extraction relative to natural rates of forest growth and resource replacement.

Rents from timber in year *t* are calculated as:

(4.2) $$R_t = \pi_t Q_t$$

where π_i denotes unit rents, equal to revenues less production costs; and Q_i denotes the quantity of roundwood extracted. Data and methods for estimating timber wealth are described below. Rents are converted into units of constant US dollars at market rates using country-specific GDP deflators before averaging to obtain $\bar{R}$.

4.1.1 Timber production

Data on annual roundwood production are obtained from the FAOSTAT database maintained by the Food and Agricultural Organization of the UN (FAO) (Table 14Table 14). As defined by FAO, roundwood production "comprises all wood obtained from removals, i.e., the quantities removed from forests and trees outside the forest, including wood recovered from natural, felling, and logging losses…" (FAO, 2014). Total roundwood production, *Q*, is equal to the sum of the production of industrial roundwood, q_{industry}, and woodfuel, q_{fuel}:

(4.3) $$Q = q_{\text{industry}} + q_{\text{fuel}}$$

Industrial roundwood is "wood in the rough" and comprises all roundwood used for any purpose other than energy, including pulpwood, sawn logs, veneer logs, and other types of roundwood such as fence posts and telephone poles. Industrial roundwood includes both coniferous and nonconiferous stocks of roundwood. Woodfuel is all roundwood that is used as fuel for purposes such as cooking, heating, or power production, and it includes wood that is used to make charcoal. Roundwood production is measured in terms of volume (cubic meters).

Table 14: Data sources for timber production

Element	Data sources and notes
Roundwood production	• Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link) • Roundwood production is the sum of coniferous industrial roundwood (FAO item code 1866), nonconiferous industrial roundwood (item 1867), and woodfuel (item 1864)

For countries missing any data in the FAO database, timber production is assumed to be zero for all years. These countries include small island economies, city states, and others for which commercial timber production is deemed to be negligible (Table 15):

Table 15: Economies with missing data that are assumed to have zero timber production

Country/Economy
Antigua and Barbuda
Bermuda
Cabo Verde
Greenland
Grenada
Hong Kong SAR, China
Isle of Man
Monaco
St. Kitts and Nevis
Macao SAR, China
Marshall Islands
Palau
Puerto Rico
San Marino
Syrian Arab Republic
Tuvalu
West Bank and Gaza

For other countries, the FAO has data on production for some years but not others. In these cases, if there is zero production value for the earliest year of data for that country, then production is assumed to also be zero in all earlier years for which data are missing. Countries and years for which zero production values are gap-filled in this way are listed in Table 16.

Table 16: Additional economies for which zero timber production is assumed for some years

Country	Years filled with zero values
Andorra	1995-2008
Faeroe Islands	1995-2008
Iceland	1995-1997
Malta	1995-1997
Tajikistan	1995-1997

Coverage for Europe and Central Asian countries prior to 2000 in the FAO database is spotty. There are several countries that are missing data on timber production for 1995-1997 in addition to those countries with missing timber production values already listed in Table 15 and Table 16 (Armenia, Azerbaijan, Georgia, Kyrgyz Republic, Turkmenistan, and Uzbekistan). For these countries, missing timber production data for 1995-1997 are gap-filled by assuming values for 1998. Values in 1998 for overharvest and unit rents are also assumed for 1995-1997.

Finally, for years prior to 2000, the FAO reported data on timber production in Belgium and Luxembourg together as for "Belgium-Luxembourg." Production and trade values for Belgium and Luxembourg in the years prior to 2000 are allocated to the two countries according to their respective shares in total timber production for Belgium and Luxembourg in 2000.

4.1.2 Timber prices and unit rents

Unit resource rents, π, are calculated as the average export unit value for roundwood, E, weighted by production volume, multiplied by a rental adjustment factor, a:

(4.4)
$$\pi = E \cdot a$$

The export unit value is the total value of exports divided by total volume of exports, and is calculated using data from FAOSTAT (Table 17). Estimates of E are constructed using regional averages, which helps correct for the observed volatility in prices at the country level. In calculating E, outliers are excluded such that if *E* for country *i* exceeds the sum of the third quartile plus 1.5 times the interquartile range (i.e., third quartile minus first quartile), it is replaced with the world median value.[22]

Table 17: Data sources for estimating timber prices and unit rents

Element	Data sources and notes
Roundwood export volume	• Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link)
Roundwood export value	• Data from UN Food and Agricultural Organization (FAO), FAOSTAT database (link)
Rental adjustment factor	• Estimates by Applied Geosolutions (2016)

The rental adjustment factor, *a*, is equal to the ratio of unit rents to the export unit value. The adjustment factor takes into account the average difference between domestic stumpage prices for timber and export log values for countries in that region, given production costs (Applied Geosolutions 2016). Adjustment ratios are estimated using data on domestic timber prices for the countries and regions indicated in Table 18 below. Production costs are taken as the sum of harvesting, skidding and loading, and transportation costs. Because data on timber production costs in countries around the world are not readily available, costs are estimated indirectly by calculating costs for typical harvesting operations in the United States and then adjusting for differences in labor costs and the overall productivity in the economy that are thought to influence domestic production costs. Also, because data on log prices are not available for any countries in the Middle East and North Africa region, the rental adjustment factor for this regional is estimated as the simple average of the adjustment factors for all other regions. The rental adjustment factor is assumed to be constant over time. Country-specific rental adjustment factors are applied where available. For all other countries, regional averages are assumed. Average export unit values, rental adjustment ratios, and unit rents for timber by region are presented in Table 18. Average values shown in the table are weighted by production.

Table 18: Average export unit values and unit rents for timber by region in 2018

Region/country name	***A = Export unit value (US$/m3)***	***B = Unit rent (US$/m3)***	***Rental adjustment factor (B/A)***
Sub-Saharan Africa	**117**	**48**	**0.41**
Ghana	108	45	0.41

[22] This method to exclude and replace outliers is consistent with the method for calculating crop export unit values in the World Bank's *Changing Wealth of Nations* (2018).

Other	117	48	0.41
East Asia and Pacific	**185**	**42**	**0.23**
Australia	176	48	0.27
China	190	32	0.17
Indonesia	234	33	0.14
Malaysia	281	325	1.15
New Zealand	75	29	0.39
Other	164	43	0.26
Eastern Europe and Central Asia	**81**	**21**	**0.26**
Russian Federation	80	21	0.26
Other	84	22	0.26
Western Europe	**94**	**18**	**0.20**
Finland	99	14	0.15
Germany	94	18	0.19
Other	93	19	0.21
Latin America and Caribbean	**158**	**37**	**0.23**
Argentina	141	27	0.19
Brazil	179	42	0.23
Chile	129	23	0.18
Costa Rica	158	108	0.68
Guyana	161	155	0.96
Other	136	33	0.24
Middle East and North Africa	**98**	**22**	**0.22**
North America	**144**	**17**	**0.12**
Canada	148	9	0.06
United States	143	20	0.14
South Asia	**102**	**10**	**0.10**
India	104	11	0.10
Other	94	9	0.10

Note: Countries listed in table are those for which rental adjustment factors are calculated from the ratio of domestic stumpage prices to export unit values by Applied Geosolutions (2016). Regional values and other are calculated as the weighted average with respect to timber production. The rental adjustment factor for the Middle East and North Africa is a simple average of all other regions' factors.

Source: Rental adjustment factors estimated by Applied Geosolutions (2016); export unit values estimated using data from FAO, FAOSTAT database

4.1.3 Lifetime of timber resources

The lifetime over which timber resources is determined by the rate of timber extraction (Q) relative to the rate of natural growth (N). If $Q > N$, then current rates of extraction are unsustainable, and the lifetime of the resources is limited. If $Q \leq N$, then extraction is assumed to be sustainable and the lifetime of the resource is taken to be infinite, though capped at 100 years in keeping with the approach for other renewable natural capital.

Data sources for estimating *T* are listed in Table 19 below.

Table 19: Data sources for estimating the lifetime of timber resources

Element	Data sources and notes
Total forest area	• FAO, *Global Forest Resources Assessment 2020* http://www.fao.org/forest-resources-assessment/explore-data/en/
Production forest area	• FAO, *Global Forest Resources Assessment 2020* http://www.fao.org/forest-resources-assessment/explore-data/en/
Multiple use forest area	• FAO, *Global Forest Resources Assessment 2020* http://www.fao.org/forest-resources-assessment/explore-data/en/
Net annual increment	• FAO, *Global Forest Resources Assessment 2015* http://www.fao.org/forest-resources-assessment/explore-data/en/
Growing stock of timber	• FAO, *Global Forest Resources Assessment 2020* http://www.fao.org/forest-resources-assessment/explore-data/en/

Natural growth *N* is calculated using data from the FAO's *Global Forest Resources Assessment* (FRA) for 2020 and is given by $N = A \cdot I$, where *A* is the area of productive forest and *I* is the average net annual increment. Productive forest area is defined in the FRA as "forest area designated primarily for production of wood, fibre, bio-energy and/or non-wood forest products" (FAO 2012: 11). FRA also provides the area of "multiple use" forests, which the FRA defines as "forest area designated primarily for more than one purpose and where none of these alone is considered as the predominant designated function" (FAO 2012: 11). To minimize discrepancies across countries given different definitions of multiple use, starting with CWON 2021, the area of timber forest is estimated by subtracting from the total forest area those forests located within protected areas, excluding protected area categories that could be used for sustainable timber production (i.e., protected areas in IUCN categories V and VI). Total forest area includes the area of all "[l]and spanning more than 0.5 hectares with trees higher than 5 meters and a canopy cover of more than 10 percent, or trees able to reach these thresholds *in-situ"* and excludes "land that is predominantly under agricultural or urban land use" (FAO 2012: 3).

FRA data on forest area are available only every five years. Gapfilling to create an annual time series is accomplished through linear interpolation. All efforts are made to avoid using other data sources (including earlier editions of the FRA) since there can be large discrepancies between other sources and the FRA 2020 estimates. When data for productive forest area is missing in FRA 2020, we assume productive area is equal to total area multiplied by 0.8.

Data on net annual increment *I* are obtained from the FAO's FRA 2015, the last FRA that collected this variable. Net annual increment is defined in the FRA as "average annual volume of gross increment over the given reference period less that of natural losses on all trees, measured to minimum diameters as defined for 'growing stock'" (FAO 2012: 9). As with the data on total forest area, the FRA data on net annual increment are in five-year intervals. Estimates for in-between years are interpolated linearly. Net annual increment values for 2020 are assumed to be the same as 2015 values. For countries where FRA estimates of net annual increment are available, data for earlier years (before 1990) are extrapolated by assuming the country value for average annual increment in 1990. Net annual increment for any additional countries not covered in the FRA or the World Bank estimates is assumed to be equal to the regional average for countries with data.

The growing stock of timber in forests designated for marketable production is estimated by assuming that the growing stock of timber per hectare of production-designated forests is equal to the average growing stock per hectare of total forest area. Data on the growing stock of timber is obtained from the FAO's FRA 2020. To estimate the growing stock of timber in production-designated forests for years prior to 1990, the average stock per hectare of forest in 1990 is assumed. If $Q > N$ (that is, if current rates of timber extraction are unsustainable), then the number of years to the exhaustion of a country's timber resources T is estimated by dividing the growing stock of timber in production-designated forest by the volume of timber that is harvested unsustainably ($Q - N$). This method of calculating the lifetime of the resource assumes that current rates of extraction remain constant and that the total growing stock of timber and area of forest do not change except for the loss of timber due to overharvesting.

4.2 Forest ecosystem service values

In addition to timber production, forests provide a range of services that are vital to the economy. Nontimber forest benefits—ecosystem services—such as nonwood forest products, hunting, recreation, and watershed protection are significant benefits not usually accounted for, which leads to the undervaluation of forest resources. This edition of The Changing Wealth of Nations builds upon the forest ecosystem services wealth introduced in the 2021 report and presents results from the updated spatially explicit regression analysis that predicts annual, per hectare values for each service category per country (Siikamäki et al. 2023). Compared to the previous report, this updated study broadens the coverage of forest ecosystem service values. Additionally, the study now provides a time series of ecosystem services values from 1995 through 2020 and develops a method to estimate the contribution of protected areas to the production of forest ecosystem services. This is an important departure from the lower-bound approach used in CWON 2021 and earlier reports, which relied on opportunity cost values to estimate the asset value of protected areas. Data sources for valuing non-timber forest ecosystem services are summarized in Table 20.

Table 20: Data sources for estimating the value of non-timber forest ecosystem services

Element	Data sources and notes

Total forest area	• FAO, *Global Forest Resources Assessment* http://www.fao.org/forest-resources-assessment/explore-data/en/2020
Annual service values per hectare of forest	• Unit values are as estimated by Siikamäki, J., et al (2023) • Annual values equal the sum of: recreation, hunting, and fishing; non-wood forest products (NWFP); and watershed protection.
Protected area boundaries	• World Database on Protected Areas - UNEP World Conservation Monitoring and IUCN

Siikamäki et al. (2023) develop a meta-analytic predictive model using regression and machine learning techniques to spatially estimate the value of the following three ecosystem services: (i) recreation, hunting, and fishing, (ii) non-wood forest products, and (iii) watershed protection. These values are produced using approximately 10km by 10km spatial resolution and then combined and spatially aggregated to estimate country-wealth from non-wood forest products. The authors analyzed 498 studies of non-wood forest benefits to develop a spatially explicit meta-regression model that predicts service values for 10km by 10km plots of forest around the globe.

Siikamäki et al. (2023) augmented the database of primary valuation estimates by incorporating new studies available. Siikamäki et al. (2021) included reviews of 659 studies, from which 270 primary value estimates from 164 studies met the criteria required to be included in the final database. The 2023 report adds to the assessment 79 new primary valuation estimates that were extracted after reviewing 677 additional papers identified mostly from the literature published since the development of the database in Siikamäki et al. (2021). The largest increase of new value estimates in percentage terms is from Asia (34 percent, 20 additional estimates), Africa (32 percent, 10 additional estimates), and Europe (19 percent, 28 additional estimates). By ecosystem service, this report adds 28 new estimates for recreation (20.1 percent of all the values for this service), 20 new estimates for habitat and species protection (20.6 percent), 17 new estimates for non-wood forest products (26.2 percent) and 14 new estimates for water services (31.1 percent). All the continents with forests and all the different forest biomes—humid tropics, dry tropics, temperate, and boreal—are represented. Socioeconomic, biophysical, climate, ecological extent, and ecological condition variables were constructed to estimate the global spatially explicit predictions of the different forest ecosystem services. The total value of forest ecosystem services per country is computed by multiplying the combined per hectare value of recreation, nonwood forest products, and water services by the total forest area per country, measured using official international forest statistics from FAO. Table 18Table 18 reports average annual service values by region for the three different service categories.

Table 18: Estimated value of non-wood forest ecosystem services, annually per hectare, and comparison with previous report (2021), in 2013 USD, by World Bank region and ecosystem service

Region	Recreation, hunting and fishing			NWFP			Water services		
	CWON 2024	CWON 2021	CWON 2024 / CWON 2021	CWON 2024	CWON 2021	CWON 2024/ CWON 2021	CWON 2024	CWON 2021	CWON 2023 / CWON 2021
East Asia & Pacific	74.4	127.1	0.58	11.6	10.5	1.11	64.4	23.4	2.75
Europe & Central Asia	34.8	42.5	0.82	4.4	4.8	0.91	20.8	30.8	0.67
Latin America & Caribbean	29.9	68.3	0.44	6.7	6.7	1.00	39.5	16.6	2.38
Middle East & North Africa	140.0	193.9	0.72	10.6	14.5	0.73	61.8	19.0	3.25
North America	92.8	276.7	0.34	4.3	4.9	0.88	44.4	45.6	0.97
South Asia	59.0	127.4	0.46	14.8	22.1	0.67	44.2	5.0	8.81
Sub-Saharan Africa	15.1	45.3	0.33	8.1	25.6	0.32	32.5	6.3	5.13
World	46.4	102.5	0.45	6.7	9.9	0.67	37.3	24.6	1.52

Note: NWFP = non-wood forest products.
Source: Siikamäki et al. (2023)

4.2.1 Ecosystem services provided by protected areas

Siikamäki et al. (2023) provide the first available estimates of the economic value of these ecosystem service categories supported by protected areas, generated by country and globally comprehensively. For each service, the authors estimate the average marginal value for cells that are in a protected area and outside of a protected area. A cell is defined to be in a protected area if 50 percent or more of its area is protected. Data on the spatial extent of protected areas comes from the World Database on Protected Areas, maintained in partnership by UNEP World Conservation Monitoring and IUCN. Although it is the primary and most comprehensive source for protected area data, some countries, including China and India, offer restricted data on protected areas for public use. All data on protected areas in this assessment is based upon publicly available data only. Consequently, the coverage of protected areas of forests likely underestimates their actual extent in countries that restrict data availability. The database corresponds to the current extent of protected areas and does not support construction of time-series data on protected areas. Table 19 shows the per hectare annual values of ecosystem services generated by protected areas by region and category of ecosystem service.

Table 19. Economic wealth provided by protected areas, by ecosystem service and in total, in absolute (US$ 2020) for year 2020, by world region and globally

Region	Total wealth provided by protected areas, by ecosystem service and in total (US$ 2020)			
	Recreation, hunting and fishing	NWFPs	Water services	Total
East Asia & Pacific	149.8	21.1	133.4	304.3
Europe & Central Asia	81.3	7.5	31.5	120.3
Latin America & Caribbean	109.5	26.0	127.3	262.8
Middle East & North Africa	5.5	0.3	2.1	7.9
North America	120.4	3.5	41.4	165.3
South Asia	22.1	4.5	14.5	41.2
Sub-Saharan Africa	35.1	21.1	88.7	144.9
World	550.9	77.7	403.3	1031.9

The annual value of non-timber forest ecosystem services is estimated by multiplying total forest area by the sum of the per-hectare monetary values for the three benefit categories. The capitalized value of ecosystem services is equal to the present value of annual services, discounted over 100 years. The present value of non-timber services is given by the following equation:

(4.5)
$$PV(S) = \sum_{i=1}^{i=100} \frac{S\ x\ F}{(1+r)^i}$$

where *S* is the sum of per-hectare service values for the three benefit categories, F is the total forest area; and *r* is the social discount rate of 4 percent. Services received during the present year are not discounted. No distinction is made between natural and planted forest. Values are estimated for the current forest area, assuming no change in forest cover in the future.

4.3 Volumes of timber and forest ecosystems

The volume estimates for timber (volume in metres cubed) and ecosystems (area in hectares) required for compilation of the Törnqvist volume indexes of renewable natural capital (see Section 2.2.4) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below.

The volume estimate for timber is represented by the productive forest area, derived using data from the FAO's Global Forest Resources Assessment (FRA 2020). The initial step involves cleaning and processing the forestry data from FAOSTAT and merging it with the FAO FRA data to identify the area designated primarily for timber production. This process utilizes the total forest area, protected forest areas, and production forest areas reported in both the 2015 and 2020 FRA assessments. When country-specific data is unavailable or inconsistent, interpolation is applied between available years, and, where necessary, a gap-filling method is used. For these cases, the productive forest area is assumed to be 80% of the total forest area, if no specific information is available at the national level. This methodology ensures that the timber volume estimates are consistent and representative across countries, covering the entire period from 1995 to 2020. The final volume measure is expressed in hectares, reflecting the area of forest land suitable for timber extraction and commercial production.

The volume estimate for non-timber forest ecosystems is represented by the total forest area, measured in square kilometers, and captures the broader ecological contributions of forests, including carbon storage, water regulation, and the provision of non-wood forest products (NWFP). This measure is primarily derived from the FAO's Global Forest Resources Assessment (FRA), which provides comprehensive data on forest extent and classification. Additionally, data from the International Union for Conservation of Nature (IUCN) is used to incorporate a more nuanced view of forest ecosystem services, particularly for values such as biodiversity, recreation, and water services. The methodology relies on a combination of national and regional data sources to estimate per-hectare values for various ecosystem services. When country-level data is missing, regional averages are used to ensure comprehensive coverage and consistency. The IUCN data is combined with the FAO forest area data to produce volume estimates that reflect the overall forest area, regardless of its designation for timber production or conservation. This process ensures that the non-timber volume captures the full range of ecosystem services provided by forests, which are crucial for maintaining biodiversity and supporting sustainable development. The resulting values are adjusted annually to account for changes in forest cover and ecological contributions over time. Additionally, the long-term value of these services is calculated by discounting the annual ecosystem service flows over a 100-year period, applying a fixed discount rate to determine the present value. This comprehensive approach captures both the ecological and economic importance of non-timber forest areas, making it a critical component of the CWON 2024 natural capital accounts.

5 Agricultural Land

Agricultural land constitutes a considerable portion of total wealth in developing countries, particularly in the low-income group. For the purposes of the World Bank wealth accounts, agricultural land includes both cropland and pastureland. There are alternative methods for estimating land wealth. One method uses information from sales of land. Another uses information on the annual flow of rents the land generates and takes the present value of such rents in the future. Given that information on land sales is often missing, the second method is used in CWON. The value of agricultural land is calculated as the present value of crop and pasture rents, discounted over 100 years consistent with the approach used for other renewable natural capital.

Annual resource rents for a given year, $TR_{c,t}$, are the sum of the rents, $R_{c,k,t}$, for each crop/livestock product, k , in each country, c, in a given year, t:

(5.1) $$TR_{c,t} = \sum_{k=1}^{n} R_{c,k,t}$$

Rents ($R_{c,k,t}$) are the product of price ($p_{c,k,t}$), quantity produced ($q_{c,k,t}$), and a rental rate parameter ($a_{c,t}$):

(5.2) $$R_{c,k,t} = \left(p_{c,k,t} \times q_{c,k,t} \times a_{c,t}\right)$$

The rental rate parameter, $a_{c,t}$, is defined by USDA's International Agricultural Productivity (IAP) database. The rental rate is proxied by land costs as a share of the total value of production as provided by IAP for each country and each decade. For countries where rental rates vary across decades, annual values are assumed to be constant within each decade. This is an improvement on from previous CWON editions, in which a time-invariant rental rate parameter based on Evenson and Fuglie (2010) was used.

Using total rent from equation 5.2, agricultural land asset value, $V_{c,t}$ is calculated as the discounted sum of total rents over the lifetime, which is capped at 100 years, with a discount rate, r, of 4 percent,

$$V_{c,t} = \sum_{t=1}^{100} TR_{c,t} \Big/ (1+r)^t$$

5.1 Production of crops and livestock products

Data on the production of crop and livestock products are obtained from the FAO Crop and Livestock Products database. Primary crop and livestock products included are listed in Table 21 and Table 22. Processed agricultural goods are not considered; however, there are some crops such as oil palm fruit and seed cotton for which the FAO treats derivative products as primary crops (e.g., palm oil and palm kernels, cotton lint, and cottonseed). Production is counted for the calendar year in which the entire harvest or the bulk of it took place. Cereal production is for dry grain only, meaning that cereals harvested for animal feed or silage are excluded. Vegetable production is also limited to products intended mainly for human consumption. Household production for self-consumption (e.g., in small gardens) is generally not counted due to limitations in the reporting of official statistics. Data on fruit production are for fresh fruit and may include fruit intended for direct consumption or for processing into other products such as jams, wine, juice, etc. Data on fruits is mainly limited to plantation or orchard crops for sale. As for livestock products, data on meat products are limited to indigenous production (i.e., animals that are raised within the country, excluding animals that are raised elsewhere and then imported for slaughter)[23].

[23] For more details on crop and livestock production statistics, please refer to the methods and standards of the FAO FAOSTAT database, http://faostat3.fao.org/mes/methodology_list/E.

Table 21: Crop products included in valuing agricultural land

Category	Crops		
Cereals	Barley	Maize	Rye
	Buckwheat	Millet	Sorghum
	Canary seed	Oats	Triticale
	Cereals, nes	Quinoa	Wheat
	Fonio	Rice, paddy	
Fibers	Agave fibers nes	Flax fiber and tow	Ramie
	Bastfibres, other	Hemp tow waste	Sisal
	Coir	Jute	
	Fiber crops nes	Manila fiber (abaca)	
Fruits	Apples	Fruit, citrus nes	Papayas
	Apricots	Fruit, fresh nes	Peaches and nectarines
	Avocados	Fruit, pome nes	Pears
	Bananas	Fruit, stone nes	Persimmons
	Berries nes	Fruit, tropical fresh nes	Pineapples
	Blueberries	Gooseberries	Plantains
	Carobs	Grapefruit (inc. pomelos)	Plums and sloes
	Cashewapple	Grapes	Quinces
	Cherries	Kiwi fruit	Raspberries
	Cherries, sour	Lemons and limes	Strawberries
	Cranberries	Mangoes	Tangerines
	Currants	Mangosteens	Mandarins
	Dates	Guavas	Clementines
	Figs	Oranges	Satsumas
Nuts	Almonds, with shell	Chestnut	Pistachios
	Brazil nuts, with shell	Hazelnuts, with shell	Walnuts, with shell
	Cashew nuts, with shell	Nuts, NES	
Oil crops	Castor oil seed	Melonseed	Seed cotton
	Coconuts	Mustard seed	Sesame seed
	Groundnuts, with shell	Oil, palm fruit	Soybeans
	Hempseed	Oilseeds, NES	Sunflower seed
	Jojoba seed	Olives	Tallowtree seed
	Kapok fruit	Poppy seed	Tung nuts
	Karite nuts (sheanuts)	Rapeseed	
	Linseed	Safflower seed	
Pulses	Bambara beans	Cow peas, dry	Pigeon peas
	Beans, dry	Lentils	Pulses, NES
	Broad beans, horse beans, dry	Lupins	Vetches
	Chick peas	Peas, dry	

Roots	Potatoes	Sweet potatoes	Yams
	Roots and tubers, nes	Taro (cocoyam)	Yautia (cocoyam)
Spices	Anise, badian, fennel, coriander	Ginger	Pyrethrum, dried
	Areca nuts	Hops	Rubber, natural
	Chilies and peppers, dry	Nutmeg, mace and cardamoms	Spices, NES
	Cinnamon (canella)	Pepper (piper spp.)	Vanilla
	Cloves	Peppermint	
Stimulants	Chicory roots	Kola nuts	Tobacco, unmanufactured
	Cocoa, beans	Maté	
	Coffee, green	Tea	
Sugar	Sugar beet	Sugar cane	Sugar crops, NES
Vegetables	Artichokes	Eggplants (aubergines)	Onions, shallots, green
	Asparagus	Garlic	Peas, green
	Beans, green	Leeks, other alliaceous vegetables	Pumpkins, squash and gourds
	Cabbages and other brassicas	Lettuce and chicory	Spinach
	Carrots and turnips	Maize, green	String beans
	Cassava	Melons, other (inc. cantaloupes)	Tomatoes
	Cauliflowers and broccoli	Mushrooms and truffles	Vegetables, fresh NES
	Chilies and peppers, green	Okra	Vegetables, leguminous NES
	Cucumbers and gherkins	Onions, dry	Watermelons

Notes: NES = not elsewhere specified.

Source: Crops included in FAO, FAOSTAT database.

Table 22: Livestock products included in valuing agricultural land

Category	Livestock products		
Meat	Ass	Goat	Other camelids
	Buffalo	Horse	Game
	Camel	Mule	
	Cattle	Sheep	
Milk	Buffalo	Cow	Sheep
	Camel	Goat	
Other	Hides, buffalo, fresh	Skins, sheep, fresh	Hair, horse
	Hides, cattle, fresh	Wool, greasy	
	Skins, goat, fresh	Skins, sheep, with wool	

Note: Meat includes indigenous meat sources (which include the meat equivalent of exported live animals and exclude the meat equivalent of imports); milk is whole, fresh milk products.
Source: Livestock products included in FAO, FAOSTAT database.

FAO data for crop and livestock production are scanty for small island nations, city states, and other small countries. The same gap-filling rules as for timber production are applied. Island economies and small states with missing data for all years are assumed to have zero crop and livestock production. Countries with crop and livestock production values equal to zero in the earliest year for which they *do* have data are also assumed to have zero production values in all earlier years.

As with timber production, crop and livestock production data for Belgium and Luxembourg prior to 2000 are grouped together and reported for "Belgium-Luxembourg." Production for these two countries is allocated according to their respective shares in total production for each crop or livestock product in 2000.

5.2 Unit prices for crop and livestock products

Unit prices are estimated for all crop and livestock products in terms of current US$ per ton. Prices are obtained from several FAO sources, each downloadable from the FAOSTAT database (Table 23).

Table 23: Data sources for crop and livestock production

Element	Data sources and notes
Prices for crop and livestock products	• FAO, Value of Agricultural Production, Production, FAOSTAT database (link) • FAO, Producer Prices – Annual, Prices, FAOSTAT database (link) • FAO, Export Value, Crop and Livestock Products, Trade, FAOSTAT database (link) • FAO, Export Quantity, Crop and Livestock Products, Trade, FAOSTAT database (link)

Unit prices as reported in the FAO's estimates of the value of agricultural production are given priority, followed by the FAO estimates of producer prices. If country-specific data on prices are unavailable for a certain product, then regional or world averages are applied. Regional and world averages are weighted by production. Producer price data from FAO are available in units of standard local currency (SLC) as well as US dollars. Estimates of prices already converted into US dollars at market rates are used first; any missing values are filled by converting prices in SLC into US dollars using the World Bank DEC alternative exchange rate.

Data are missing from the FAO estimates of producer prices for the meat products listed in Table 24, so the prices for substitute products are assumed.

Table 24: Meat products for which producer prices are not available, so prices for substitutes are used

Item	FAO item code	Substitute	Substitute item code
Meat indigenous, ass	1122	Meat, ass	1108

Meat indigenous, buffalo	972	Meat, buffalo	947
Meat indigenous, camel	1137	Meat, camel	1127
Meat indigenous, cattle	944	Meat, cattle	867
Meat indigenous, goat	1032	Meat, goat	1017
Meat indigenous, horse	1120	Meat, horse	1097
Meat indigenous, mule	1124	Meat, mule	1111
Meat indigenous, sheep	1012	Meat, sheep	977
Meat indigenous, other camelids	1161	Meat, other camelids	1158

Export unit values are used in place of domestic prices only where data on producer prices and the value of agricultural production are missing. Export unit values are calculated by dividing total exports by the total export value. Because trade data are not available for “rice, paddy” (item 27) and “bastfibres, other” (item 782), trade data on “rice” (1946) and “jute + bast fibres” (1980) are used instead to estimate export unit values. Where country-specific trade data are missing, regional or world averages are applied instead.

Finally, there are some products for which pricing information—including export unit values—is entirely absent, although FAO does have data on production. These include those products listed in Table 25 below. For these products, prices or export unit values for similar products as shown in the table are assumed. For products with multiple substitutes, the average unit price (in US$/ton) of the substitutes is taken. Also, where country-specific estimates are lacking, regional or world averages are assumed.

Table 25: Additional items missing pricing information for which prices for substitute products are used

Item	FAO item code	Substitute items	Substitute item codes
Sugar crops, NES	161	Average of sugar crops	156, 157
Jojoba seed	277	Oilseeds nes	339
Tallowtree seed	305	Oilseeds nes	339
Hemp tow waste	777	Fiber crops nes	821
Coir	813	Fiber crops nes	821
Hides, cattle, fresh	919	Hides, cattle, wet salted	920
Hides, buffalo, fresh	957	Hides, buffalo, dry salted Hides, buffalo, wet salted	959 958

Skins, sheep, fresh	995	Skins, sheep, dry salted Skins, sheep, wet salted	997 996
Skins, goat, fresh	1025	Skins, goat, wet salted	1026
Hair, horse	1100	Hair, fine Wool, hair waste Hair, goat, coarse	1218 1009 1031

Note: NES: Not elsewhere specified

5.3 Volumes of agricultural land

The volume estimates for agricultural land (area in hectares) required for compilation of the Törnqvist volume indexes of renewable natural capital (see Section 2.2.4) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below.

The volume estimates for cropland and pastureland are derived using data from the World Development Indicators (WDI) series, which are based on land use data compiled by the Food and Agriculture Organization (FAO). The WDI dataset provides a comprehensive overview of land area usage, allowing for detailed calculations of agricultural land distribution across different countries and regions. For cropland, the volume is determined by combining the percentages of land classified as arable land and permanent cropland relative to each country's total land area. Arable land typically refers to land used for the cultivation of annual crops, which are replanted after each harvest, while permanent cropland includes land used for perennial crops such as orchards and vineyards. The combined percentage is then multiplied by the total land area of each country to derive the total cropland volume, expressed in square kilometers. The pastureland volume is determined by first calculating the total agricultural land area, which includes all land used for farming and livestock activities, and then subtracting the cropland area to isolate the remaining land dedicated specifically to grazing. This calculation ensures that cropland and pastureland are distinctly separated, and that the pastureland volume does not overlap with areas already classified as cropland.

For the CWON 2024 report, the WDI land area data were updated to include annual estimates from 1995 to 2020, providing a robust time series that reflects changes in agricultural land use over a 25-year period. This updated dataset allowed for a more detailed understanding of the allocation of land between crop cultivation and grazing activities. The refined methodology also incorporates adjustments to better account for variations in land classification, ensuring that shifts in land use—such as the expansion or reduction of cropland and pastureland—are accurately captured. This approach provides a more precise measurement of agricultural land areas, which is essential for understanding long-term trends in land use and the sustainability of agricultural practices. Moreover, using data based on FAO's internationally recognized standards helps maintain consistency and comparability across countries, making the estimates more reliable for cross-country analyses and policymaking.

6 Mangroves

As a type of forest, partial mangrove asset values are implicitly included in the forest asset accounts already. However, forest asset value is based only on value for timber, nontimber forest products, watershed services, and recreation services. Mangroves also provide a critical ecosystem service that is not currently included: protection from coastal flooding.[24]

The value of mangroves for coastal flood protection was estimated in several steps, which are further elaborated in Menéndez et al. (2023). First, a combined set of process-based storm and hydrodynamic models are applied to identify the area and depth of flooding using model scenarios with and without reefs and mangroves for five storm frequency events, 1 in 5, 10, 25, 50, and 100 years driven by local storm data.

These flood extent and depth data are then overlaid on historical data on populations and the value of CWON produced capital assets, downscaled to 90 by 90 meters to identify a probabilistic distribution of flood damages (risk) and avoided damages (habitat benefits). All models were run for three years with data on the historical distribution of mangroves (1996, 2010, 2015 and 2020), aggregated to the national level, then extrapolated and/or interpolated to provide annual values for 1995 to 2020.

6.1 Estimating flood risk, flood protection benefits and the asset value of mangroves

The flood protection benefits provided by mangroves are assessed as the flood damages avoided to people and property by keeping mangroves in place. Menéndez et al. (2023) coupled offshore storm models with coastal process and flood models to measure the flooding that occurs: (i) with and without mangroves (ii) under cyclonic and non-cyclonic storm conditions (iii) by storm frequency (return period), across the globe. These flood extents and depths are used to estimate the annual expected flood damages to people and property and hence the expected benefits of mangroves in social (people protected) and economic terms (value of property protected). Estimates are based on a set of global statistical models, hydrodynamic process-based models and socioeconomic data. All these processes are grouped into 5 steps following the Averted Damages (Expected Damage Function) approach, commonly used in engineering and insurance sectors and recommended for the assessment of coastal protection services from habitats. Many aspects of these models such as connections between wind, waves, run-up and flooding have been extensively validated.

The Averted Damages approach provides a rigorous foundation for estimates of flood risk and habitat benefits (Menéndez et al. (2023)). This approach is (a) quantitative in contrast to other approaches that use indicator (expert) scores to assess shoreline vulnerability, (b) it uses process-based models and statistical tools to assess hydrodynamics, (c) it uses the methods and tools of risk agencies, insurers and

[24] Mangroves also provide protection from coastal erosion, but that value is not yet included.

engineers, (d) it is consistent with approaches for national accounting, and (e) it accurately captures impacts of extreme events.

Flood models were used to generate a dataset of several thousand simulations to describe the physical relationships between tropical cyclones, offshore wave climate, mangrove extent and geometry and extreme water levels (i.e., flood height) along the shoreline for five storm frequency events (1 in 5, 10, 25, 50, 100-yr) driven by local storm data. This dataset is then used to estimate how mangroves modify extreme water levels for every kilometer of mangrove shoreline globally. Global flood depths and extents are then estimated by intersecting the global extreme water levels with 90-meter SRTM-DTM (Shuttle Radar Topography Mission). Finally, the resulting maps of flood depths and extents on socioeconomic asset information downscaled to 90 x 90 meters. Flooded socioeconomic assets are then assessed by flood depth to identify flood damages (risk) and avoided damages (mangrove benefits).

To estimate coastal damage and risk and a multi-step approach is implemented:

Step 1. Global Population and Stock Distribution

The distribution and density of population is obtained from the spatial raster GHS-POP R2022A. This dataset contains global residential population estimates at 250 m resolution for 1975, 1990, 2000, 2015 and 2020. These global population rasters were disaggregated from census or administrative units to 250 m grid cells, and informed by the distribution and density of built-up as mapped in the Global Human Settlement Layer (GHSL) global layer per corresponding epoch. Menéndez et al. (2023) used the five years (1975, 1990, 2000, 2015 and 2020) to adjust 1996 and 2010 scenarios, which are the target years of this analysis. Global grid population from 1996 was adjusted by interpolation of 1990 and 2000 population distribution. Global grid population from 2010 was adjusted by interpolation of 2000 and 2015 population distribution. Then they calibrate both, 1996 and 2010 interpolated grids, with nationwide population statistics from the World Bank (World Bank Data) The calibration consists of adjusting the total people per country from the interpolated grids to the World Bank data. Global stock is calculated using Penn World Table, version 10.0 (PWT 10.0). This version is a database with information on relative levels of income, output, input and productivity. The table includes 182 countries and 68 years, between 1950 and 2019.

For the analyses of global stocks, Menéndez et al. (2023) used PWT 10.0 data on produced capital stocks at constant 2017 national prices (the "rnna" variable from PWT 10.10) and transformed these into constant 2020 national prices using country-based consumer price index data from the World Bank. Then, they calculate the stock per capita at each country and multiply these national values by the population located at each grid cell. A global stock distribution raster at 250 meters resolution is generated.

Step 2. Resampling Population and Stock Grids to Flood Maps Resolution (90m)

To overlay flood and assets maps, both must be at the same horizontal resolution. Menéndez et al. (2023) downscaled socioeconomic data rather than upscaling flood grids. Global population and stock rasters at 250 meters are resampled to the same horizontal resolution as the flood maps (90 m). They used ArcGIS toolbox to carry on the spatial redistribution of population and stock grids, and then calibrate the new rescaled rasters, by adjusting the total population and total stock per country at 90 m resolution to those at 250 m.

Step 3. Exposure: People and Stock in Flooded Areas

Here Menéndez et al. (2023) calculated the number of people and then the capital stock exposed to coastal flooding in 1996, 2010, 2015, and 2020 with and without mangroves. They first reclassified the flooding raster into 1 and 0 values. Then they assigned 1 to flooded pixels with water, and 0 to dry pixels and multiplied population rasters by the reclassified flood raster to obtain the global distribution of people exposed to coastal flooding. The capital stock exposed to flooding is then calculated by multiplying people exposed by capital stock per capita at national level from PWT 10.0. The exposure layers inform how many people and assets are in flooding areas, but not the real damage to people and the real economic loss (risk). Calculating flood risk requires estimation of flood damages using damage functions, which relate flood damages at a location to the flood depth at that location.

Step 4. Damage Coefficients

Flood damage depends on the water depth and the type of asset. Menéndez et al. (2023) used different damage functions for population and capital stock. For people, the damage function assumed that, in a grid cell, people are not affected by water below 30cm in depth and all people are affected by flood water depths greater than 30cm. This a commonly used threshold in civil protection services to decide when people must be evacuated.

For capital stock, they combined data from the EU Joint Research Council (Huizinga et al. 2017) and Hazus (Scawthorn et al. 2006) flood depth damage curves. The best combination of these curves globally results in a damage function that ramps up linearly from 0 to 50 percent of damage when water depth is below 1m. Then damage increases at a slower rate from 50 percent at 1m water depth to 100 percent at 5m. The author used these curves to calculate a global raster of damage coefficients to people and capital stock.

Step 5. Risk- People and Stock Damaged by Coastal Flooding

To calculate risk, Menéndez et al. (2023) multiplied damage coefficient rasters by people and capital stock exposure rasters. A total of 160 risk maps for the different conditions and scenarios were generated as a combination of asset type (x2), year (x4), storm condition (x2), ecosystem presence (x2), and return period (x5)

Step 6. Nationwide Aggregation Results

Risk to people and stock is aggregated at national scale. Menéndez et al. (2023) first created a 10 km external buffer at each country and identified the pixels that lay into each country's buffer boundary. They then calculated the total number of people and the total stock value on each country under each scenario.

Step 7. Annual Expected Risk and Benefits

In addition to assessing risk for specific events (such as a 100-year storm event), Menéndez et al. (2023) also examined average annual expected damages and benefits provided by mangroves. To estimate annual risk, they integrated the values under the extreme value distribution curves that compare capital stock damaged, or people affected, by storm return period—in other words, the integration of the expected damage with the probability of the storm events.

Step 8. 100-Year Asset Value Calculation

Menéndez et al. (2023) calculated the present value of mangrove benefits over a period of 100 years. They assumed a constant benefit flow over 100 years (consistent with the valuation of other renewable natural capital assets in CWON) and a 4 percent discount rate to obtain the 100-year asset value.

(6.1)
$$PV = \sum_{i=1}^{i=100} \frac{AEB}{(1+r)^i}$$

where *PV* is the Present Value, *AEB* are the Annual Expected Benefits, *r* is the discount rate (4 percent) and "*i*" is each year within the life cycle period (i=1-100 years).

Table 26 presents some key data sources.

Table 26: Data Sources for Mangroves Wealth Estimation

Indicator	Data sources and notes
Total mangrove area	• Global Mangrove Watch Database, www.globalmangrovewatch.org
Coastal assets at risk	• Coastal population: Global Human Settlement Layer (GHS-POP GRID) dataset, from the European Commission, https://ghsl.jrc.ec.europa.eu/ghs_pop2019.php • Coastal produced capital: Penn World Table version 9.1 produced capital data, spatialized using coastal population, https://www.rug.nl/ggdc/productivity/pwt/).
Annual service values per hectare	• Modelled by Beck et al. 2021

6.2 Mangrove Data

6.2.1 Population Data

Menéndez et al. (2023) took global exposure data for people from the GHS-POP grid dataset from the European Commission. This new package, released in 2022 (GHS R2022A, (Schiavina et al. 2022)) substitutes the previous version (GHS R2019) and provides estimates of global populations and their distribution for 1975, 1990, 2000, 2015, and 2020, as well as future projections to 2025 and 2030. GHS R2022A matches or outperforms other data sources for accuracy in epochs 2018 and 2020 and matches or outperforms also all the other single epochs (1975, 1990, 2000, and 2015) included in the previous release GHS R2019. The global distribution of population used for 1996, 2010, and 2015 is 250m resolution (GHS R2019), while 2020 population distribution released in 2022 (GHS R2022A) with the new version is at 1km resolution.

6.2.2 Capital Stock Data

Menéndez et al. (2023) used data on produced capital stocks from PWT 10.0 from the Groningen Growth and Development Center. This version is a database with information on relative levels of income, output, input, and productivity. The table covers 182 countries and 70 years (1950–2019). They used the nationwide data of capital stock at constant 2017 national prices and transformed these into constant 2020 national prices by using country-based consumer price indexes. Then, they calculated the stock per capita at each country and multiplied these national values by the population located at each grid cell. We then obtained the global stock distribution at 250m resolution. There were 22 tropical nations that had mangroves but were not included in the PWT; most of these gaps were filled with national data from the World Bank. There were a few remaining countries and territories the authors were not able to include in the analyses due to the lack of economic data (Eritrea, French Guiana, New Caledonia, Micronesia, Palau, Somalia, Guadeloupe, Martinique, Timor Lester, Mayotte, Samoa, US Virgin Islands, Saint Martin, and American Samoa).

The new updated version of the PWT (10.0, Feenstra et al. 2015) was released in June 2021. The authors used the capital stock at constant national prices ("rnna") and total population ("pop") to calculate the capital stock per capita ratio at national level. Several changes were introduced in PWT 10.0 relative to the version used in CWON 2021 (PWT 9.1). These differences result in changes in the economic valuation of mangroves worldwide. The main updates are:

- capital stock in PWT 9.1 was in constant 2011 national prices, while capital stock in PWT 10.0 is in constant 2017 national prices
- in PWT 9.1, the time series was 1950 to 2017. PWT 10.0 covers the period 1950 to 2019.
- capital stock was recalculated in some countries (e.g. China, Sudan) using an outdated nominal value for GDP, resulting in values much higher than previously estimated in some countries.

6.2.3 Gross Domestic Product

World Development Indicators from the World Bank (https://datacatalog.worldbank.org/dataset/world-development-indicators) were used to obtain GDP data for each country involved in this study. GDP information is available from 1960 to 2020.

6.3 Volumes of mangrove resources

The volume estimates for mangrove resources required for compilation of the Törnqvist volume indexes of renewable natural capital (see Section 2.2.4) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below.

Menéndez et al. (2023) took mangrove extent data from the updated database of Global Mangrove Watch (GMW 3.0; Bunting et al. 2022). This update includes new mangrove distribution maps corresponding to the 2016 to 2020 period and updates/improvements of the historical mangrove distribution data for the period 1996 to 2015. In CWON 2021, GMW 2.0 was used for 1996, 2010, and 2015. For CWON 2024, GMW 3.0 was used to update 1996 to 2015 mangrove coverage and add the year 2020. The most significant difference in these datasets is that the improved GMW 3.0 shows a consistently greater global coverage than GMW 2.0 (about 7 percent greater). To consistently assess mangrove benefits over time, all data (not just 2020) were updated, the flood models were re-run, and new assessments of risk and benefits were developed.

7 Fisheries

Fisheries wealth was calculated in CWON 2021 as the discounted value of the stream of rents expected over the lifetime of the asset. Landed value is based on estimates of the Sea Around Us (SAU) project housed at the University of British Columbia, which is more comprehensive and detailed than the United Nations Food and Agriculture Organization's (FAO's) fisheries data.

For CWON 2024, the CWON 2021 results were re-calculated without the adjustment to rent for subsidies that was included in 2021 and then extrapolated (using the Stata command *ipolate*) to cover 2019 and 2020. The change to allow subsidies to remain part of rent in CWON 2024 was made to align fisheries wealth estimates with the value of other assets in CWON, as fisheries were the only asset in CWON 2021 to have rent estimated with the exclusion of subsidies. The use of simple extrapolation to add 2019 and 2020 to the time series was due to the lack of the necessary data to estimate values for those years starting from basic data. What follows in this section is a description of the method applied to estimate fisheries wealth in CWON 2021, without the approach that had been taken to deducting subsidies from rent.

7.1 Fisheries data

The calculation of fisheries wealth requires data on marine fisheries production (catch), ex-vessel price of each exploited species, and fishing costs.

7.1.1 Catch data

Lam and Sumaila (2021) obtained catch data from two different sources including Food and Agriculture Organisation of the United Nations (FAO) and the SAU database. Marine capture production data (tonnes) of each country and species from 1991 to 2018 were obtained from FishStat, the FAO's Fisheries and Aquaculture statistics database. Annual catch data were extracted from the *Sea Around Us* database of "reconstructed" catch data[25], which covers the years 1991 to 2019 distributed onto 180,000, 30' latitude x 30' longitude spatial cells of the world ocean.

The catch allocation process by the SAU produced spatial time series of landings data from 1991 to 2019 that were aggregated into different fishing entities and that distinguished between landings by different taxa, different fishing gear types, between distant-water and domestic fleets, different catch types (landings and discards) and between different fishing sectors (including industrial, subsistence, artisanal and recreational). Lam and Sumaila (2021) included 203 countries in their analysis while 31 countries were excluded, mostly small island states. There are 2,741 taxa at different taxon levels (species, genus, family, order, class and ISSCAAP levels) included in the database. Each of the taxa is associated with a functional

[25] "Reconstructed" is the term used by SAU to describe the annual catch data by country they compile by combining data from a wide variety of sources and then interpolating to fill the remain gaps. Further details are found in Pauly and Zeller (2015).

group which plays a specific functional role in the ecosystem, and there are 31 functional groups in the databases.

The catch reported to FAO from its members countries is lower than the SAU reconstructed catch (FAO, 2016). The small-scale fishery sectors, i.e. artisanal, subsistence and recreational received little attention in data collection systems, so their catches are underrepresented in, or absent from, official catch statistics, as are discards and illegally caught fish. Thus, the total reconstructed catch from 1991 to 2016 was around 1.5 – 1.8 times of the total reported catch in Europe and East Asia, which is comparable to the ratio of global reconstructed to the reported catch (i.e. about 1.5 times). The “catch reconstruction” approach utilized a wide variety of data and information sources to estimate the catch of those sectors that are missing from the official reported data. Globally, the reconstructed catch tends to decrease in the recent decade but reported catch remain more or less stable in this decade. In the East Asia and Pacific region, the reported catch still tends to be stable in the recent 10 years, but this is mainly due to the over-reporting by a few countries.

Lam and Sumaila (2021) extended the catch series for the present study based on FAO catches in 2017 and 2018. This was performed by first comparing the complete list of fishing countries in the *Sea Around Us* catch database with a list of all countries occurring in the FAO data in 2017 and 2018. Then, the proportion of catch of each fishing country in the *Sea Around Us* catch database to that reported by FAO in 2016 was calculated. Finally, these proportions and the FAO production data in 2017 and 2018 were used to estimate the reconstructed catch of each fishing country in these two years, assuming that these proportions did not change much since 2016. The results are catch by each fishing country in 2017 and 2018.

7.1.2 Landed values and price data

Ex-vessel prices are the prices that fishers receive directly for their catch, or the price at which the catch is sold when it first enters the supply chain. Sumaila et al. (2007) first established a global ex-vessel fish price database to understand the economic behavior of the world fisheries and address the issue of lacking information for sustainably management of marine resources. The first version of the fish price database provided the ex-vessel prices for each exploited marine taxon, by each fishing country for each year from 1950 to 2006 and it is capable of combining to each recorded catch data in the earlier version of the SAU catch database. The fish price database was constructed by collecting and compiling scattered data from secondary data sources and working with the international partners. A rule-based approach was adopted to estimate missing prices data, using a combination of various rules across taxa, countries and years. Also, a system of penalties was used as a measure of uncertainty of each of the data point.

This price database is a living database with continuous updates on both the input data and the price estimation methods. The most up-to-date database has fish price data from 1950 to 2010 for marine taxa that are destined for both direct and non-direct human consumption. By combining the catch data with the fishing ex-vessel price data of each marine taxon, the landed values can be estimated for different fishing country at different spatial locations. For example, the total landed values in each grid cell in a particular year is calculated by:

$$LV_{yr} = \sum_{i}^{i=m}(\sum_{j}^{j=n}(C_{i,j,yr} * P_{i,j,yr})) \quad (7.1)$$

where LV_{yr} is the total landed values in a particular grid cell in a particular year (*yr*), *i* is the fishing country, *m* is the number of countries fishing in this grid cell, *j* is the exploited marine taxon, *n* is the number of marine taxa caught by each fishing country in that grid cell in year *yr*, $C_{i,j,yr}$ is the annual total catch of a taxon (*i*) caught by country *j* in year *yr* and $P_{i,j,yr}$ is the unit ex-vessel price data of this particular taxon (*i*) by fishing country (*j*) in year *yr*.

Since the last round of the update of the price data was only up to year 2010, Lam and Sumaila (2021) extended the ex-vessel price data from 2011 to 2018. Here assuming the ex-vessel prices of each taxon by each country remind unchanged after 2011. Lam and Sumaila (2021) carried forward the price data of each taxon by each fishing entity in 2010 or the latest year to the data gaps from 2011 to 2018.

Lam and Sumaila (2021) used the information on World Bank price deflators to convert the 2010 USD price to 2018 real US dollars.

7.1.3 Fishing cost data

Lam and Sumaila (2021) updated the global fishing cost database from Fisheries Economic Research Unit (FERU) at the UBC to cover the years from 1991 to 2018, and to further distinguish costs of small-scale, large-scale and distant water fleets. Small scale fleet includes all vessels under 12m or 15 GT using static gears (drift and/or fixed netters, vessels using pots and/or traps, vessels using hooks, vessels using passive gears only for vessels). Large scale fleet segment includes all vessels using towed gears (dredgers, demersal trawlers and/or demersal seiners, vessel using other active gears, vessels using polyvalent active gears only, purse seiners, beam trawlers, pelagic trawlers) and vessels over 12m or 15GT using static gears operating within the EEZ of the flag state. The long-distance fleet includes vessels over 24m or 100GT operating in other countries fishing regions or beyond the EEZ of the flag state. The fishing cost data in this database is arranged by year, fishing entity, super gear type and fishing sectors. Gear types included in the database were based on the gear categorization system of the SAU. The fishing sectors are segregated into Industrial, subsistence, artisanal and recreational fishing sectors.

Lam and Sumaila (2021) collected secondary data for vessels operating in major fisheries and in major fishing nations in each of the seven World Bank regions of the world: (1) Sub-Saharan Africa; (2) East Asia and Pacific; (3) Europe and Central Asia; (4) North America; (5) Middle East and North America; (6) Latin America and Caribbean; and (7) South Asia. The first step was to identify the sources of fishing cost data, mainly secondary sources, i.e. websites and grey literature, such as government, FAO, and consultant reports (see Lam and Sumaila 2021 for more details). The authors collected 4,300 data points with fishing cost data from various sources. These data are reported in 56 countries in the seven regions. The observed data is biased towards the high-income group and the number of data in this group represents about 89 percent of the total number of observed data. Fishing cost data in the other three income groups are under-represented.

7.2 Fishing subsidies

As noted above, while the CWON 2021 methodology for fisheries included deduction of subsidies from fisheries rent, this practice was discontinued for CWON 2024 to align the approach to valuing fisheries resources with that used for other assets, none of which are valued with subsidies excluded. Lam and Sumaila (2021) should be consulted by those interested in the approach used to deduct fisheries subsidies in CWON 2021.

7.3 Fisheries wealth

Like other renewable assets, the present value of fisheries wealth is estimated over a period of 100 years. A constant resource rent flow and 4 percent discount rate is assumed. The present value formula is:

(7.2)
$$PV = \sum_{i=1}^{i=100} \frac{PR}{(1+r)^i}$$

where *PV* is the Present Value, *PR* are the Annual Private Rents, *r* is the discount rate (4 percent) and "*i*" is each year within the life cycle period (i=1-100 years).

7.4 Volumes of fisheries resources

The volume estimates for fisheries resources required for compilation of the Törnqvist volume indexes of renewable natural capital (see Section 2.2.4) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below. The data were provided by SAU researchers.

The approach rests on so-called "surplus-production" modeling, which assumes that a given marine ecosystem has a specific carrying capacity (*k*, roughly similar to unfished biomass, B_o) and that if this population is reduced through fishing the population will tend to grow back toward its carrying capacity. Such growth is conceived as the product of two parameters, one being the intrinsic population growth rate of the population (*r*), as determined by the attributes of the individuals in the population in question the other being the current abundance or biomass (*B*) of the population and its closeness to B_o as expressed by the term $1\text{-}B/B_o$. The nature of this growth model is such that the biomass of a very small population cannot grow by a large amount, even if its *r* is relatively high, and neither will a population that is near carrying capacity because, in this case, $1\text{-}B/B_o$ is close to zero. In other words, the maximum population growth rate occurs at an intermediate abundance. Thus, human extraction of biomass via a fishery can, in principle, maintain a fish population at any given biomass level by removing every year an amount of biomass equivalent to the natural growth of that population in that year.

The fisheries stock assessment method used to derive the volume estimates (fisheries biomass in tonnes) is built on this conceptual framework. It consists of tracing, for an exploited population with a time series of annual catch tonnage, multiple trajectories of its likely biomass, each defined by a pair of population growth rate (*r*) and carrying capacity (*k*) values and identifying the trajectories that remain viable while accommodating the catches taken from this population.

A range of *r* values is available from FishBase (www.fishbase.org) for finfishes and from SeaLifeBase (www.sealifebase.org) for invertebrates. The range of carrying capacity (*k*, or B_0) that is appropriate to a given stock will be specific to it, with the catch itself providing a scale. Thus, the maximum of a catch time series can be used as the lower limit for the range of *k* values, while some high multiple of this maximum can be used as upper estimate. In practice, the method amounts to producing potential biomass trajectories given a time series of catch data, a range of pairs of intrinsic growth rate and carrying capacity (*r* and *k*) estimates, and broad constraints on acceptable trajectories. These broad constraints should express prior knowledge on (a) the approximate level (in percent) to which carrying capacity was reduced at the start of the time series (here 1950) or the year when the fishery was opened and (b) the level to which carrying capacity was reduced at the end of the time series (also in percent of *k*). Such independent knowledge about the relative population depletion can be obtained from general knowledge about a given fishery (“good”, “not as good as it used to be”, “bad”, “very bad”) and translated into broad percentage or fractional ranges relative to carrying capacity (*k*). For example, for a “good” fishery, a value of 40 percent-80 percent of the unfished biomass level (*k*) might be used, while for a “bad” fishery, a value of 10 percent to 40 percent might be used.

8 Hydroelectric resources

Estimates of hydroelectric asset values for all countries where either 1) hydroelectric generation accounted for more than 5 percent of total national generation in 2020 or 2) where total installed hydroelectric generating capacity in 2020 was 100 MW or greater were prepared for CWON 2024 following the NPV-RVM method.[26] CWON 2024 was the first edition to include such values. It built up on the pilot study of renewable energy values with data for 15 countries that had been published in CWON 2021 (Smith et al., 2021).

8.1 Estimating hydroelectric resource rent and asset value

8.1.1 Hydroelectric resource rent

Equation 8.1 expresses the version of the RVM used to estimate rent for hydroelectric assets in a given country and year t.

[26] These restrictions were introduced to ensure that countries included in the study would have markets for hydroelectric generation sufficiently well established for the global data used in this study to reflect conditions in the country.

$$RR_t^{hydro} = TR_t^{hydro} - O\&M_t^{hydro} - subsidies^{hydro} - (rK_t^{hydro} + \delta^{hydro}) \quad (8.1)$$

where,

RR_t^{hydro} = residual value estimate of hydroelectric resource rent in year *t* in the country in question

TR_t^{hydro} = total revenue from sales of electricity generated at so-called "renewable" hydroelectric plants[27] in year *t* in the country, including any subsidies paid on generation

$O\&M_t^{hydro}$ = cost for labour, materials, fuel, and other supplies to operate and maintain the produced assets (that is, the dams or other civil infrastructure required to create reservoirs plus the hydraulic turbines and other equipment needed to generate electricity and transfer it from the hydroelectric station to the local power grid) used to generate hydroelectricity in year *t* in the country

$subsidies^{hydro}$ is an estimate of the subsidies received by hydroelectric producers

r = economy-wide average annual rate of return to produced capital in the country (a constant)

K_t^{hydro} = total value of produced capital used to generate hydroelectricity in year *t* in the country

δ^{hydro} = annual rate of depreciation of the produced capital used to generate hydroelectricity in the country (a constant).

In practice, data on subsidies paid to hydroelectric producers are difficult to obtain. Direct subsidies paid to producers are difficult to observe, since such subsidies are unlikely to be reflected in end-user electricity prices and, as is explained later, our methodology relies on residential end-user prices as a means of estimating producers' revenues and hence hydroelectric resource rent. For this reason, subsidies are not accounted for in the valuation of hydroelectric assets, which is consistent with all other CWON assets. Thus, a modified version of Equation 8.1 without subsidies was the basis for the estimation of hydroelectric resource rent in CWON 2024 in practice:

[27] Renewable hydroelectric plants are those where water flows through the hydraulic turbines only as a result of natural forces. These contrast with so-called "pumped storage" plants the water flowing through the turbines is pumped from a lower reservoir below the turbines back into an upper reservoir to be used again. This pumping usually occurs at night when demand for electric power is low and excess power is therefore available from non-hydro sources. Pumped storage plants were not considered in this study. So-called "mixed" plants are those which include some pumped storage capabilities along with renewable generation. For the purposes here, mixed plants were considered renewable.

$$RR_t^{hydro} = TR_t^{hydro} - O\&M_t^{hydro} - (rK_t^{hydro} + \delta^{hydro} \quad (8.2)$$

where all variables are as defined above.

8.1.2 From rent to resource value

With hydroelectric rent estimated following Equation 8.2 for each country and year between 1995 and 2020, the next step was to determine the expected pattern of future rents for the NPV calculation. This required decisions regarding two parameters: the level of rent in future years and the number of years for which rent will flow. Regarding the latter, it was assumed that rent will flow for 100 years in keeping with the assumption used in the valuation of other renewable natural resource assets in CWON. For the former, in keeping with the general approach to renewable natural resource asset valuation in the CWON and in the SEEA-CF (SEEA-CF ¶5.133), future hydroelectric rents were assumed to be equal to the rent observed in the time period in question. For example, to value hydroelectric assets for 2020, assumed a 100 year series of rental incomes equal to the estimated 2020 rent is used in the NPV calculation.

With the current rent and its expected future pattern determined, estimation of the value of hydroelectric assets in a given country proceeded according to Equation 8.3.

$$V_t^{hydro} = \sum_{n=1}^{100} \frac{RR_t^{hydro}}{(1+r_g)^n} \quad (8.3)$$

where,

V_t^{hydro} = value of hydroelectric assets in year *t* in the country

RR_t^{hydro} = resource rent accruing to hydroelectric assets in in year *t* (as defined in Equation 8.2 and including subsidies) in the country

T = hydroelectric asset life in years (assumed to be 100 years in all countries)

n = future periods from 1 to 100

r_g = economy-wide discount rate (assumed, following CWON convention, to be 4 percent for all countries and years).

8.2 Data sources and assumptions

8.2.1 Revenues from electricity generation

Two data points were required to estimate revenues from hydroelectricity generation (TR_t^{hydro} from Equation 8.2):

- the quantity of hydroelectricity generated, and

- the price received by hydroelectric power producers in each country and year.

Global data on generated quantities of hydroelectricity were obtained from the International Renewable Energy Agency (IRENA, which provides these data annually for most countries in the world going back to 2000.[28] The United Nations provides similar data covering the period back to the 1990s through its *Energy Statistics Database*.[29] The generation data used in CWON 2024 were derived from a combination of these two sources. In general, the two sources agreed exactly on generation figures for a given country and year. Where they did not, a simple average of the data from the two sources was used unless there was clear reason to prefer the figure from one over the other.

Obtaining data on the average annual prices received by hydroelectric power producers ("producer prices" hereafter) at the country level is more difficult, as no globally complete database of producer prices exists either from public or private data suppliers.[30] Given this, producer prices were estimated indirectly. This was done starting from the only available database of electricity prices with something close to global coverage, the International Energy Agency (IEA)'s *Energy Prices* database.[31] This database, which is only available by paid subscription, contains weekly, monthly, quarterly and annual end-user (residential, commercial and industrial) electricity prices in nominal local currency units (LCUs) for some 140 countries from 1970 to 2022. Since the most complete country coverage in this database is for annual residential end-user prices, those prices (adjusted to account for delivery charges and other non-production costs – see below) were chosen as the basis for estimating the annual producer prices required. For countries not covered by the IEA database, regional average residential electricity prices were calculated and used as a proxy for national prices. For countries included in the IEA database but with data missing for certain years, missing data were estimated from the available data by either backward or forward linear extrapolation.

To estimate producer prices in each country IEA residential prices were multiplied by a time-invariant conversion factor that reflects the share of the price expected to be received by hydroelectric producers. These conversion factors were determined empirically for the individual countries listed in Table 27 by identifying factors that, when applied to the IEA residential electricity price data, resulted in figures that best matched the electricity prices used for the country in question in the pilot CWON 2021 study of renewable energy assets (Smith et al., 2021). Since the prices used in the pilot study were derived from country-level electricity market data, they were considered accurate. In determining these country-specific factors, priority was given to finding factors that resulted in prices that matched pilot study prices

[28] See https://pxweb.irena.org/pxweb/en/IRENASTAT?_gl=1*1djkx00*_ga*MTM2ODIxMzA0Mi4xNjk4NjkyMjYx*_ga_7W6ZEF19K4*MTY5ODY5MjI2MC4xLjEuMTY5ODY5MjU0Mi42MC4wLjA.

[29] See http://data.un.org/Data.aspx?d=EDATA&f=cmID percent3aEC.

[30] Preparing such a database would be challenging given the difficulties of estimating annual prices when energy markets in countries with competitive wholesale electricity markets today include pricing mechanisms that adjust to demand and supply on an hourly basis. In addition, in competitive, regulated and hybrid electricity market models there are multiple mechanisms for generating revenues by power producers. Besides electricity, electricity producers also sell capacity readiness, and other ancillary services that system operators buy to maintain grid stability and security.

[31] See https://www.iea.org/data-and-statistics/data-product/energy-prices#overview.

best for recent years. For countries not included in the pilot study, another approach to determining the conversion was required.

Table 27 - Residential-to-producer price conversion factors by country/region

Country/region	Residential-to-producer price conversion factor
Canada	0.6
United States	0.28
Australia	0.25
Brazil	0.5
China	0.72
Japan	0.46
Russian Federation	0.5
Türkiye	0.6
India	0.9
Europe and Central Asia Region (western and central European countries)	0.25
Europe and Central Asia Region (other than western and central European countries)	0.61
Rest of world, competitive markets	0.61
Rest of world, non-competitive markets	0.8

Source: World Bank.

For countries in western and central Europe, the factor (0.25) was similarly chosen to best match the prices used in the pilot study for other European countries (France, Germany, Italy, Spain, Sweden, and the United Kingdom). For all other countries with a competitive electricity market according to the World Bank's *Global Power Markets Structure Database* (Akcura, 2024), the average conversion factor (0.61) of the countries listed in Table 27 was used, weighted by each country's share of the combined 2020 hydroelectricity generation. This factor implies that transmission and distribution charges and traders'/suppliers' margins on average account for 39 percent of residential price. Finally, for other countries deemed not to have competitive electricity markets, the factor was set to 0.8 based on expert judgement. This value was chosen to reflect the likelihood of government subsidization of residential prices in these countries, with households paying capped electricity prices close to what power producers themselves receive.[32]

Following the estimation of producer prices in LCUs for all countries, conversion from LCUs to United States dollars (USD) was accomplished using the market exchange rate of the reference year (i.e., prices

[32] As a test of the reasonableness of the above approach, price data from a commercial database from the Energy Regulators Regional Association (ERRA) were analyzed. Though the ERRA database covers only 44 countries and is missing many values, it does offer reasonable coverage of residential and producer prices for electricity at the country level on a quarterly basis for the period 1999-2022. An analysis of the ratio of producer to residential prices in this database suggests that the ratio of 0.61 applied to most countries in this study is appropriate. For the period and countries covered by the ERRA database, the average ratio of producer to residential prices was 0.58. These countries are, for the most part, similar to those to which we have applied the factor of 0.61; that is, lower- or middle-income countries.

in 1995 LCUs were converted to USD by applying the 1995 LCU to USD market exchange rate, obtained from the World Bank *World Development Indicators* database. Finally, total annual revenues from sales of hydroelectric power by country (TR_t^{hydro}) were obtained by multiplying estimated hydroelectric generation by the estimated producer price for each country and year.

8.2.2 Costs of electricity generation

Hydroelectricity generation costs are of two types, both of which had to be estimated indirectly.

1) **User costs of capital**: The annual costs of employing the hydroelectric powerplant (including the dam and any other civil works) in the production process (rK_t^{hydro} in Equation 8.2), comprising the expected annual return to the owner of the powerplant plus the annual cost of depreciation of the powerplant (the δ^{hydro} variable in Equation 8.2).
2) **Operating and maintenance costs**: The annual expenses required to operate and maintain the powerplant, including labour, materials, fuel and other supplies ($O\&M_t^{hydro}$ in Equation 8.2).

8.2.3 Capital costs

As with electricity prices, no global database of country-level capital costs for hydro generation exists. The closest to this is a set of regional investment cost estimates available from IRENA as part of its annual report on costs of renewable energy generation (IRENA, 2023).[33] IRENA presents these estimates as regional averages for two periods (2010-2015 and 2016-2021),[34] with separate estimates for the costs of installing large and small hydro plants. To render these capital cost data suitable for use, it was necessary first to extend them to cover the full period 1995-2020[35] and then to convert the figures from constant USD to nominal USD using the implicit GDP price deflator for the United States (US).[36]

With an annual timeseries of nominal capital investment costs from 1995-2020 by country in hand, the next task was to create a time series of values of the produced capital stocks used in hydroelectric generation in each country (K_t^{hydro}). Estimating K_t^{hydro} was complicated by the fact that considerable investment in hydroelectric generation infrastructure took place prior to 1995 in almost all countries. Therefore, an estimate was required of the 1994 produced capital stock value for each country before the 1995-2020 time series could be compiled. The 1994 estimate was derived by applying an approach outlined in the OECD manual on measuring capital stocks (OECD, 2009; Section 15.7), similar to the

[33] See https://www.irena.org/Publications/2023/Aug/Renewable-Power-Generation-Costs-in-2022#. Accessed July 29, 2023.

[34] IRENA's regional breakdown is Asia, Africa, Central America and the Caribbean, Eurasia, Europe, Middle East, North America, Oceania and South America. In addition to these regions, the IRENA capital investment cost data provide specific estimates for three countries: Brazil, China and India.

[35] Annual values for the IRENA capital costs were estimated as follows: Annual investment costs during the 2010-2015 period were assumed equal to IRENA's 2010-2015 average investment cost value, for the 2016-2020 period they were assumed equal to IRENA's 2016-2021 average value, and annual investment costs prior to 2010 were assumed equal to the average of the IRENA's 2010-2015 and 2016-2021 values.

[36] This approach parallels that used by IRENA derive the constant price values (IRENA, personal communication).

approach taken in the valuation of oil and gas resources (see Section 3.2.2). According to that approach, a reasonable estimate of the stock of produced capital in any base year may be derived by dividing the value of investment in the base year by the sum of the capital's deprecation rate plus the long-term growth rate of real GDP in the country in question. Equation 8.4 expresses this approach to estimating base-year stocks of hydroelectric powerplant produced capital stocks.

$$K_0^{hydro} = \frac{I_0^{hydro}}{\delta^{hydro} + \theta} \qquad (8.4)$$

where,

- K_0^{hydro} is the value of the produced capital stock used for hydroelectric generation in the base year (1994 in all but a few cases[37]) in a given country
- I_0^{hydro} is the value of investment in produced capital used for hydroelectric generation in the base year in the country
- δ^{hydro} is the annual rate of depreciation of produced capital used for hydroelectric generation (a constant of 1.67 percent in all countries and years based on the assumption that hydroelectric generating dams and equipment have universal 60-year service lives)
- θ is the long-term annual growth of real GDP in the country, derived from World Bank data.

The main missing piece of information in equation 8.4 was the value of investment, I_0^{hydro}, which had to be separately estimated. The installed hydroelectric generation capacity in each country in 1994 was divided by the assumed age of the oldest hydroelectric plants in the country[38] to derive an estimate of the annual average quantity of capacity additions over the history of the country's hydroelectric power industry. This quantity was taken to be the addition of new capacity in 1994, which was then multiplied by our estimated 1994 investment cost derived from the IRENA data to estimate the value of I_0^{hydro} in nominal USD.

Once K_0^{hydro} was estimated, an annual time series of hydroelectric produced capital stocks (nominal USD) from 1995-2020 for each country was estimated using a standard perpetual inventory method approach. That is, produced capital investment was added in each year to the previous year's stock value and depreciation was deducted. The value of investment in each year was then calculated by multiplying the

[37] Four countries had no installed capacity for hydroelectric generation in 1995: Belize, Cambodia, Liberia and Sierra Leone. For these countries, the value of produced capital stocks used in hydroelectric generation were simply estimated by cumulating the net investment in produced capital beginning in whatever year the country's hydroelectric generation began.

[38] This age was taken to be 50 years in all countries except Brazil, India and those North America, Eurasia, Europe, North America and Oceania, where it was assumed to be 75 years.

newly installed hydroelectric generating capacity in that year[39] by that year's estimated value of capital investment costs per unit of installed capacity (in MW).

8.2.4 Operating and maintenance costs

In addition to providing estimates of capital investment costs by region, the IRENA renewable energy cost report (IRENA, 2023) provides estimates of operating and maintenance costs for hydroelectric plants. These estimates are highly generalized, however, with IRENA simply reporting that, on average, operating and maintenance costs at hydroelectric plants can be assumed to be around 2 percent of the capital cost of the installed produced capital. In the absence of any better estimate, this figure was applied uniformly to all countries and years.

8.3 Estimating rent and asset values

With estimates of the revenues generated from hydroelectric generation and the associated capital and operating and maintenance costs in hand, it was straightforward to estimate the rent attributable to hydroelectric assets in each country and year using equation 8.2. The only additional variable required was r, the economy-wide average annual rate of return to produced assets. Ideally, country-specific values of r would have been used but such rates are not readily available. We assumed instead the following annual rates (intended to reflect real returns), which were also used in the pilot study (Smith et al., 2021): 4 percent in Europe, North America and Oceania; 8 percent in Africa, Central America and the Caribbean, Eurasia, Middle East, South America; and 10 percent in Asia.[40] Once the hydro resource rent was estimated, the final step was to calculate the value of hydroelectric assets as the present value of future rents over the assumed lifetime of hydroelectric assets (100 years) using equation 8.3.

In certain instances, the value of RR_t^{hydro} dropped below zero in a given country and year due to temporary situations respecting electricity prices or electricity generation levels, both of which fluctuate over time. In those instances, the value of V_t^{hydro} was set to zero.

8.4 Estimating hydroelectric asset values in real terms

The volume estimates for hydroelectric assets required for compilation of the Törnqvist volume indexes of renewable natural capital (see Section 2.2.4) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below.

The quantity of electricity generated annually in a country measured in MWh was chosen as the physical volume measure. An alternative could have been the installed generating capacity measured in MW to

[39] The newly installed hydroelectric generating capacity was calculated as the difference between the opening and closing stock of installed generating capacity in the year.

[40] Making assumptions regarding these rates is less than ideal. However, the impact on the overall results is muted by the fact that the expected returns to produced assets do not have a large bearing on the value of resource rent. For example, reducing the assumed rate of return on produced assets by 25 percent (from 4 percent to 3 percent) for Canada increases the 2020 estimate of hydroelectric resource value by just 7 percent.

represent the physical volume. This was rejected because the installed capacity fails to capture the actual volumes of valuable electricity generated due to the different operational priorities of multifunctional reservoirs. Furthermore, changes in generated quantities as time goes by implicitly capture quality changes in both the hydroelectric asset and the produced assets used to capture it, which is a desirable feature for the volume index. Due to aging of equipment and environmental factors such as sedimentation of reservoirs (Schellenberg et al., 2017), there tends to be a reduction in the capacity use factor of a given hydroelectric plant to generate electricity as time passes. Moreover, the changing climate is impacting the availability of water resources in varying ways across the planet, meaning that previous generation levels may become difficult to maintain due to declining water availability.[41]

[41] This is happening, for example, in the Colorado River basin of the United States, where the Hoover Dam is less and less capable of generating electricity to its full potential because of reduced water levels in its reservoir, Lake Mead. (NASA, no date. See https://earthobservatory.nasa.gov/images/150111/lake-mead-keeps-dropping. Accessed September 2, 2023.)

9 Produced Capital

Produced capital consists of manufactured or built assets such as machinery, equipment, and physical structures. Estimates of produced capital stocks in CWON also include the value of built-up urban land, which is valued as a mark-up on other produced assets. This section first describes data sources and methods for estimating the value of machinery, equipment, structures and other produced assets. It then explains the mark-up for urban land. It should be noted that CWON 2024 is the final edition in which urban land will be treated in this manner, as its classification as a part of produced capital is inconsistent with both the SEEA and the SNA. Beginning with the next edition, urban land will be classified as a type of natural capital. At the same time, an improved methodology for estimating the value of urban land will be implemented.

9.1 Machinery, equipment, and structures

For the calculation of physical capital stocks, several estimation procedures can be considered. Some of them, such as the derivation of capital stocks from insurance values or accounting values or from direct surveys, entail enormous expenditures and face problems of limited availability and adequacy of data. Other estimation procedures, such as the accumulation methods and, in particular, the perpetual inventory method, are cheaper and more easily implemented since they require only investment data and information on asset service lives and depreciation patterns. These methods derive capital series from the accumulation of investment series and are the most popular. The perpetual inventory method (PIM) is, indeed, the method adopted by most OECD (Organisation for Economic Co-operation and Development) countries that estimate capital stocks (Bohm et al. 2002; Mas, Perez, and Uriel 2000; Ward 1976) and is the one used here. Most country-level produced capital estimates (88 percent) in CWON are taken directly from the PIM-based estimates in the Penn World Table (PWT) 10.0 database. For countries with no PWT data, an approach is borrowed from previous CWON reports, which is used to estimate a complete investment series from (detailed below).[42]

9.1.1 Main approach – Countries with PWT data

PWT 10.0 uses the PIM to estimate produced capital stocks for 180 countries from 1970 to 2019. Since PWT 9.0, this database has estimated produced capital broken down into four general classes of assets: residential and non-residential structures, machinery and (non-transport) equipment, transport equipment, other assets (see Table 28). Investment data comes from national account statistics and partly from estimates using the commodity-flow-method. See Feenstra and Inklaar (2015, p.28) for further details.

[42] There are 7 countries in the balanced CWON 2024 dataset that use alternative investment or growth-based estimates for produced capital. These countries are: Guyana, Kuwait, Micronesia, Papua New Guinea, Qatar, Solomon Islands, Tuvalu. There are 46 countries in the total unbalanced dataset with estimates using these approaches.

Stock *K* of each asset *a* in country *i* and year *t* is defined as:

(8.1) $$K_{a,i,t} = K_{a,i,t-1}(1-\delta_{a,i,t}) + I_{a,i,t}$$

where $\delta_{a,i,t}$ is the depreciation rate and $I_{a,I,t}$ is investment for asset *a* in country *i* and year *t*.[43] The total capital stock is the sum of K_a for each of the four asset classes.

Table 28: Categories of manufactured assets in the Penn World Table, global average depreciation rates (1970 – 2019) and capital-output ratios

Asset	Depreciation rate	Capital/output ratio *k*
Structures (residential and non-residential)	2.1 percent	2.2
Machinery (including computers, communication equipment and other machinery)	13.4 percent	0.3
Transport equipment	20.5 percent	0.1
Other assets (including software, other intellectual property products and cultivated assets)	21.9 percent	0

Source: PWT 10.1

In CWON 2024, the PWT capital stock data are expressed in constant 2020 US$ at market exchange rates, using the PWT's investment-specific deflators to bring the data to real terms.

Values for the year 2020, which is not included in PWT 10.0 is estimated using 2020 investment data from the World Bank's WDI and each country's previous year depreciation rate from PWT 10.0.

In the PWT, capital stocks *K* in year t = 0, the first year for which investment data are available for a country, are estimated by assuming an initial capital-output ratio, *k*, such that:

(8.2) $$K_0 = Y_0 \cdot k$$

Initial capital-output ratios Y_0 for all countries are set equal to the median capital-output ratio for all countries and years for which data are available. Initial capital-output ratios vary by asset type (Table 29),

[43] From PWT 8.0 onwards average depreciation rates vary across countries and time, as countries differ in the asset composition of their capital stock and depreciation differs across assets (Feenstra and Inklaar, 2015). This is an improvement upon previously used fixed country and time depreciation rates for each asset class.

with initial stocks of information and communication technology (ICT) assets set to zero, given their short lifespans and small share in total assets.

Table 29: Initial capital-output ratios

Asset	Capital/output ratio *k*
Structures (residential and non-residential)	2.2
Machinery (including computers, communication equipment and other machinery)	0.3
Transport equipment	0.1
Total	2.6

Source: Inklaar and Timmer (2013)

The primary sources of data for capital investment, *I*, by asset type are the:

- OECD national accounts;
- Economic Commission for Latin America and the Caribbean (ECLAC) national accounts; and
- EU KLEMS database.[44]

In the PWT 10.0, for any given year between 1970 and 2019, there are only 18-26 countries for which reported data are available from any of these sources for capital investment by asset type. Capital investment for the remaining 141-149 countries in the PWT 10.0 is estimated using an alternative method. First, data on investment by asset type are taken from the International Comparison Program (ICP) database of the World Bank. The ICP database covers 176 countries and provides investment data for the years 1970, 1973, 1975, 1980, 1985, 1993, 2005, 2011, and 2017. Trends in investment values for in-between years in the ICP data and from 2018-2020 are gap-filled. They are assumed to mimic trends in indirect estimates of investment that are obtained by applying the commodity flow method (CFM), which assumes that investment in an asset varies with the economy-wide supply of that asset, where supply equals to output plus imports minus exports. In the case of structures such as buildings—which can neither be exported nor imported—investment is assumed to be equal to value added by the construction industry, as given in the UN National Accounts, Main Aggregates database for most years[45]. For machinery and transport equipment, data on output are obtained from the UNIDO INDSTAT database. Figures for imports and exports are sourced from the UN Comtrade or Feenstra's World Trade Flows databases. Gaps within individual data series are interpolated linearly. Due to significant year-on-year variation in output and exports, smoothing techniques are then used to eliminate outliers.

[44] http://www.rug.nl/research/ggdc/data/eu-klems-database

[45] For 1970, 1973, 1975, 1980, 1985, 1993, 2005, 2011, and 2017 data on investment in structures are taken from the International Comparison Program database of the World Bank.

In summing investment for each asset type, further adjustments are made to correct for exaggerated or unrealistic investment shares. For any given country and any given year, total investment in structures, machinery, and transport equipment is compared to data on gross fixed capital formation (GFCF)[46]. Investment in each of the asset types is re-scaled according to the ratio of computed investment to GFCF. For example, in 1991, investment computed for Azerbaijan using the CFM is 3.037 times reported GFCF, so investment in each asset type is divided by 3.037.

Investment in computers, communication equipment, software, and other machinery must be further disaggregated from total investment in machinery and equipment. This is done using data on investment in ICT from EU KLEMS, The Conference Board, and WITSA, though data are only available for "a subset of countries."

9.1.2 Complementary approach for countries without PWT data

For countries without PWT estimates of the produced capital stock, the perpetual inventory method is used, but without disaggregating investment by asset type[47]. Instead, a single depreciation rate of 5 percent is applied across all asset types, countries, and years. Also, a so-called "one-hoss-shay" retirement pattern is assumed, so that the value of all assets fall to zero after year 20. In this way, the total capital stock *K* in year *t* is given by:

(8.3)

$$K_t = \sum_{i=0}^{19} I_i(1 - .05)$$

where *I* is total investment, converted to constant US dollars at market rates using country-specific GDP deflators. Total investment is approximated by gross capital formation. For the countries with incomplete series of gross capital formation data, investment series were estimated from data on output, final consumption expenditure (private and public), exports, and imports for the missing years. With this information, the investment series may be derived from the national accounting identity Y=C+I+G+(X-M) by subtracting net exports from gross domestic savings. In all cases, the ratios of the investment computed this way and the original investment in the years in which both series are available are very close to one. Still, to ensure comparability between both investment series, the investment estimates derived from the accounting identity were used only if the country-specific median of these ratios, for the period 1960–2020, was close to one (greater than 0.7 but less than 1.3). For the remaining countries still without complete investment series, data on gross fixed capital formation are used for the missing years. For countries missing complete investment series, produced capital is estimated after adjusting the values obtained using a lifetime assumption of 14–19 years (as the case may be). The adjustment made is that

[46] It is not clear what data sources are used for GFCF, although this is not a problem. Data on GFCF are consistently available for more than 200 countries in the UN National Accounts Main Aggregates database.

[47] There are 7 countries in the balanced CWON 2024 dataset which use alternative investment or growth based estimates for produced capital. These countries are: Guyana, Kuwait, Micronesia, Papua New Guinea, Qatar, Solomon Islands, Tuvalu. There are 46 countries in the total unbalanced dataset with estimates using these approaches.

values obtained using less than 20 years are multiplied with the median of the ratio of capital obtained from 20 years to that obtained from less than 20 years.

Former Soviet states and other newly formed countries present a particular challenge in constructing long-running investment series. Investment series for the post-Soviet states and other European countries missing data are estimated indirectly by extrapolating from trends in neighboring countries for which data are available. Proxy states with full investment series include Bulgaria, Turkey, and Hungary. For these three countries, total investment is summed for a base year (in constant US dollars) and then take the ratio of investment in the base year to investment for the three countries in other years to construct an index. This index is then used to extrapolate investment trends for the countries with missing data. In the end, this method of extrapolating investment by proxy is used to construct estimates of produced capital for only one economy with missing data, Kosovo (in 2014).

Finally, for countries missing data on produced capital stock and investment for only the most recent year or earliest year (2020 or 1995), the average growth rate of the produced capital stock in the 10 earlier years or 10 subsequent years is extrapolated to fill the missing value.

Table 30 lists all the data sources for estimating investment and the stock of machinery, equipment, and structures.

Table 30: Data sources for produced capital

Elements	Data sources and notes
Produced capital stock	• Feenstra, Inklaar, and Timmer (2015) • Data and background documentation for each version of the Penn World Tables (PWT) are available for download (link) • Inklaar and Timmer (2013) outlines the method for PWT capital stock estimates.
Investment	• World Bank, "Gross fixed capital formation (current USD)" (NE.GDI.FTOT.CD), World Development Indicators (WDI) database (link). • World Bank, "GDP (current USD)" (NY.GDP.MKTP.CD), WDI database (link). • World Bank, "Exports of goods and services (current USD)" (NE.EXP.GNFS.CD), WDI database (link). • World Bank, "Imports of goods and services (current USD)" (NE.IMP.GNFS.CD), WDI database (link). • World Bank, "Final consumption expenditure (current USD)" (NE.CON.TOTL.CD), WDI database (link). • World Bank, "Gross capital formation (current USD)" (NE.GDI.TOTL.CD), WDI database (link).

9.2 Urban land

Drawing on Kunte et al. (1998), urban land is valued in CWON 2024 (for the final time)[48] as a fixed proportion of the value of produced capital. Ideally, this proportion would be country-specific. In practice, detailed national balance sheet information with which to compute these ratios was not available. Thus, like Kunte et al. (1998), a constant proportion equal to 24 percent is assumed:

(8.4) $$U_t = 0.24K_t$$

where *U* is the value of urban land and *K* is the produced capital stock (machinery, equipment, and structures).

9.3 Volumes of produced capital

The volume estimates for machinery, equipment, and structures and urban land required for compilation of the Törnqvist volume indexes of produced capital (see Section 2.2.2) and aggregate comprehensive wealth (see Section 2.2.7) are derived as below.

9.3.1 Volume of machinery, equipment, and structures

The volume of machinery, equipment and structures is taken to equal to the variable "cn" (from the PWT 10.0, which is, itself, a Törnqvist volume index of these assets.

9.3.2 Volume of urban land

The volume (area in hectares) of urban land is based on data from the Centre for International Earth Science Information (CIESIN) at Columbia University and the UN Population Division's World Urbanization Prospects. As CIESIN urban land estimates are available only for the years 2000 and 2015, an urban land to population ratio is calculated for 2000 and 2015. This ratio is then linearly interpolated and extrapolated to fill the time series between 1995 and 2020. To estimate urban land area, this ratio is multiplied by urban population for each year between 1995 and 2020. For 3 countries (Monaco, Channel Islands and St. Martin), urban land estimates exceeded total land estimates and so urban land estimate was set to total land.

[48] As noted earlier, CWON 2024 is the last edition in which urban land will be considered part of produced capital. Future editions will treat it as part of natural capital and an improved estimation method will be implemented.

10 Net Foreign Assets

Net foreign assets (NFA) are a measure of the cross-border assets and liabilities held by a country's residents. A country's external asset position, or net foreign assets (*NFA*), is calculated as:

(9.1) $$NFA = FA - FL$$

where *FA* are total foreign assets and *FL* are total foreign liabilities. Total foreign assets are:

(9.2) $$FA = equity_a + FDI_a + debt_a + derivatives_a + forex$$

where $equity_a$ are portfolio equity assets; FDI_a are foreign direct investment liabilities; $debt_a$ are debt assets; $derivatives_a$ are financial derivatives assets; and $forex_a$ are foreign exchange reserves (excluding gold). Similarly, total foreign liabilities are:

(9.3) $$FL = equity_l + FDI_l + debt_l + derivatives_l$$

where $equity_l$ are portfolio equity liabilities; FDI_l are foreign direct investment liabilities; $debt_l$ are debt liabilities; and $derivatives_l$ are derivatives liabilities.

Portfolio equity holdings measure ownership of shares of companies and mutual funds below the 10 percent threshold that distinguishes portfolio from direct investment. Foreign direct investment (FDI) assets and liabilities includes controlling stakes in acquired foreign firms (at least 10 percent of an entity's equity – in practice, however most FDI holdings reflect majority control), as well as greenfield investments. For some countries, FDI is foreign property investments. Debt assets and liabilities includes portfolio debt securities, plus bank loans and deposits and other debt instruments.

Estimates of *NFA* are mostly obtained directly from the External Wealth of Nations (EWN) database (link) developed by Lane and Milesi-Ferretti (2007; 2018). The Lane and Milesi-Ferretti database, last updated in 2021, provides estimates of NFA for 1970-2022 for a total of 212 economies. Lane and Milesi-Ferretti primarily draw upon reported International Investment Positions (IIP) in individual countries' balance of payment (BOP) and IIP statistics, disseminated by the IMF. The sole conceptual difference is the EWN database excludes central bank gold holdings from financial assets (since they are not a claim on another country). Otherwise definitions for each component of NFA are official definitions taken from the IMF's Balance of Payments Manual.

If a country does not have official reporting on the IIP for specific years or entirely, estimates are deduced from reporting of stocks for each component and subsequent, or preceding, reported flows over time for each component. For a small minority of countries that do not publish IIPs, estimates are derived from alternative sources, including partner-country bilateral data from the IMF Coordinated Direct Investment Survey and the IMF Coordinated Portfolio Investment Survey; cumulative flows with valuation adjustments; World Bank and IMF statistics on external debt; UNCTAD statistics on foreign direct investment; and a variety of national sources. These countries are typically Caribbean offshore financial centers (e.g. Bermuda, the British Virgin Islands and the Cayman Islands) or countries with large sovereign wealth funds who have limited financial disclosures (e.g. United Arab Emirates). For further details, country-year metadata is provided with the EWN database.

Table 31: Data sources for net foreign assets (NFA).

Elements	Data sources and notes
NFA	• The External Wealth of Nations Mark II database. Estimates of NFA for 1970-2019 for 214 economies (link), based on methods described in Lane and Milesi-Ferretti (2007).

For a small minority of country-years included in CWON but with gaps in the EWN database, additional data sources and methods are used for extending the coverage of the EWN database to additional countries-years as described in Table 32.[49] First, an extensive reconstruction approach has been developed drawing upon similar alternative data sources to those used by Lane and Milesi-Ferretti, from the following sources: (1) International Monetary Fund (IMF) Balance of Payments and International Investment Position (BOP/IIP) database; (2) IMF Coordinated Portfolio Investment Survey database; (3) UN Conference on Trade and Development (UNCTAD) UNCTADSTAT database; (4) World Bank Joint External Debt Hub; (5) World Bank International Debt Statistics; and (6) Bank for International Settlements (BIS) Locational Banking Statistics.[50]

Reconstructed estimates can then be further extrapolated and interpolated for additional missing country-years (e.g., gap-filling). This is done by regressing trends over time for missing components of *NFA* using data from existing years. The decision rules followed are as follows:

- To extrapolate a time trend for a component of *NFA*, a country must have at least 10 years of data for that component. Missing values may be extrapolated for up to 5 years.
- Only years for which data are available from at least one source in Table 32Table 31 for at least one component may be gap-filled.
- Where overlap exists between the Lane and Milesi-Ferretti estimates of *NFA* and the reconstructed estimates, the reconstructed estimates are screened for quality and consistency. If

[49] The reconstruction approach is only used for a few countries and is data intensive. It is under review by the CWON team and may be discarded in future updates.

[50] Note that in (1), the IMF BOP/IIP database, debt assets and liabilities are the sum of debt securities and other investment. In (6), the BIS data, "total liabilities" are external debt liabilities of counterparties *owed to* reporting banks in the listed country and are thus treated as debt assets; "total claims" are treated as foreign liabilities *owed by* reporting banks in the listed country. Data are reported as of the end of the year or for the fourth quarter.

reconstructed estimates of *NFA* are 25 percent more or less than the Lane and Milesi-Ferretti estimates on average, then the reconstructed time series is discarded.

Table 32: Data sources for reconstructed net foreign assets (NFA) by WB Staff, for country years with missing data in the External Wealth of Nations database.

Elements	Data sources and notes
Equity	• International Monetary Fund (IMF). "Assets, Portfolio investment, Equity and investment fund shares, US Dollars." Balance of Payments and International Investment Position Statistics (BOP/IIP) database (link) • IMF. "Liabilities, Portfolio investment, Equity and investment fund shares, US Dollars." BOP/IIP database (link). • IMF. "Assets, Equity, BPM6, US Dollars." Coordinated Portfolio Investment Survey (CPIS) database (link). • IMF. "Liabilities, Equity, BPM6, US Dollars." CPIS database (link).
FDI	• IMF. "Assets, Direct investment, US Dollars." BOP/IIP database (link). • IMF. "Liabilities, Direct investment, US Dollars." BOP/IIP database (link). • UN Conference on Trade and Development (UNCTAD). "Foreign direct investment: Inward and outward flows and stock, annual, 1980-2014." UNCTADSTAT database (link).
Debt	• Bank for International Settlements (BIS). "Amounts outstanding/stocks, Total claims, All instruments, All currencies." Locational Banking Statistics (link). • BIS. "Amounts outstanding/stocks, Total liabilities, All instruments, All currencies." Locational Banking Statistics (link). • IMF. "Assets, Portfolio investment, Debt securities, US Dollars." BOP/IIP database (link). • IMF. "Liabilities, Portfolio investment, Debt securities, US Dollars." BOP/IIP database (link). • IMF. "Assets, Other investment, US Dollars." BOP/IIP database (link). • IMF. "Liabilities, Other investment, US Dollars." BOP/IIP database (link). • IMF. "Assets, Debt Securities, BPM6, US Dollars." CPIS database (link). • IMF. "Liabilities, Debt Securities, BPM6, US Dollars." CPIS database (link). • World Bank. "External debt stocks, total (DOD, current US$)" (DT.DOD.DECT.CD). International Debt Statistics database (link).

Derivatives	• IMF. "Assets, Financial derivatives (other than reserves) and employee stock options, Financial derivatives (other than reserves), US Dollars." BOP/IIP database (link). • IMF. "Liabilities, Financial derivatives (other than reserves) and employee stock options, Financial derivatives (other than reserves), US Dollars." BOP/IIP database (link).
Forex	• IMF. "Total Reserves excluding Gold, Foreign Exchange, US dollars." International Financial Statistics (IFS) database (link). • World Bank. "24_International reserves (excluding gold)."Joint External Debt Hub (link).

Extrapolated estimates of *NFA* are only used for countries missing data for only a few years in the 1990s, such that a complete time series may be obtained for all years from 1995 or earlier to 2020. Internal gaps in time series for individual components are interpolated linearly. Countries for which *NFA* is reconstructed and extrapolated or interpolated to cover additional years include those in Table 33.

Table 33: Countries and years for which NFA is reconstructed by WB Staff from alternative sources

Country	Years filled
Armenia	1992-1995
Belarus	1992-1993
Croatia	1993-1995
Luxembourg	1994 -2001
Moldova	1991 -1993
Namibia	1987-1988
Romania	1985-1989
Slovenia	1991

Country-years for which there is insufficient data from reconstructed sources but data in the EWN are extrapolated from available EWN data subject to the decision rules described above (Table 34).

Table 34: Countries and years for which NFA is extrapolated from the External Wealth of Nations Database

Country	Years filled
Afghanistan	1997-2001
Bosnia and Herzegovina	1995-1997
Iraq	2000-2004

Marshall Islands	1999-2003
Montenegro	2002-2005
Palau	1995-1999
Tajikistan	1995-1996
Timor-Leste	2002-2004
Tuvalu	1997

Finally, for only two countries with missing data, *NFA* is assumed to be zero based on expert judgment by World Bank staff. These countries include those in Table 35 below.

Table 35: Countries and years with missing estimates of NFA for which NFA is assumed to be zero

Country	Years filled
Iraq	1995-1999
West Bank and Gaza	1995-2018

10.1 Volumes of financial capital

As noted in Section 2, the concept of volume does not apply to financial assets, so these are treated differently in the compilation of the volume index. See Section 2.2.6 for details.

11 Human Capital

This section explains how the lifetime income approach developed by Jorgenson and Fraumeni (1989, 1992a, 1992b) was implemented to estimate human capital wealth. According to this approach, human capital is estimated as the total present value of the expected future labor income that could be generated over the lifetime of the women and men currently living in a country (Fraumeni 2008; Hamilton and Liu 2014).

11.1 Data and methodology

The implementation of the lifetime income approach requires data by age and gender on population, employment and labor force participation, education, earnings profiles, and survival rates. The data sources for each variable are included in Table 36. The estimation is carried out in seven steps, as described this section.

In the equations below, country and gender dimensions of variables are omitted for ease of presentation.

11.1.1 Step 1 - Estimating the Earnings Regressions

The World Bank's International Income Distribution Database (I2D2), a unique database of more than 2,000 household surveys maintained by the World Bank, is the main data source used in construct of a database containing information on the number of people, their age, gender, earnings, educational attainment, school enrolment rates, and employment rates. The I2D2 database lacks cover for for a small number of countries (Angola, Guinea-Bissau, Israel, New Zealand, and Saint Lucia), so it is supplemented with data from three additional sources: the World Bank's Global Labor Database (GLD), the Luxembourg Income Study (LIS), and the New Zealand Treasury. These data are used to estimat Mincerian coefficients (Mincer, 1958) for the relationship between wages and years of schooling and years of work experience. The Mincerian coefficients are estimated as:

(10.1) $$Ln(w_i) = \alpha + \beta_1 e_i + \beta_2 X_i + \beta_3 X_i^2 + \mu_i$$

where $Ln(w_i)$ is the natural log of earnings for the individual i, e_i is years of schooling (from 0 to 24), X_i is labor market working experience (estimated as AGE_i (from age 15 to 64) - e_i - 6), X_i^2 is working experience-squared, and μ_i is a random disturbance term reflecting unobserved abilities. The coefficient β_1 measures the return to an extra year of schooling as the coefficients β_2 and β_3 measure the return to working experience. Since working experience shows a decreasing marginal return, in general, the coefficient β_3 is expected to be a negative value. The constant, α, measures the average log earnings of individuals with zero years of schooling and working experience. Equation (10.1) is estimated for each economy for each survey year for male and female separately.

Table 36: Data Sources for Human Capital Wealth Calculations

Indicator/Variable	Data Source(s)	Notes
Annual earnings	I2D2, GLD, LIS or New Zealand Treasury	Annual earnings are calculated utilizing the Mincerian regression results. The (relative) earnings profile by age, education, and gender is derived for each country and year given the corresponding data availability.
Education attainment	I2D2, GLD, LIS or New Zealand Treasury	Years of education by age and gender are derived for each country and year.
Employment rates	I2D2, GLD, LIS or New Zealand Treasury	The employment rate and self-employment rate by age, gender, and education level are calculated for each country and year. These rates are calculated for employed (or self-employed) persons divided by the whole population, which includes the employed, self-employed, unemployed, and the people out of the labor force.
School enrolment rates	I2D2, GLD, LIS or New Zealand Treasury	This indicates whether an individual by age, gender, and education is enrolled in school or not; used for the probability of remaining employed in future years.
Employment	ILO	The ILO employment data are used as control totals for scaling up employment from the I2D2 database. ILO employment data are also used for filling data gaps when necessary.
Compensation of employees, GDP	United Nations National Accounts database	The Compensation of Employees data are used as input to control totals for scaling up annual earnings estimates from the I2D2 database and for filling the data gaps. In addition, the GDP data are used for expressing variables as a percentage of GDP.
Labor share of earnings of the self-employed	Penn World Table database	Penn World Table estimates of the labor component of the earnings of the self-employed out of total earnings of the self-employed. Used as input to control total labor earnings.
Total labor earnings	United Nations National Accounts database and Penn World Table database	Compensation of Employees plus labor earnings of the self-employed. This combined labor earnings estimate is used as a control total for scaling up earnings estimates from I2D2 to the national level.
Population	United Nations' World Population Prospects	By gender and age groups. The distribution of workers from the I2D2 database is scaled up using the population data.

Survival rates	The GBD study from the Institute for Health Metrics and Evaluation	Survival rates are calculated utilizing the death rates obtained from the GBD study. The GBD database includes global, regional, and national age- and gender-specific mortality for 369 diseases and injuries in 204 countries and territories.

Note: GBD = Global Burden of Disease; GDP = gross domestic product; GLD = Global Labour Database; I2D2 = International Income Distribution Database; ILO = International Labour Organization; LIS = Luxembourg Income Study.

As some countries have data on levels of education (e.g., primary, secondary, tertiary) instead of number of years of schooling a conversion between years of schooling and level of education is required before the Mincerian coefficients may be estimated. In such cases, including the levels of education as dummy variables in the Mincerian equation, the Mincerian coefficients are estimated for each level of education. For example, if a country's schooling data are represented as primary, secondary, and tertiary, Equation (10.1) is converted to the following form:

(10.2) $$Ln(w_i) = \alpha + \beta_{1p}e_{ip} + \beta_{1s}e_{is} + \beta_{1t}e_{it} + \beta_2 X_i + \beta_3 X_i^2 + \mu_i$$

where the subscripts *p, s,* and *t* represent the levels of education (i.e. primary, secondary, and tertiary). Hence, the private rate of return to different levels of schooling (*r*) can be derived from the following equations:

(10.3) $$r_p = \beta_{1p} S_p$$

(10.4) $$r_s = (\beta_{1s} - \beta_{1p}) \; / \; (S_s - S_p)$$

(10.5) $$r_t = (\beta_{1t} - \beta_{1s}) \; / \; (S_t - S_s)$$

where S_p, S_s, and S_t stand for the total number of years of schooling for each successive level.

Wages/earnings profile by age, education and gender, $AIN_{s,a,e}$, can be readily derived for each economy/year using the following equation.

(10.6) $$AIN_{s,a,e} = \exp\left(\alpha + \beta_1 e + \left(\beta_2 + \beta_3 X_{s,a,e}\right) X_{s,a,e}\right)$$

Based on the results of the Mincerian regressions, a matrix of expected earnings, *H*, is constructed. Each cell in the matrix accounts for labor earnings of the population of age '*a*', gender '*s*', and education level '*e*'. If $n_{s,a,e}$ is the number of workers of age '*a*', gender '*s*', and years of schooling '*e*', each cell in the matrix is defined as:

(10.7) $$H_{s,a,e} = n_{s,a,e} \, . AIN_{s,a,e}$$

11.1.2 Step 2 - Scaling Up Earnings and Estimating Labor Earnings of the Self-Employed

For the calculation of human capital, total earnings should include not only wages but also the value of any additional benefits provided to employees, such as social security payments, health insurance, housing or other benefits in cash or in-kind. The earnings profiles from the surveys represent an underestimate of total earnings because they include only wages but not any additional benefits. To adjust for this underestimate, Compensation of Employees from the System of National Accounts (SNA) is used to benchmark survey earnings profiles. In this approach, the relative wages from the surveys matter rather than the absolute level values.

However, there is one more step needed to include all human capital. Total labor income consists of two components: the incomes of the employed and the self-employed. The earnings of the employed workers are included in the SNA under Compensation of Employees. The earnings of the self-employed are included in the SNA under Mixed Income or a more general category, Gross Operating Surplus, which includes all incomes not accruing to employees, mostly returns to capital and natural resources. The estimation of each component, and how they are used to benchmark survey earnings profiles is discussed in this section.

Earnings of employees

The household surveys used for the computation of the earnings profiles—as well as the probability of working—are nationally representative. The surveys are in most cases of good quality, but they may still generate estimates that are not consistent with Compensation of Employees in the SNA. Compensation of Employees includes the economic value of benefits, such as housing or health insurance, in addition to wages, but household surveys typically report only the wages received, thus underestimating total compensation. In some countries, additional benefits, in cash or in-kind, can be substantial. Total earnings from the survey, and the resultant human capital, are expected to be too low in comparison with the share of labor earnings in gross domestic product (GDP) because they do not include other benefits. This is addressed by using Compensation of Employees as part of the control total to scale up earnings profiles from the surveys.

Estimating the labor income of the self-employed

The economic role of the self-employed can be especially important in many low- and middle-income countries where subsistence agriculture and informal economy are very common. However, the earnings of the self-employed are not well represented in the national accounts of many countries because, with few exceptions, Compensation of Employees includes only workers who are formally employed. The earnings of the self-employed are included as part of another category, Mixed Income or Gross Operating Surplus, which also includes income accruing to produced capital and natural resources (resource rents). Earnings of the self-employed workers may also be poorly represented in household surveys.

Correcting this omission requires i) identifying the earnings that can be attributed to the self-employed and ii) distinguishing the labor component of earnings from returns to other factors of production, which are all combined. For human capital estimates, only the labor portion from the earnings of the self-employed should be included. The Penn World Table (PWT) database has made estimates of the labor component of the income of the self-employed (Feenstra et al. 2015), which is described in the following text.

For the purpose of disaggregating the earnings by employment, we used the shares of labor income of employees and self-employed from the PWT data on total compensation of labor except for China where its income group average was used[51]. The PWT data on total compensation of labor construct a 'best estimate' labor share based on four options for adjustment, discussed below, to estimate the shares of labor income of employees and self-employed.

The first two adjustment estimation methods proposed by PWT are used for countries that report mixed income as a separate income category in national accounts, roughly 60 countries. Mixed income isolates total income earned by self-employed workers from resource rents and returns to produced capital by other producers. Mixed income combines both capital and labor income accruing to the self-employed, and can be considered as an upper bound to the amount of labor income earned by the self-employed. The two adjustment methods are:

1) All mixed income is allocated to labor assuming self-employed workers only use labor input.

2) Half of the mixed income is allocated to labor assuming self-employed workers use labor and capital in the same proportion.

The third adjustment method assumes the self-employed earn the same average wage as employees. However, this method has some drawbacks for countries where the share of employees in the labor force is low. Assuming self-employed earn the same average wage as employees will overstate the labor income of the self-employed in those countries. In particular, in most low-income countries agriculture employs about half of the self-employed. This leads to the fourth adjustment method, which is based on the share of agriculture in GDP. Total value added in agriculture is considered a good enough proxy for the labor earnings of the self-employed.

As explained all four methods have some drawbacks, and therefore the Penn World Table data on total compensation of labor construct a 'best estimate' labor share. Adjustments based on mixed income are applied where available since the mixed income captures the income of self-employed. The second adjustment method is preferable since the first adjustment method assumes no use of produced capital by the self-employed. The third and fourth adjustment methods are used if there is no mixed income data and the share of labor compensation of employees is below 0.7.

Total labor earnings

[51] Official data on labor income for China includes income of both employed and self-employed workers.

The PWT database has made estimates of the labor component of the earnings of the self-employed, which we add to Compensation of Employees to produce the control total for total labor earnings to scale up survey-derived earnings profiles by age, gender, and years of education. This approach implicitly assumes that the demographic and earnings profiles of the self-employed are the same as employee workers in formal labor markets. Although we know that is unlikely, there is insufficient data with global coverage to refine treatment of the self-employed at this time.

The total labor compensation (*W*) consists of two parts: (*comp_employ*) + (*comp_self*). By using the PWT data, it can be calculated as the following:

(10.8) $$W = comp_{employ} + comp_{self} = LABSH * GDP$$

(10.9) $$comp_{employ} = LABSH_{employ} * GDP$$

(10.10) $$comp_{self} = LABSH_{self} * GDP$$

where $LABSH$[52] , $LABSH_{employ}$ and $LABSH_{self}$ represent the total labor share (including both employees and the self-employed), labor share of employees and self-employed, respectively. Therefore, $comp_{employ}$ and $comp_{self}$ stand for total compensation of employees and self-employed, respectively.

We also assume that the annual labor income ($AIN_{s,a,e}$) is the same for both employees and the self-employed and is estimated by using information for employees in the I2D2 database (equation 10.6). Then the following adjustment can be made:

(10.11) $$\sum_{s,a,e}\left[\overline{AIN}_{s,a,e} * n_{s,a,e}\right] = W ,$$

where $n_{s,a,e}$, as before, includes the number of people for both employees and the self-employed, and $\overline{AIN}_{s,a,e}$ is the after-adjustment annual income. $\overline{AIN}_{s,a,e}$ is estimated as follows:

(10.12) $$\overline{AIN}_{s,a,e} = \frac{W}{\sum_{s,a,e}\left[AIN_{s,a,e} * n_{s,a,e}\right]} * AIN_{s,a,e}$$

After the lifetime income ($h_{s,a,e}$) for each cell (by gender *'s'*, age *'a'* and education *'e'*) has been derived (as described in step 6), one can apply the I2D2 sample share of the self-employed to the corresponding population data to generate the human capital for the self-employed.

[52] The LABSH variable in the PWT is expressed as a share of GDP at basic prices. Therefore, when incorporated in the human capital wealth calculations, LABSH is multiplied by an adjustment factor, reflecting the ratio of GDP at basic prices to GDP at market prices. Thus, the resulting LABSH is expressed as a share of GDP at market prices and used accordingly in equations (10.8)-(10.10).

In other words, the human capital for total employed (employees + self-employed) is calculated first by using the adjusted annual income profiles as shown in equation (10.12). Then among the calculated total human capital, the part contributed by the self-employed can be separately estimated.

11.1.3 Step 3 - Filling the Data Gaps

Since the estimations rely on labor force and household surveys, it is important to have at least one survey for each year and each country. Unfortunately, this is not the case for most countries. Moreover, some countries have only one survey for the entire period. Therefore, filling the data gaps is a crucial step for the human capital wealth calculations. Even though the current method for filling the gap has some drawbacks, it is useful.

To fill the data gaps, the estimated Mincer parameters and I2D2 sample employment and enrollment rates for the survey year are held constant until the next available survey year, and control totals for earnings for each of the intervening years are used to generate the human capital estimates for the years between two survey years. For example, if there exists only one survey for a country, the parameters of this one survey are used for the entire period. If there exist three surveys (for example, 1995, 2000, and 2010) for 1995–2018, the parameters from 1995 are used for 1995–1999, the parameters from 2000 are used for 2000–2009, and the parameters from 2010 are used for 2010 and onward.

Table 37: Countries and Number of I2D2 Surveys

Survey Count	# of countries
1	29
2	15
3	12
4	14
5	5
6	7
7	6
8	3
9-11	8
12	11
13	15
14-19	10
20 or more	11
Total	**146**

Note: I2D2 = International Income Distribution Database.

Obviously, there are significant problems associated with this method. First, an occasional jump occurs between human capital estimates from a non-survey year to a survey year. For example, if there are surveys for 2000 and 2010, all the data gaps for 1995-1999 are filled with the parameters of the 2000 as the parameters of the 2010 survey are used for filling the gap for 2001-2018. So, a jump could occur between human capital estimates of 2000 to 2001. In addition, if there is only one survey, all the period must be estimated with one survey data and this doesn't allow policymakers to see the effects of policy changes if any.

11.1.4 Step 4 - Scaling Up the Employment and Population

Since the survey data do not capture the whole population, the data from the surveys are adjusted to population estimates from the United Nations to ensure that estimates are adequate.

If $n_{s,a,e}$ is the number of workers of age *'a'*, gender *'s'*, and years of schooling *'e'*, and *P* is the total number of population of a country received from the United Nation's World Population Prospects, the scale parameter α is calculated as:

(10.13)
$$\alpha = \frac{P}{\sum_{s,a,e}[n_{s,a,e}]}$$

Thus, the scaled number of workers of age *'a'*, gender *'s'*, and years of schooling *'e'*, $N_{s,a,e}$, is calculated as:

(10.14)
$$N_{s,a,e} = \alpha * [n_{s,a,e}]$$

11.1.5 Step 5 - Calculating Survival Rates for Each Country

Survival rates utilize death rates obtained from the Global Burden of Disease Study (GBD)[53]. The GBD database includes global, regional, and national age- and gender-specific mortality for 369 diseases and injuries in 204 countries and territories for 1990–2019. Survival rates are calculated as:

(10.15)
$$v_{a+1} = 1 - death_a$$

where v_{a+1} is the probability of surviving one more year at age '*a*', and $death_a$ is the death rate at age '*a*'. Equation (10.15) is calculated for each country for each survey year for male and female separately.

11.1.6 Step 6 - Calculating the Lifetime Income

Two stages in the life cycle of an individual of working age are distinguished: ages 15-24 and ages 25-65. The main assumption here is that individuals ages 15–24 have the possibility to receive further education,

[53] The Global Burden of Disease Study 2019 database is used for the human capital calculations. http://www.healthdata.org/gbd/2019.

while those ages 25–65 are assumed to have no such possibility. Based on this assumption, the lifetime labor income of an individual is calculated as follows:

- Persons aged 25-65

(10.16) $$h_{s,a,e} = p^{m}_{s,a,e} w^{m}_{s,a,e} + p^{s}_{s,a,e} w^{s}_{s,a,e} + d * v_{s,a+1} * h_{s,a+1,e}$$

- Persons aged 15-24

(10.17) $$h_{s,a,e} = p^{m}_{s,a,e} w^{m}_{s,a,e} + p^{s}_{s,a,e} w^{s}_{s,a,e} + \left(1 - r^{e+1}_{s,a,e}\right) * d * v_{s,a+1} * h_{s,a+1,e} + r^{e+1}_{s,a,e} * d * v_{s,a+1} * h_{s,a+1,e+1} \cdot$$

In these equations $h_{s,a,e}$ is the present value of the lifetime income for an individual with age of '*a*', gender *'s',* and education of '*e*', $p^{m}_{s,a,e}$ is the probability to be employed, $w^{m}_{s,a,e}$ is the received compensation of employees when employed, $p^{s}_{s,a,e}$ is the probability to be self-employed, $w^{s}_{s,a,e}$ is the received compensation of employees when self-employed, $r^{e+1}_{s,a,e}$ is the school enrolment rate for taking one more year's education from education of '*e* ' to one-year higher level of '*e+1*', d is the discount factor and v_{a+1} is the probability of surviving one more year.

Equations (10.16) and (10.17) suggest that the lifetime income of a representative individual consists of the current labor income and the lifetime income in the next year. The current labor income is adjusted by the probabilities of being either employed or self-employed, and the lifetime income in the next year is adjusted by a discount factor and the corresponding survival rate. In addition, for an individual aged 15-24, there are two courses of action: first holding the same education level and continue to work, and second taking one more year education and earn income after completing the education.

The probabilities of being either employed ($p^{m}_{s,a,e}$) or self-employed ($p^{s}_{s,a,e}$) can be approximated by the employment rate or self-employment rate for people with age of *'a'*, gender *'s'*, and education of *'e'*. Note that these rates have to be calculated by the employed (or self-employed) persons divided by the whole population that includes the employed, self-employed, unemployed, and the people out of the labor force. The sample ratios from the I2D2 database are used.

The empirical implementation of equations (10.16) and (10.17) is based on backwards recursion. This suggests that the lifetime labour income of a representative individual aged 65 is zero since it is presumed that there is no working life after the age 65. Therefore, the lifetime labour income of a person aged 64 is her current labour income. Likewise, the lifetime labour income of a representative individual aged 63 is sum of her current labour income and the present value of the lifetime labour income of a person aged 64. Hence, the present value of the lifetime income matrix is created for an economy by applying the backwards recursion to equations (10.16) and (10.17).

In CWON 2018 and 2021, human capital was calculated under the assumption that labor earnings would grow at a constant rate over the working lifetime. This approach was discontinued with CWON 2024 due to the inconsistency it created between the estimation of human capital and the value of other capital types, especially natural capital. Since there was no assumption of future growth in the rents attributable to other capital types, the inclusion of the wage growth factor for human capital had the effect of exaggerating the share of total wealth attributable to human capital and downplaying that of other capital types.

Step 7 - Generating the Lifetime Income for All People in an Economy

The calculations from step 1 to step 6 generate the lifetime income profiles for a representative individual cross-classified by age, gender, and education. The lifetime income profiles for a representative individual are multiplied by the corresponding number of people in a country, and thus the human capital stock by age, gender, and education is calculated.

Summing up the stocks of human capital across all classified categories generates the estimate of the aggregate value of the human capital stock for each country:

(10.18)
$$HC = \sum_{s,a,e} \left[h_{s,a,e}\right] * \ pop_{s,a,e}$$

where HC is the human capital stock, $h_{s,a,e}$ is the present value of the lifetime income for an individual with age of '*a*', gender '*s*', and education of '*e*', and $pop_{s,a,e}$ is the population of age '*a*', gender '*s*', and education level '*e*'.

11.2 Volumes of human capital

Ideally, the volume of human capital should be measured by the number of workers segmented by age, gender, and education cohorts to compile accurate value estimates. However, such granular labor force data is not consistently available on an annual basis for all countries in the CWON accounts. Currently, the only available data are estimates for total male and total female workers produced by the International Labour Organization (ILO). While using these figures as a proxy for human capital volumes is technically correct, it results in a volume index that changes minimally over time and is highly correlated with overall population growth. This is problematic because it does not capture important shifts in workforce composition, such as improvements in education and increased workforce experience since 1995.

To address these limitations, we adjust the ILO data by applying the Human Capital Index (HCI) from the Penn World Table (PWT) 10.0. The PWT HCI accounts for returns to education and experience, thus providing a more accurate reflection of human capital quality. By scaling the raw labor force numbers with the HCI, we can approximate changes in workforce composition as education levels improve over time. With these adjustments, real per capita changes in human capital will be driven by three factors: (i) relative wage and nominal value changes, (ii) shifts in labor force participation, and (iii) variations in education levels, which better capture the evolving quality of the labor force.

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