TECHNICAL REPORT: ANALYZING THE DRIVING FORCES OF CHANGES IN NATURAL CAPITAL WEALTH THROUGH DECOMPOSITION ANALYSIS

The Changing Wealth of Nations 2021

Managing Assets for the Future

WORLD BANK GROUP

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Analyzing the Driving Forces of Changes in Natural Capital Wealth Through Decomposition Analysis

by Rutger Hoekstra

Metrics For The Future

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1. Introduction

The World Bank's *Changing Wealth of Nations 2021* (CWON2021) report provides data for natural, human, produced and financial capital for 146 countries (World Bank, 2021). The report provides these wealth estimates for the period 1995 to 2018 which offers valuable insights for policy makers about the development of their country's asset base. The CWON2021 is the latest instalment of a series of World Bank reports which started in 2006 with *Where is the Changing Wealth of Nations* (World Bank, 2006).

In the CWON2021, a new type of analysis has been added for natural capital, both renewable and nonrenewable. The novel "decomposition methodology" helps to understand *why* natural capital wealth is increasing or decreasing. While historical developments of capital stocks are insightful, they do not make clear what the underlying factors are that contribute to the changes in values. What role have prices, costs, discoveries, and depletion played in the value of iron ore reserves? What factors have played a role in the changes to cropland wealth? Decomposition analysis provides a quantitative approach to answer these questions. This analysis helps policy makers to understand the most important variables which are relevant in managing their wealth base.

The decomposition results have been briefly discussed in the CWON2021 (Chapters 3 and 9). This working paper will provide a detailed overview of the methodology and a more extensive discussion of the results. In addition, this report also elaborates on the role that decomposition analysis might play in future editions of the CWON.

To illustrate decomposition methodology, take the example of the asset value of oil reserves. There are various factors (the physical oil reserves, the extracted oil in a year, discoveries of new reserves, oil prices as well as the production costs of drilling) that influence oil's asset value. New discoveries of oil will add to oil wealth. Changes in unit rent will alter the value of oil, but rents are dependent on unit prices and costs. If oil prices increase that will have a positive effect on the value of the reserves. However, if the production costs of drilling increase *more* than the increase in oil prices, the value of oil assets will decline because the unit rent decreases. Finally, extraction of oil has two effects which work in opposite directions. Firstly, additional production increases wealth because revenues are brought forward in time. These income streams will therefore become more valuable because they are discounted less. The second effect is that, since it is a nonrenewable resource, the lifetime of the oil reserves reduces which contributes negatively to the oil wealth. As will be discussed later in this report, this has implications for interpreting comprehensive wealth as a sustainability metric.

This above discussion shows that there are many factors which are simultaneously affecting the value of the oil reserves. It is possible to isolate the quantitative impact of each factor using decomposition analysis. Decomposition has been used extensively in the scientific literature to understand changes in economic development and environmental pressures. Section 2 discusses the literature and explains the basic formulae underlying the decomposition methodology. Chapter 3 provides an overview of all the decomposition results for all types of natural capital. Chapters 4 and 5 go deeper into the nonrenewable assets and renewable natural resources respectively. Section 6 draws conclusions, while Chapter 7 provides suggestions for future work on decomposition analysis of wealth estimates.

2. Decomposition Analysis

2.1 Literature

There is a long history of using decomposition analysis to understand the driving forces of economic development and environment pressures.[1] It has been used to understand changes in the economy such as employment and other economic variables. But starting in the 1970s, decomposition has also been applied to analyze macroeconomic changes related to environmental pressures such as carbon emissions, energy use, raw material use, water use, and so on. These environmental decompositions are used to isolate the effect of changes in economic growth, economic structure, production technologies, consumption patterns, changes in the energy mix, recycling rates, globalization, and many other factors. There are various distinct methodologies in macroeconomic decomposition with names such as Index Decomposition Analysis (IDA) and Structural Decomposition Analysis (SDA) which will be further discussed below.

Before the mathematical aspects of decomposition are discussed, a couple of examples from the literature are used to illustrate the insights which can be obtained. An example of an IDA[2] is Mohlin et al. (2019), which analyses the United States CO_2 emissions from the power sector. Emissions from this sector increased over the period 1990–2005 and peaked soon after. By 2015 they had declined by 20% compared to 2005. They found "the two main factors driving the CO_2 decrease were natural gas substituting for coal and petroleum, and large increases in renewable energy generation (primarily wind)—which were responsible for 60% and 30% of the decline respectively since 2005." These quantitative statements, which link the underlying factors to the changes in environmental pressures, are typically for the decomposition literature.

In the case of SDA, which is based on input-output modelling (Miller & Blair, 2009), the decomposition can also include final demand categories such as household and government consumption and investments. For example, Peters et al. (2007) analyzed China's CO_2 emissions and found that "…infrastructure construction and urban household consumption, both in turn driven by urbanization and lifestyle changes, have outpaced efficiency improvements in the growth of CO_2 emissions." The article quantifies these effects and provides evidence for the importance of the various factors.

A recent application of SDA has been to analyze the influence of globalization on environmental pressures. These types of application have become prevalent since the availability of global input-output databases has improved[3]. An example of such a decomposition is Hoekstra et al (2016) [4] which quantifies the underlying factors that have driven global CO_2 emissions (e.g. growth, outsourcing, technological

[1] For an early overview of SDA (both economic and environmental), see (Rose & Casler, 1996) which also explores similarities with another type of decomposition called shift-share analysis. See Hoekstra and van den Bergh (2002), Su & Ang (2012) for overviews of environmental SDA. For a recent overview of environmental IDA&SDA see Wang, Ang, & Su (2017).

[2] An Index Decomposition Analysis (IDA) uses macroeconomic data but does not adopt the input-output (IO) model. Decomposition analyses that use the IO are referred to as Structural Decomposition Analysis (SDA).

[3] An overview of these types of global input-output databases such as WIOD, EXIOBASE, EORA is provided by Tukker & Dietzenbacher (2013).

[4] This paper was part of a special issue of *Economic Systems Research* (2016, Issue 2) on Structural Decomposition Analysis (SDA) applied to global input-output tables.

improvements). Changes in global value chains in the 1990s and 2000s have meant that production shifted from developed countries with cleaner technologies, to countries with more CO_2 intensive technology, such as China. The paper shows that the net effect, referred to as the "Environmental Cost of Sourcing" (ECS), amounted to an 18% increase of total global CO_2 emissions for the period 1995-2007. The decomposition analysis, therefore, enables the quantification of the detrimental global impact of "carbon leakage" which occurs when developed countries outsource their production to low-wage countries.

To date, the environmental decomposition literature is dominated by analyses of flow variables such as emissions, waste, material use and water use. Decomposition analysis of stocks, such as the changes in natural capital wealth are rare.[5] The decomposition methodology presented in this report, is to the best of our knowledge, a novel addition to the tools to inform decision making about managing natural capital.

2.2 Methodological Basics

Decomposition analysis starts with a specified mathematical relationship. Assume that the variable *x* is the product of *y* multiplied by *z* as shown in the equation below.

$$x = y \cdot z$$

Assuming that *y* and *z* are independent, changes in variable in *x* can be directly linked to the changes in *y* and *z*. This can be expressed by the following formula (using the product rule):

$$\Delta x = \Delta y \cdot z + y \cdot \Delta z$$

Where

$$\Delta x = x_t - x_{t-1}$$

$$\Delta y = y_t - y_{t-1}$$

$$\Delta z = z_t - z_{t-1}$$

To calculate the equation $\Delta x = \Delta y \cdot z + y \cdot \Delta z$ in discrete time, a weighting methodology is adopted. The literature provides many options and theoretical rationales (Hoekstra & van den Bergh, 2003). A frequently used decomposition is called the Sun-Dietzenbacher-Los decomposition, which provides a "complete" decomposition in the sense that there is no residual term (Dietzenbacher & Los, 1998; Sun, 1998). In the case of a two-variable multiplicative decomposition the formula is as follows (following Sun's derivation)[6]:

[5] We have been able to uncover only two examples. The SEEA Central Framework (UN et al., 2017) provides a theoretical discussion without empirical application. The only publication we could find that has a real-world application is a brief chapter of the *Changing Wealth of Nations* (World Bank, 2010). In this application a slightly different decomposition specification is used to the one presented in this report. This publication also provided some specific formulae to decompose crop wealth.

[6] The formula splits the residual term equally amongst the underlying factors. For a 2-factor decomposition that is half, but the formula becomes more complex as the number of variables increases (Sun, 1998). Note that when we are considering the changes over a 10-year period this could be done by analyzing 1) the entire period 2) annual time steps. The latter is preferable because it adds information about the development path which is why the annual data of the CWON2021 are used.

$$\Delta x = \underbrace{\left(\Delta y \cdot z_{t-1} + \frac{1}{2} \cdot \Delta y \cdot \Delta z\right)}_{\text{Effect of } \Delta y \text{ on } \Delta x} + \underbrace{\left(\Delta z \cdot y_{t-1} + \frac{1}{2} \cdot \Delta y \cdot \Delta z\right)}_{\text{Effect of } \Delta z \text{ on } \Delta x}$$

For the sake of regularity, the following in this report:

$$\Delta x = D^{\Delta y} + D^{\Delta z}$$

Where

$D^{\Delta y}$ – Effect of Δy on Δx

$D^{\Delta z}$ – Effect of Δz on Δx

Figure 1 visually represents the above decomposition. The figure also shows that additional underlying factors can be brought into play if y and z have further underlying variables (for example if $y = y_1 \cdot y_2$ and $z = z_1 \cdot z_2$). This type of "nested decomposition" is used in this report.

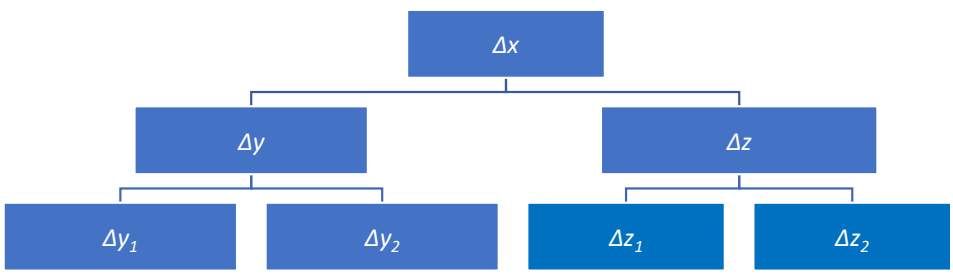

Figure 1. A nested decomposition

2.3 Decomposition of Natural Capital

In the CWON2021 there are 11 categories of natural capital. The specific formula for each type differs slightly, however, there is a common foundation which defines the future value as a resource rent annuity:

$$V_t = R_t \cdot \left(1 + \left(\frac{1}{r} \cdot \left(1 - \frac{1}{(1+r)^{T_t - 1}}\right)\right)\right)$$

$$R_t = q_t \cdot \pi_t$$

Where

V_t– Value of an asset in year t

R_t– Rent in year t

q_t– Production in year t

π_t– Unit Rent in year t

T_t– Lifetime of resource in year t (In the CWON, the maximum lifetime is 100 years).

r – Fixed discount rate (4%)

Decomposing the formula into three parts gives you (see figure 2 for a graphic depiction).

$$\Delta V = D^{\Delta q} + D^{\Delta \pi} + D^{\Delta T}$$

Where

$D^{\Delta q}$ – Effect of changes in volume on changes in wealth

$D^{\Delta \pi}$ – Effect of changes in unit rent on changes in wealth

$D^{\Delta T}$ – Effect of changes in lifetime on changes in wealth

The full decomposition formulae for this base case are provided in Annex 1.

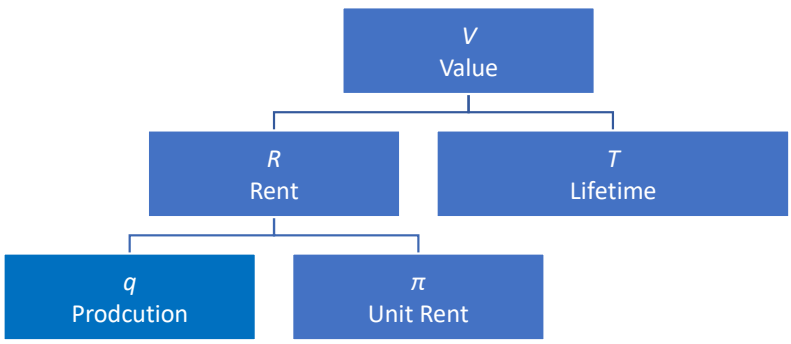

Figure 2. Nested three-part decomposition of natural capital

Figure 2 implies that there are three decomposition factors:

1. *Production effect*. The effect of the changes in the rents due to changes in the prodcution q (which could be phsyical factors such as area, resources extracted, harvested or used). For example, if the extraction of oil rises and eveything else stays the same, wealth will increase because of a rise in rents.
2. *Unit rent effect*. The effect of the changes in the rents due to change in the unit rent π. If the unit rent increases it leads to an increase the value of natural capital.
3. *Lifetime effect*. Changes in the lifetime of the stock will affect the value of the asset. In the case of renewable natural resources with an infinite lifetime, or resources for which there is more than 100 years of supply, the decomposition effect is 0.[7] However, if the lifetime of a nonrenewable resource (e.g. oil) drops from 25 years to 24 years, then the value of the resource also diminishes.

[7] The CWON2021 calculations cuts off the wealth calculations at 100 years. For a renewable resource which has an infinite lifetime or more than 100 years, the maximum is therefore set at 100 years.

These are the biophysical limits of a finite stock. Note, the lifetime effect does not automatically have to be negative because discoveries of nonrenewable resources increase the size of the physical stock.

For some natural capital stocks it is possible to further decompose the value changes in underlying factors. For example, unit rents can be further decompsed into unit prices and unit costs. Section 3 will first discuss the results of the three-part decomposition, before proceding towards more detailed analysis of changes in natural capital.

3. Results Overview

Table 1 presents the results for the three-part decomposition shown in Figure 2. The table shows the value of natural capital in 1995 and 2018 as well as the contribution of the three decomposition effects to the increase/decrease in natural capital wealth. Overall, the value of natural capital increased by 68%, with renewables increasing by 38% but nonrenewable assets by 129%.

All production effects are positive, except for a small negative effect for mangroves. This production effect, which quantifies the role of increasing biophysical use of a resource, is the biggest positive contributor to changes in wealth. Only in the case of forests (ecosystem services), mangroves and fisheries is the production effect not the largest factor.

The overall unit rent effect is positive but the size and sign does vary significantly per type of natural capital stock. For natural capital assets which are linked to food (crops, livestock and fish) the unit rent effect is significantly negative. The other negative unit rent effect is for metals/minerals (this will be explored further in the next section in terms of the underlying metals/minerals and their price and cost dynamics).

The table shows that for many natural capital assets, the lifetime effect is 0. This is because for many resources the lifetime is infinite or larger than 100 years and the impact on assets value is therefore non-existent. For nonrenewable assets such as metals and minerals, the lifetime effect is positive, which indicates that the discoveries or other addition to stock are contributing to wealth increases.

Table 1. Three-part decomposition natural capital (1995-2018, global)

		Rent effect			
	1995	Volume effect	Unit rent effect	Lifetime effect	2018
Natural capital	38,409	22,120	5,381	–1,370	64,542
Renewable natural capital	25,776	9,456	2,013	–1,660	35,586
Forests, timber	2,544	239	99	–154	2,728
Forests, nontimber	4,879	91	2,487	0	7,458
Mangroves	213	–13	348	0	548
Fisheries	1,225	62	–1,080	0	207
Protected areas	1,927	971	849	0	3,747
Cropland	10,631	6,018	–456	–1,506	14,687
Pastureland	4,356	2,088	–233	0	6,211
Nonrenewable natural capital	12,633	12,665	3,368	290	28,956
Oil	9,588	6,345	3,363	–188	19,108
Natural gas	1,090	1,695	559	–55	3,288
Coal	949	2,150	383	0	3,482
Metals and minerals	1,007	2,475	–937	533	3,078

Unit: Constant 2018 USD (millions)

Reproduction of Table ES.1 in CWON2021

Table 1 provides the overall decomposition results for the 1995-2018 period but Figure 2 shows that the decomposition effects differ significantly over time. The figure uses 5-year time steps and the decade from 2000-2010 is clearly a significant period, where the volume and unit rent effects provide the greatest contribution to increases in wealth. However, the unit rent effect started to reverse in the 2010-2015 period and its contribution became even more negative after 2015. Figure 4 shows that the production effect heavily dominates in upper/middle income countries. In the latter sections, the changes in renewables and nonrenewable natural capital stocks will be further analyzed, in terms of both time and regions.

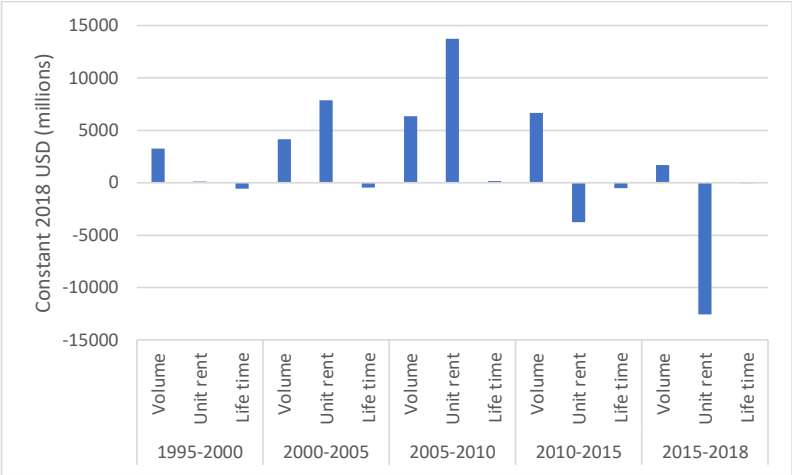

Figure 3. Decomposition for natural capital (5-year periods, global)

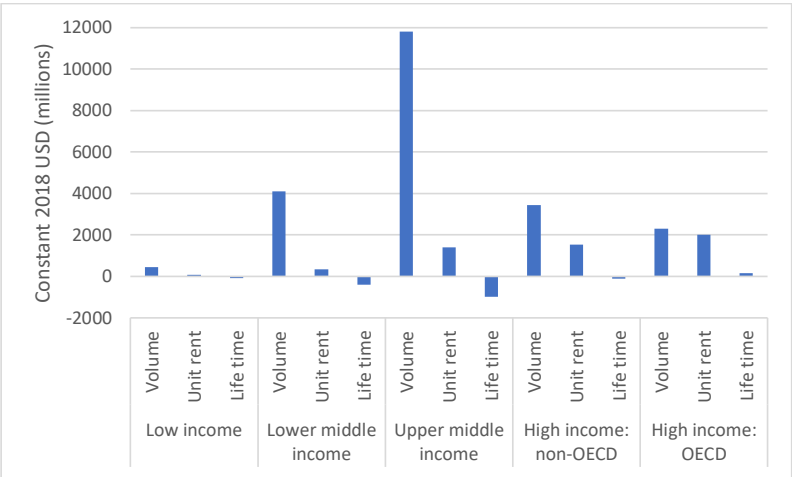

Figure 4. Decomposition for natural capital (1995-2018, per income group)

4. Nonrenewable Natural Capital

4.1 Decomposition

In this section, fossil fuels (coal, gas and oil) and metals/minerals (10 types) are each decomposed in a nested decomposition shown in Figure 5. The figure shows that the unit rent effect, which is distinguished

in Figure 2, is further decomposed into a unit price and unit cost effect. Additionally, the lifetime effect is split into stock and production effects. The formulae for these are provided in Annex 1.

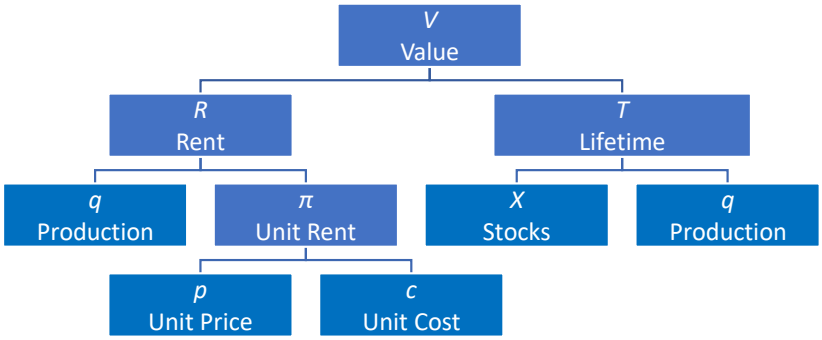

Figure 5. Nested decomposition for nonrenewable natural capital

4.2 Overall Developments

The five-part decomposition results for the 1995-2018 period are shown in Figures 6 and 7 for total fossil fuels and metals/minerals respectively. The "waterfall" figures, which is frequently used to illustrate decomposition results, shows asset wealth for the year 1995 in the left bar. The decompositions effects are added and subtracted (every bar started where the previous bar ends) to finish at the level of 2018.

Fossil fuel wealth more than doubled in the period 1995-2018 in real terms. Increases in extraction has had the largest positive effect on the changes in wealth. The reason is that when extraction increases this will lead to more revenues being brought forward in time. Given that the discount rates lead to a lower valuation of rents in the future, the value will increase if extraction speeds up. However, speeding up production also simultaneously has a negative effect because when extraction of a nonrenewable resource increases, the lifetime of the asset drops. The results show that the net effect is positive. Note that this net production effect will decrease if the discount rate is assumed to be lower than 4%.

Overall, the net production effect is counterintuitive from a sustainability perspective. It seems to suggest that policy, aimed at increasing wealth, should strive towards *increasing* fossil fuel extraction, while climate policy should be aimed at *reducing* it.[8] This counterintuitive interpretation shows the difference between a narrow vision looking at a single-capital stock rather than a broader sustainability perspective which includes environmental externalities. Further research could investigate the effect of discount rates, the incorporation of the social cost of carbon or creating an indicator that is founded on the idea of strong sustainability rather that weak sustainability. Section 7.1 discusses these potential strategies which might be explored in the next CWON.

The stock effect, the increase in physical stock of nonrenewable assets, also has a positive effect on wealth changes. This suggests this is due to discoveries of new fossil fuel resources. However, it may also be an

[8] This is because the production effect will *always* exceed the lifetime effect because of discounting.

artifact of the data. The data related to the "stock" of natural resource is dependent on geological, economic, and administrative conventions. A closer look at the data for some of the largest oil producing countries and conversations with experts make it seem plausible that fossil fuels stocks are partially influenced by administrative adjustments, rather than "real" increases in stock due to new discoveries. This means the stock effect might overstate the "real increase in physical stocks". The current data does not allow for a distinction between discoveries/depletion as opposed to changes in administrative registration. For fossil fuels it does not have a major effect on the results.

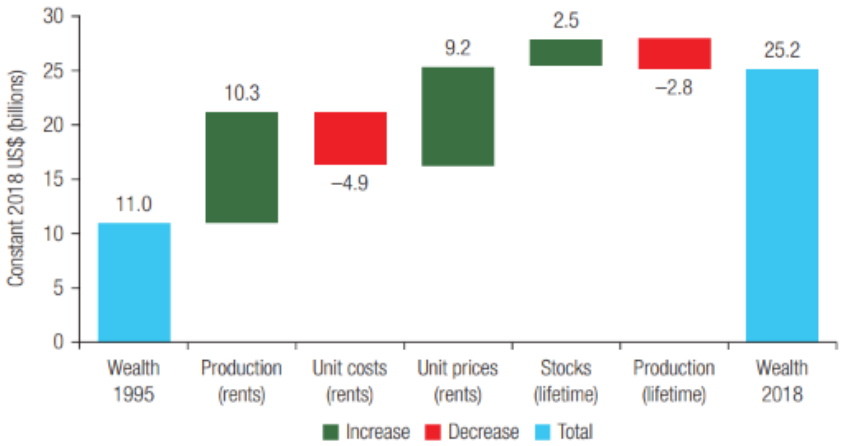

Figure 6. Decomposition for fossil fuels (1995-2018, global)

Reproduction of Figure 9.16 from CWON2021

Rising unit prices play a major role in explaining the increase in fossil fuel wealth. On the other hand, increases in the unit costs have contributed to lowering the value of fossil fuels reserves. This could be caused by the fact that, as resources are depleted, the costs increase because the easy-to-mine fossil fuels are exploited first. However, it may also be due to other production costs increasing (materials, labor or other production factors, safety and environmental regulations). The net effect on rents remains positive because the price effects outweigh the cost effects.[9]

Turning to metals/minerals wealth, Figure 7 shows that total wealth more than tripled over the 1995-2018 period. However, compared to fossil fuels, which represent around 29 billion in 2018 (2018 US$), this is a much smaller asset base. One striking difference with fossil fuels is the sign of the unit price effect. While, price increases play a major role in explaining the wealth changes for fossil fuels, the prices levels for metals and minerals have been contributing to decreasing wealth. It also seems that increasing mineral stocks have much greater effect in explaining growth in wealth, than for fossil fuels. Again, it is not known to what extent these are true discoveries rather than administrative changes.

[9] Note also that the costs do not yet include real carbon taxes (which are levied where the fossil fuels are used) or even hypothetical social costs of carbon. Including these would change the wealth/decomposition results.

When considering the overall developments, it is important to keep in mind that fossil fuels are interconnected because they compete in global markets for final energy. However, metals and minerals end up in far more varied end markets Demand, supply and many other market characteristics consequentlyvary significantly. It is therefore important to take a closer look at the individual fossil fuels and metals/minerals. Table 2 summarizes the decomposition results for all the various fossil fuel and metal/mineral assets.

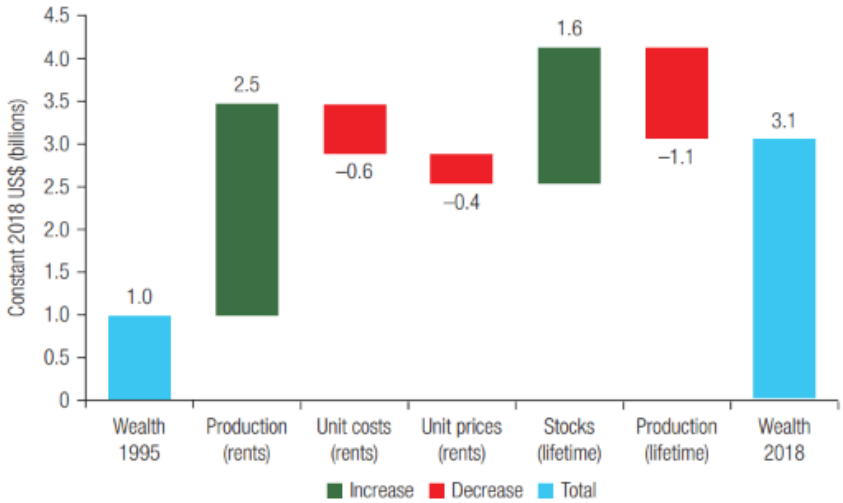

Figure 7. Decomposition for metal and minerals (1995-2018, global)

Reproduction of Figure 9.17 from CWON2021

Table 2 shows that the fossil fuel results are dominated by the oil assets. Roughly speaking, the value of oil assets doubles and the asset value of gas and coal triples/quadruples. All fossil fuels are heavily dominated by the production effect, although the exception is brown coal wealth, which was boosted primarily by price effects.[10] Price and cost effects are important for oil and gas and brown coal but less important for hard coal.

Table 2 shows that half of the increase in metals/minerals wealth can be accounted for by iron ore with a smaller role for copper, phosphate and gold. The rest of the metals and minerals have a small effect on the total wealth estimates.[11] The impact of production and stock effects are consistent over all categories.

[10] The CWON does not publish results for brown coal and hard coal separately, but the source data does allow for a separate decomposition of both types. 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 5,700 kcal/kg (UN-ECE, 1988).

[11] Note that phosphate and tin start off with no value in 1995. This is not because there has no production of these resources, but rather because rents were negative (i.e. costs outweighed prices). The CWON methodology is such that wealth estimates are then assumed to be zero for those years.

The cost and price effects are, however, vastly different. Increasing costs had a negative effect on five metals (copper, gold, lead, silver and tin) and reducing prices had a negative impact on wealth for three metals/minerals (bauxite, iron ore and tin). For the most important metal, iron, the increase in production and stock have had the greatest effect. But the price of iron has dropped which has depressed wealth significantly. Bauxite is the only resource which saw a decrease in wealth. This is primarily due to price declines.

Table 2. Five-part decomposition for natural capital (1995-2018, global)

	1995	Production Effect	Unit Cost Effect	Unit Price Effect	Stock Effect	Production Effect	2018
Nonrenewable natural capital	12,633	12,665	-5,708	9,076	4,216	-3,926	28,956
Fossil Fuels	11,626	10,189	-5,132	9,437	2,622	-2,864	25,879
Oil	9,588	6,345	-3,772	7,135	1,374	-1,562	19,108
Natural gas	1,090	1,695	-1,436	1,995	365	-419	3,288
Coal	949	2,150	76	307	883	-883	3,482
Coal-Hard	805	2,066	79	-82	798	-798	2,868
Coal-Brown	143	84	-3	390	84	-84	614
Metals and minerals	1,007	2,475	-576	-361	1,595	-1,062	3,078
Bauxite	133	53	49	-135	14	-19	95
Copper	201	426	-319	336	264	-213	695
Gold	213	121	-460	540	70	-95	389
Iron ore	367	1,457	118	-1,098	1,081	-526	1,398
Lead	6	17	-18	36	17	-14	43
Nickel	47	69	54	-126	60	-49	56
Phosphate	0	248	45	7	32	-88	244
Silver	11	26	-41	59	24	-20	59
Tin	0	5	-7	14	-4	1	8
Zinc	29	54	3	7	37	-40	91

Unit: Constant 2018 USD (millions)

4.3 Price Volatility and Wealth

Wealth estimates reflect long-term value of a country's assets and are not supposed to fluctuate with market prices or production. This is why a 5-year moving average of total rents is used to calculate wealth in the CWON2021. However, even with this moving average, the volatility differs per variable and decomposition illustrates this. Figure 8 provides the annual decomposition effects aggregated for all types of nonrenewable assets (fossil fuels and metals/minerals). The results will therefore be dominated by the results for oil. The figure shows that most decomposition effects are fairly stable. The main exception is the price effect which is the most significant driver of wealth, both in a negative and positive direction. The prices for many commodities increased between 2000 and 2012, and thereby contributing to

significantly higher nonrenewable asset wealth. Price decreases after that period are largely responsible for lower wealth estimates.

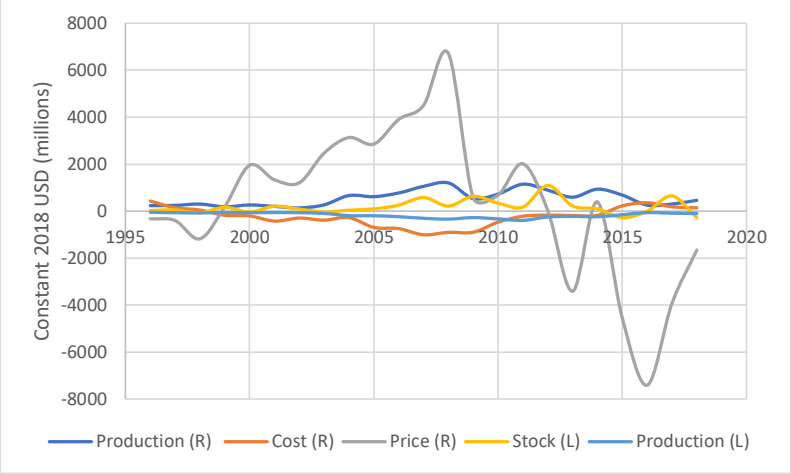

Figure 8. Decomposition for nonrenewable natural capital (annual, global)

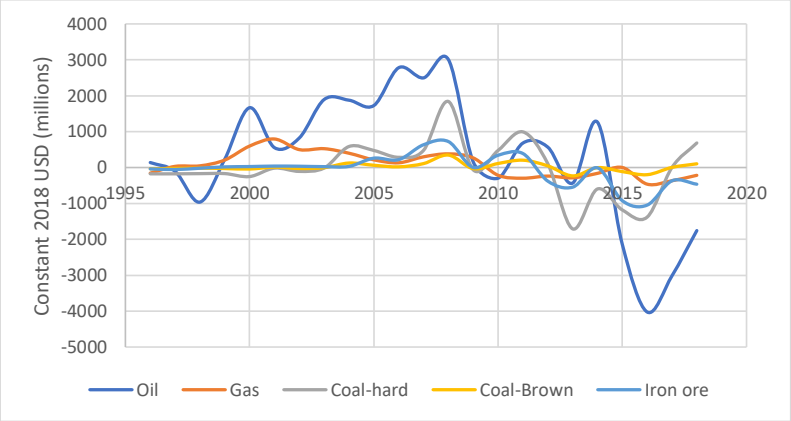

Figure 9. Unit price effects for high-wealth nonrenewable natural capital (annual, global)

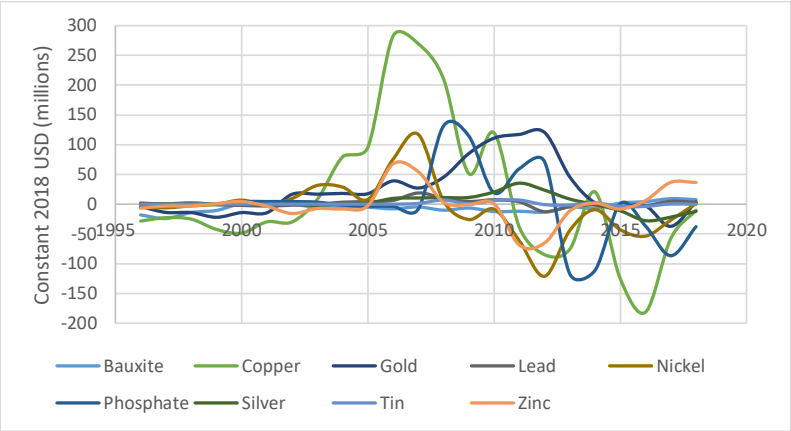

Figure 10. Unit price effects for low-wealth nonrenewable natural capital (annual, global)

Figure 9 and 10 takes a closer look at the price effects of individual resource types. Figure 9 focusses on the price effects for fossil fuels and iron ore. Iron ore is added because these are the largest nonrenewable assets and are shown on a different scale to the "smaller" ones (Figure 10). Although the precise timing does differ, the pattern is unmistakable. Increase in prices start to contribute to rising wealth in the period around 2000 and start to become negative in the years after the financial crises of 2008-2009. The exact timing of the increase and decrease may differ, but the overall pattern repeats over all nonrenewable commodities.

While wealth calculations are meant to stimulate long-term policies, short term volatility often forces governments to act in ways that are not conducive to this goal. While the wealth calculations have already smoothed out volatility through the moving average, the decomposition still reveals which are the most important sources of wealth volatility. Policies that target these particular sources of volatility (e.g. long term price contracts) could help the shift towards more long term policies and make governments less prone to short-termism.

4.4 Energy and Circularity Transitions

The decomposition results make clear that nonrenewable assets experience different economic pressures as technological changes, supply and demand vary per natural capital type. In some cases, the assets may be servicing a dominant market (e.g. fossil fuels in the energy market), while in other cases they may not be competing at all. That makes it important to view the decomposition results in the context of the market developments that are likely in the coming decades. Society is set for a major transformation as public, political and scientific pressure mounts to tackle global environmental issues such as climate change. Two major transitions, that are interlinked, are frequently mentioned in this regard: 1) the energy transition away from fossil fuels towards renewables, and 2) the transition to a "circular economy" to improve society's use of the materials by recycling, recovery, re-use and redesigning of products.[12]

[12] https://www.worldbank.org/en/news/feature/2021/05/24/transitions-at-the-heart-of-the-climate-challenge

Given these transitions, it is useful to think of the decomposition effects and how they may develop over time. In terms of the energy transition there are a couple of different effects which could contribute to lower fossil fuel wealth. Long term oil prices are declining from their highs in 2008, despite the recent post-COVID spike. On average the decomposition results show the costs of extraction is increasing and might be expected to increase in future. At the same time, it might be expected that exploration of new fossil fuel resources will slow down as the shift to renewables intensifies. This might lead to a larger percentage of the stock being categorized as a stranded asset, which thereby diminishes the stock which can reasonably be expected to be mined (also called proven reserves) and therefore lifetime of the resources (Manley et al., 2017). These developments will mean the decomposition effects for physical stocks will depress fossil fuel wealth, going forward.

Countries that are part of Organization of Petroleum Exporting Countries (OPEC) do have levers with which they can manage the underlying factors which influence oil wealth. OPEC influence prices by agreeing on production levels of its members. They thereby influence other parts of the energy market, such as natural gas, which shows similar price developments. In future, it may be expected that OPEC will have less ability to set prices and production as alternative sources of power become more prevalent. Carbon taxation or subsidies on electrical vehicles will also lead to demand shifting away from fossil fuels. OPEC countries might be able to still keep prices high by reducing production, but high prices will make investments in renewables attractive, undermining long-term demand.

The energy transition will also have consequences in metals/mineral wealth. Some of these materials will be a vital part of battery packs for electrical vehicles or for large scale energy storage. There are various chemistries which can be employed, based on lead, iron, lithium, cobalt, nickel, iron and phosphate (Kirsten Hund et al., 2020). It is currently uncertain what the dominant technology will be and the major player in this field, Tesla, is betting on multiple chemistries. This provides them a flexible base upon which they can profit off price differences and market differences in terms of vehicle range and charging times. As electrical vehicle production scales, the exploration, production and perhaps prices would be expected to increase. It might also become interesting for wealth accounts to start tracking some other metals/minerals such as rare earth metals as they become economically important in this transition.

Apart from the energy transition, the transition towards a “circular economy” is increasingly popular in policy circles. The goal of “circularity” is to reduce the amount of resources being used in the economic process, through recycling, redesigning, reusing and reducing materials and products. These efforts will probably have some effects on demand for fossil fuels as well as metals/minerals (and perhaps also wood/paper as substitutes are sought for plastics). However, it should be noted, in many advanced countries recycling rates are already up to 30-50% and metal scrap already has a market-price.[13] It is not entirely clear how the acceleration towards a circular economy would affect the overall wealth, either price, production or other effects. Fossil fuel wealth may also be affected by the circular economy as many chemicals, plastics and other materials are made from fossil fuels. Policies to reduce the use of these materials will therefore also lower demand for these resources on top of the effects of the energy transition.

Renewable natural resources such as wood are also likely to be affected by the energy and circular transition. Biofuels are stimulated as a source of energy in some developed countries (and it remains a

[13] See for the United States: https://www.usgs.gov/centers/nmic/recycling-statistics-and-information

major source of energy in homes in the developing world). Wood is also a viable alternative for many of the structural applications of plastics and metals. The transitions are therefore likely to enhance the value of these assets due to price or production increases.

4.5 Focus on Specific Countries

The underlying factors that are contributing to wealth can differ significantly per country. Figure 11 provide details about the top-five countries in terms of fossil wealth (based on data for 2018). Note that top-five countries represent a sizeable portion of fossil fuel wealth. For oil and gas around 60% of wealth is in the top-five countries. For both hard and brown coal it is closer to 90%. The concentration is further accentuated by the dominance of leading countries. Saudi Arabia represents 26% of oil wealth in 2018, Russia 31% of gas wealth, China 42% of hard coal wealth and the United States 68% of brown coal wealth according to the CWON2021 data.

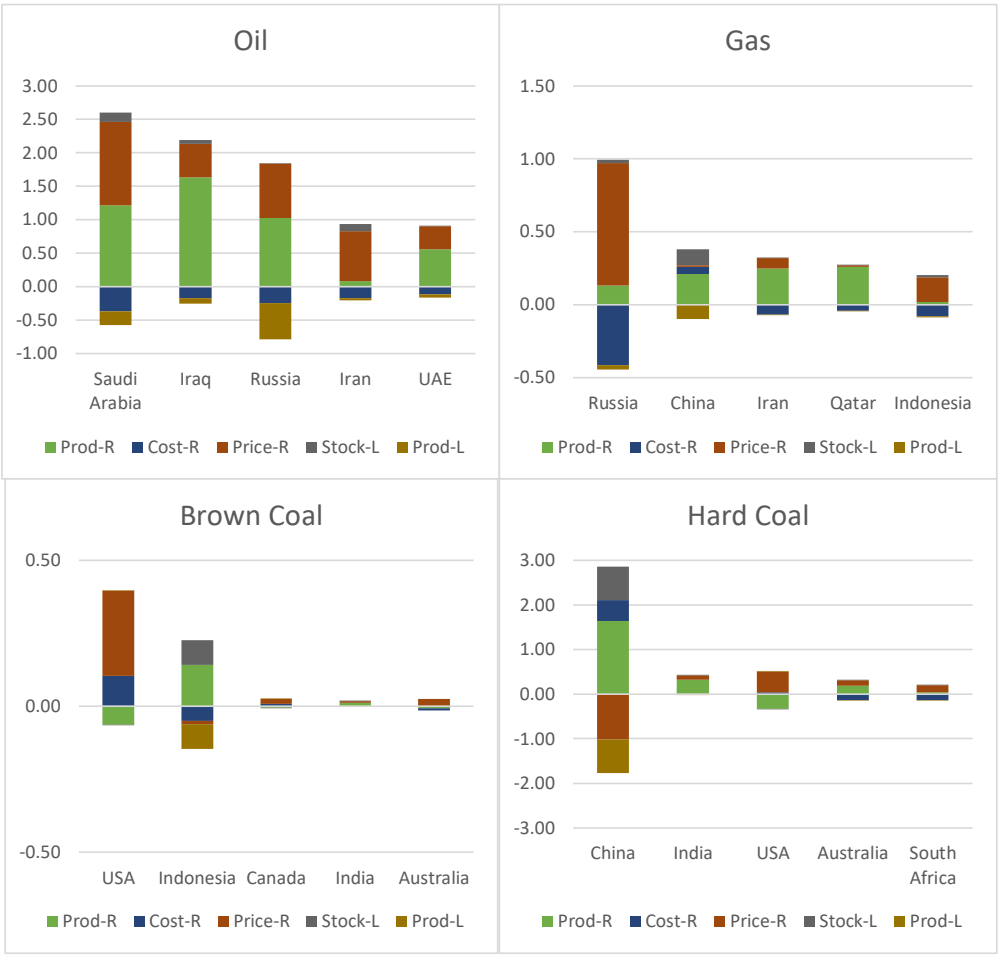

Figure 11. Decomposition for fossil fuel (1995-2018, Top 5 countries)

Unit: Constant 2018 USD (billions)

The dominance of just a couple of countries implies that the global results are heavily dominated by the development in these countries. Countries can have differences in terms of production, exploration, cost structures or responding to price changes in the market. Figure 11 shows that the developments in the top countries are very similar in oil, but less coherent for the other fossil fuels. For oil, the signs of the decomposition effect are all consistent, only varying in relative importance per country. For gas and both types of coal, the decomposition effects vary significantly, both in terms of sign and magnitude. For example, the wealth of Russian gas has been negatively affected by increasing unit costs, while this effect is less profound in other countries. In fact, in China, the unit cost effect is positive, indicating lowering costs.

These results suggest that the policy implications are very different per country. For example, the impact of unit cost may be a geological feature, or a reflection of economic factors such as labor costs. In the case of geological conditions this will also be an indication of where assets will be classified as "stranded" first. Fossil fuel reserves that cannot earn a sufficient return will remain untapped.

The results also suggest that there will be geo-political implications of shifts in natural capital wealth as the energy and circularity transitions affect the resources differently. Various countries will see their wealth increase due to price or production developments. This will change the geo-political power structures away from certain regions and countries and organizations, such as OPEC. It might also mean that there are new countries and companies that become more powerful. Raw materials that are needed for electrification stand to become even more valuable while fossil fuel wealth will dimmish. Diplomatic attention will start to also shift from certain regions to others.

5. Renewable Natural Capital

5.1 Decomposition

The CWON distinguishes seven renewable resources: cropland, pastureland, forests (2 types: wood and ecosystem services), protected areas, mangroves and fisheries. All these natural capital stocks are in some way conceptually related to land area (and/or water). However, not all the renewable capital stocks distinguish land area as a variable in the underlying calculation.

For those that distinguish land in the underlying estimation (protected areas, forest- ecosystem services and mangroves) the decomposition shown in Figure 12 is used. In these cases, the lifetime effect is zero because the asset is assumed to be limitless in the calculations. For the other natural capital stocks (cropland, pastureland, forests (timber) and fisheries), the production levels are used as a basis for the decomposition (Figure 13). In some cases, e.g. crops, the lifetime effect is present.

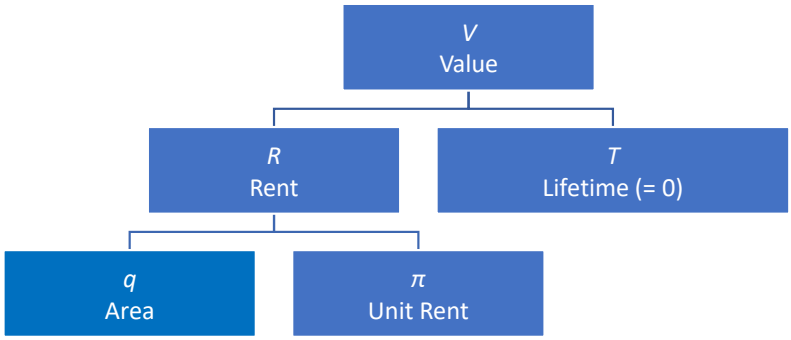

Figure 12. Nested decomposition for protected areas, forests (ecosystem services) and mangroves

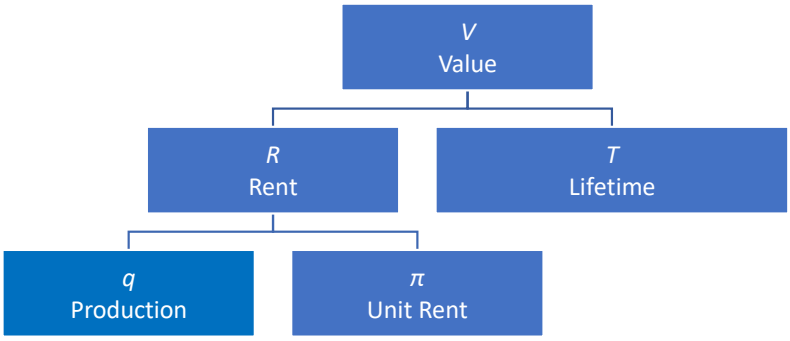

Figure 13. Nested decomposition for cropland, pastureland, forests (timber) and fisheries

5.2 Overall Developments

Table 3 shows the decomposition results of the seven renewable natural resource of the CWON. The top and bottom panel shows the decomposition analysis according to Figures 12 and 13 respectively. As the table shows in some cases, some additional decomposition nested effects could be distinguished . For example, for forests (ecosystem services) the unit rent is further broken down into specific ecosystem services (i) (recreation, hunting, and fishing ("recreation"), (ii) watershed protection ("water"), and (iii) non-wood forest products ("NWFP"). Similar, the decomposition for fisheries further distinguishes between unit prices and unit costs.

Table 3. Decomposition for renewable natural capital (1995-2018, global)

Unit: Constant 2018 USD (millions)

Natural Capital	**1995**	**Production (Area)**	**Rent**				**Life Time**	**2018**
			Unit Rent	**Water**	**Recreation**	**NWFP**		
Protected areas	1.927	971	849					3.747
Forests, timber	4.879	91	2487	2137	560	-209		7.458
Mangroves	213	-13	348					548
Natural Capital	**1995**	**Production**	**Rent**				**Life Time**	**2018**
			Unit Rent	**Unit Cost**	**Unit Price**			
Cropland	10.631	6.018	-456				-1.506	14.687
Pastureland	4.356	2.088	-233				0	6.211
Forests, timber	2.544	239	99				-154	2.728
Fisheries	1225	62	-1080	-1542	462			207
Renewable Natural Capital	**25776**	**9456**	**2013**				**-1660**	**35586**

The table shows that the production effects (whether they are area or production) are positive for all capital stocks except mangroves. This indicates that while the area covered by mangroves has decreased the rent per unit area has increased. This also highlights that the biophysical variable (the area of mangroves) decreases while the overall value increases. Note, the mangrove results are also heavily dominated by a couple of countries with very different wealth developments and decomposition results.

For many resources, such as cropland and pastureland, the increase in production explains around 50% of the increase in wealth. Forest (ecosystem services), fisheries and mangroves are the exceptions where the production effect are heavily dominated by the unit rent effect. Note that cropland is the only renewable asset which also has a significant lifetime effect.[14] The negative effect is due to the fact that the wealth calculations for this renewable introduce an assumption about the future productivity growth in agriculture which is diminishing over time.

5.3 Changes in Area and Production

Table 3 shows that the production effect provides the most important contribution to increases in renewable wealth. This can be either through increases in area or in production. Note that some resources, such as cropland, are calculated via production but are linked to land area. So when analyzing the production effect it could be due to increasing land being used for crops or increasing productivity (production per unit area).

Looking at the production effects over time, Figure 14 shows that cropland and pastureland have a positive sign for almost the entire period. Only 2008/2009 for cropland and 2014/2015 & 2017/2018 for pastureland have a negative production effect. The production effects are quite volatile, although pastureland seems to be more constant over time. The linear trendlines of Figure 14 also show the production effects are trending downward slightly.

Figure 15 shows the production effects for three smaller renewables. Mangroves and forest (ecosystem services) have been excluded because these production effects are negligible. The figure shows that the sign of the production effect fluctuates significantly. For fisheries, in particular, this effect fluctuates significantly. Table 3, shows that the net effect over the entire period (1995-2018) is relatively small, but looking at the annual results does show that there are large underlying shifts in this effect.

[14] For forest (timber) there is no lifetime effect when natural growth exceeds harvest rate (N>Q) because in this case the lifetime is assumed over 100 years/infinite. However, if harvest is greater than natural growth, increasing production will have a lifetime effect just like non-renewable resources, as the time to depletion can be reduced by increasing production.

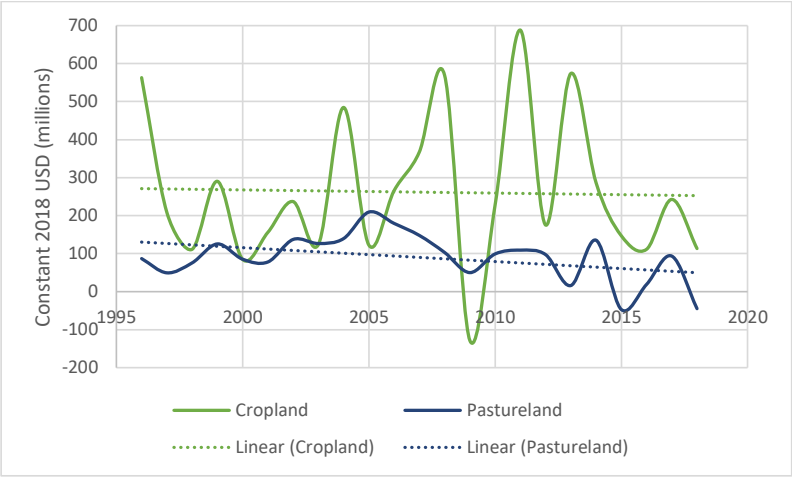

Figure 14. Production effects for cropland and pastureland (annual, global)

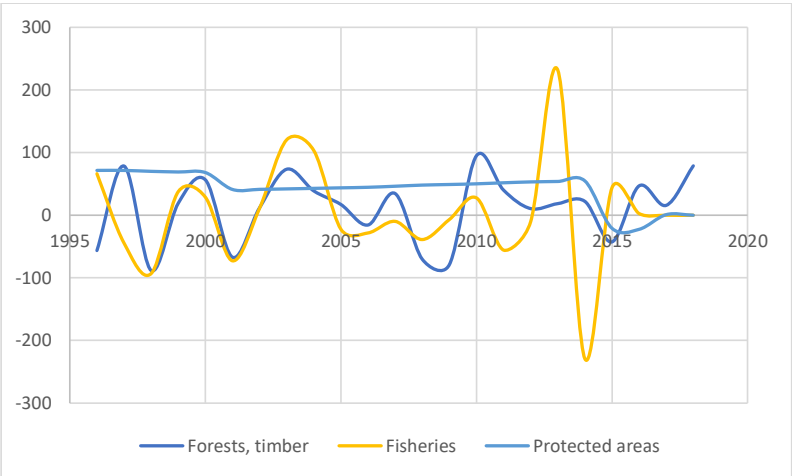

Figure 15. Production effects for forest (timber), fisheries and protected areas (annual, global)

5.4 Food Transition: Rent, Price and Cost

It is often argued that to protect biodiversity, mitigate climate change and mage water sustainably, a food transition is needed where animal-based products are replaced by plant-based alternatives. The three resources that are driven mostly by food demand are cropland, pastureland and fisheries. What is striking is the fact that these are the only assets where the unit rent effects are negative. For fisheries, it is clearly shown that to be heavily influenced by an increase in unit costs. For cropland and pastureland calculations, the rent is assumed to be a constant share of the price, and so changes can only be interpreted as a price effect.

Figure 16 shows that the volatility in the unit rent effect is large for all the three types of food products. Years in which unit rents improve, can swiftly be followed by a year in which unit rents turn negative. Figure 17 shows that the unit rents also vary per region, with some country groups showing large positive unit rent effects in years in which others show large negative effects. Compared to nonrenewable assets, the volatility is much greater. This could be caused by weather conditions (droughts and floods) or other factors that cause supply shocks which affects price and production levels.

In the food transition, there will be less livestock, especially beef, which is the most water and land intensive. That will also lead to shifts in cropland because reduction in foodstuffs used to feed livestock. In addition, the crops for human consumption might also see a shift. These changes are likely to have a significant impact on the decomposition effects, and therefore the overall effect on wealth. They will affect, production, prices and costs of these renewable natural assets. Countries will have to formulate policies that take into consideration these developments, as well as the additional volatility caused by climate change's effect on the weather and droughts.

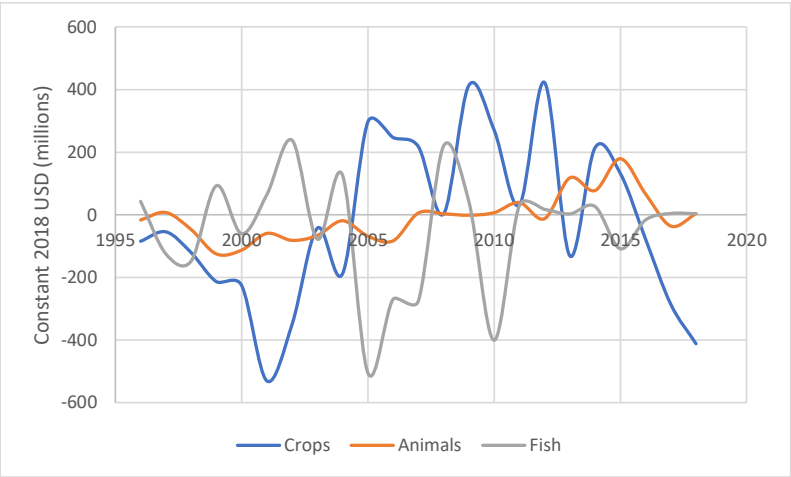

Figure 16. Unit rent effect for crops, animals and fish (annual, global)

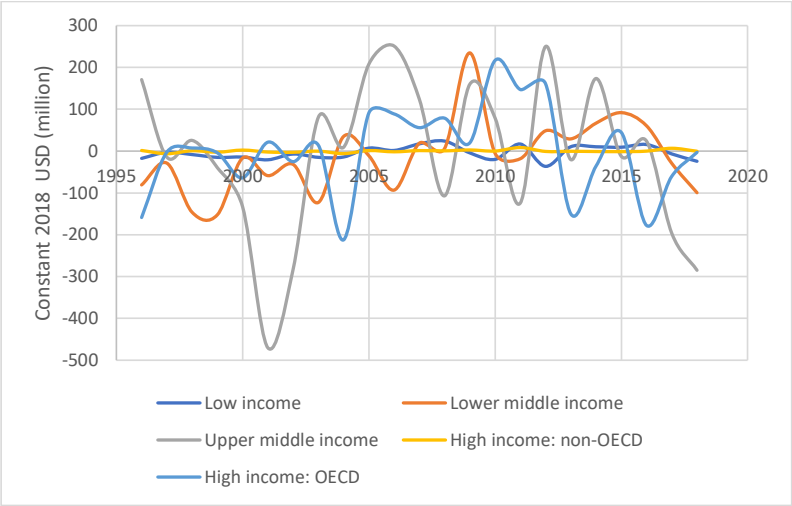

Figure 17. Unit rent effect for crops (annual, per income group)

5.5 The Crucial Role of Water

While water is not a natural capital resource in the CWON2021, all renewable assets listed in Table 3 have important links to water. Most obviously, is the connection of fisheries and mangroves to water, but the same holds for cropland, pastureland, forests and protected areas. The productivity and value of these resources are dependent on the quantity and quality of water which is available.

While water has not been explicitly valued in the CWON2021, in some cases the role of water is made explicit in the calculation of other renewable resource. For example, the decomposition results for forests (ecosystem services) shows that by far the largest contribution is from "watershed services". In fact, this decomposition effect contributes over 2 billion dollars over the entire period. Another example: the valuation of mangroves is based on the contribution to coastal protection from flooding.

Water is not only important in terms of the absolute wealth creation but may also be in terms of the volatility. Too little water (droughts), low-quality water (pollution) or too much water (flooding) can have significant effects on the amount of production of crops and other products from renewable natural resources. The volatility in the supply will also have impacts prices and therefore unit rents. The volatility in the production and prices effects of crops is much greater than these effects for animals, which could be because of droughts or other water-related effects. Managing cropland wealth, is therefore also a matter of managing water. This stresses the importance of measuring the value water resources (see future research).

6. Conclusions

This paper has presented a novel decomposition approach that analyses the underlying driving forces of changes in natural capital wealth. The results have made clear which are the largest contributing factors

for the many types of natural capital stocks which the CWON distinguishes. The results also showed how some effects, such as prices, lead to significant volatility in the wealth estimates.

The degree to which policy makers have influence on the decomposition variables differs. Some forms of natural capital are heavily regulated at the national level. In some cases, production (and therefore prices) can even be guided by international organizations such as OPEC. A government also has a large degree of control over exploratory activities within its borders. On the other hand, for many natural capital stocks, global prices or weather patterns are exogenous.

For nonrenewable assets price increases in the decade between 2000-2010 are the primary factor driving the increases in wealth. The other variables also contributed either positively or negatively but too a far lesser degree, and with less volatility. The post 2010 slump in the prices of nonrenewable assets contributed negatively to wealth. The detailed results show the effects can differ significantly between countries, especially in the case of coal.

In terms of renewable natural resources, the results showed a significant amount of variability in price and volume (production and area) effects. This is different to the sub-oil assets where the volatility is mostly due to price developments. The variability is likely to be linked to climatological situations and their impact on water.

The decomposition results are also be linked to the energy transition, circular economy transition and food transition. These developments are already having some impacts on wealth, but are set to accelerate in the coming decade. The impacts could be through production, land use, price, costs, and resource lifetime (e.g. stranded assets and reductions in exploration). The decompositions presented in this paper are a useful way of isolating these individual effects and modelling potential future developments.

Finally, the decomposition results lead to questions about wealth as a measure of sustainability. The fact that increases in oil production contributes to higher natural capital wealth has policy implications that go against climate change policies. Ways to deal with these issues, and other improvements to future CWON editions, are discussed in the next section.

7. Future Research

This is the first comprehensive use of decomposition analysis to understand changes in natural capital stocks. The analysis raises new questions and several lessons can be drawn for the benefit of future editions of the CWON and wealth accounting endeavors at large. Apart from the content-related lessons that are discussed in the next sections, the decomposition has also helped data validation (see Annex 1).

7.1 Wealth and Sustainability

The decomposition raises some important about the interpretation of wealth as a sustainability metric. Increasing oil extraction increase the value of oil wealth, because the rents are brought forward in time which means that the total rent revenue is discounted less. The policy implication is that it is good to extract oil as fast as possible. This is clearly not compatible to the idea that fossil fuel extraction needs to come down fact to mitigate climate change. Note that this counterintuitive result has also been pointed

out in the literature as the "green paradox" which stated that environmental policies might lead to increases in oil extraction (van der Ploeg & Cees Withagen, 2012). However logical this from a financial analysis perspective, it makes little sense in terms of climate change and global sustainability.

A similar issue is the idea that a large portion of the fossil fuels reserves will need to remain underground to prevent further climate change. However, these "stranded assets" will shorten the lifetime of the resource and therefore diminish wealth. In other words, a negative wealth development is consistent with a sustainable future. Given that the climate is not a capital stock in its own right in the CWON methodology, there is no corresponding increase in global wealth which compensates for the loss in oil wealth in individual countries.

There are other assumptions in the CWON calculations which cast doubt on the interpretation of the wealth as a sustainability index. For example, in the calculation of the wealth of protected areas, it is assumed that these will exist for 100 years and that they will be able to provide the same watershed, recreation and other ecosystems services for those 100 years. In other words, no damage or loss of ecosystem function is assumed. In this case, it is hard to interpret this as a sustainability measure.

In future editions of the CWON, the relationship between wealth and sustainability should be further explored. The topics of "weak vs strong sustainability", "critical natural capital" and "planetary boundaries" should be used to further develop the wealth approach. For example, Dasgupta (2021)-Chapter 4 showed how the production function underpinning comprehensive (or inclusive) wealth frameworks might incorporate environmental limits. In addition, For it might be fruitful to add estimates of the social cost of carbon and other externalities in the wealth calculations (Arrow et al., 2012). A strategy might also be to add capital stocks which grow as fossil fuels diminish (renewable energy production or a "climate asset"). Finally, it would seem fruitful to add other "Beyond-GDP" metrics such a planetary boundaries to see whether they provide a different view of sustainability which helps to further strengthen the discussion of sustainability in the CWON (Hoekstra, 2019).

In all of these strategies, it is useful that the decomposition results allow one to distinguish physical variables (production/stocks/areas) from economic variables such as prices, costs and rents. When considering the various options, the effect it has on wealth calculations as well as the decomposition analysis should be considered simultaneously.

7.2 Transitions/Systems Approach

For the next edition of the CWON, it would be good to first determine which decomposition analyses are of interest before doing the data processing and wealth calculations. Rather than viewing each of the natural capital stocks as independent, they should be viewed in the context of three major transitions:

- Energy Transition. To resolve climate change by transitioning away from fossil fuels to renewable energy.
- Circular Economy Transition. Reducing the resources used by society by improving their use.
- Food Transition. Protecting biodiversity and mitigating climate change, by managing the land used for food (as well as bioenergy, construction materials, recreation and other commodities and services provided through land use).

Such a systems approach would help to see the links between the various transition processes. The various natural assets identified in the CWON can contribute to multiple transitions. For example, oil demand will be affected by the energy transition, but will also be impacted by the circular economy because plastics are increasingly recycled and sometimes banned. Biological resources such as wood and crops can also be an alternative energy sources or materials for economic processes (e.g. construction). But this will also lead to more pressure on the other functions of land such as food. Even within food, it is well known that the land use of crops and animals is different. And even within livestock production, the density of cattle per grazing area is vastly different for Argentina or the Netherlands.

Using a "transition lens" would probably have the most impact on the measurement of renewable natural resources. Currently, the link to land is not reflected in all of the capital stocks. Most importantly, cropland and pastureland are calculated according to production figures and there is no link to the amount of land use. To fully analyze the land/food/water transition, the starting point of the data collection would then be a consistent database of all land area in a country over time. Subsequently, the productivity (i.e. the amount of production per unit area)[15] and the price and costs per unit of production would complement the generic nested decomposition (see figure 18). Only the water-based assets, fisheries and mangroves, do not make that much sense to assign to "area".[16]

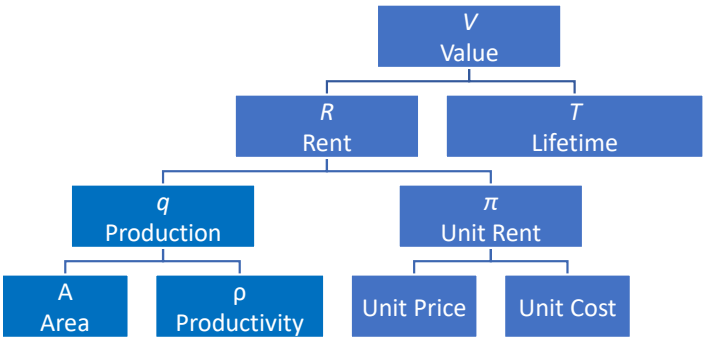

Figure 18. Nested decomposition for renewable natural resources

7.3 Spatial Resolution and the Importance of Water

A focus on land also provides an opportunity to add a spatial dimension to the CWON. Many projects on natural capital accounting which measure ecosystem services are now spatially explicit (see for example the ARIES platform)[17]. It therefore becomes possible to provide policy advice at the sub-national levels. These capital stocks, and their management, require location-specific policies.

[15] Note that for crops, the productivity gains are now used as a factor in the lifetime component.

[16] Over longer periods, the population developments also become important in the context of these transitions. The decompositions could be formulated from the per capita perspective.

[17] https://aries.integratedmodelling.org/

The spatial dimension also provides the opportunity to expand our understanding of the value of water, which is one of the major natural capital assets which is not included in the CWON. The decomposition results presented in this paper have suggested that water resources play a major role in wealth creation as well as their volatility. In fact, many of the renewable natural capital stocks, such as crops, are highly dependent on water. The value of water is also much a function of its scarcity which is correlated to geography. Adding a spatial dimension might therefore also be a good moment to add water as a capital stock in the CWON methodology. This will also raise some important methodological difficulties because the value of cropland will need to be split between water and land.

7.4 Volatility

While the management of wealth should be geared towards long-term value creation, this goal is sometimes overshadowed due to short-term volatility. The decomposition results have shown which of the underlying factors ae contributing most to volatility, namely unit rents (particularly the price component) and the production effect, in the case of renewables. Managing the absolute levels of wealth is important, but policies that address the volatility in wealth are also vital. In some cases, volatility will be severely damaging to the economy. A drought might force farmers off their land or lead to bankruptcy, while they could be earning a decent living in years with normal weather. Insurance, pricing policies and other policy tools can help overcome some of these volatility effects.

In the next edition of the CWON, the issue of volatility would be an interesting topic from a methodological and policy perspective. At the moment, a fair amount of volatility is already being taken out of the calculations because a 5-year moving average of the rents is being used for the wealth calculations. This is a rather arbitrary methodological choice which would lead to different results if it was 3 of 7 year moving average. At the same time, it also dampens the real effect of volatility on natural capital wealth, and the influence and the policy implications this might have. It would therefore be good to revisit this topic in the next edition of the CWON.

7.5 Human capital

The CWON also has estimates for human capital which are based on detailed underlying data. This would enable a decomposition of human capital into component parts such as increase in education levels, income per education level, births, deaths, aging populations etc. This would provide policy makers with detailed analysis of the driving forces behind their work force. As far as can be ascertained, decomposition methodology has not been applied to human capital. To pilot test this approach, a country would need to have annual data for all decomposition variables. In practice, this is not the case for many CWON countries. For example, few countries have annual surveys to measure the income differentials per education level. Methods to smooth the underlying variables will probably be needed.

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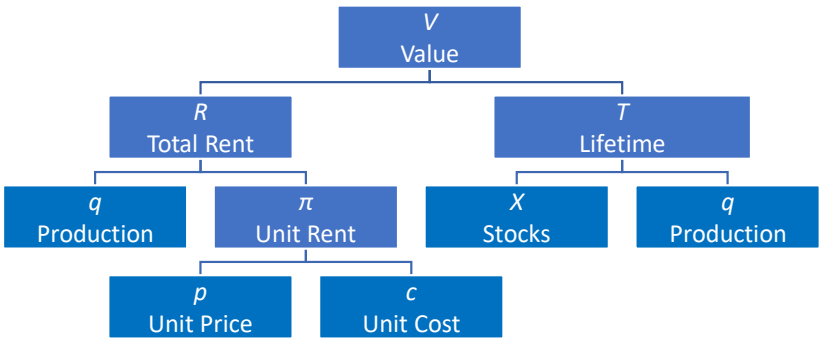
Annex 1. Decomposition Formulae and Data Treatment

Generic Decomposition Formulae for Natural Capital

Although there are variations of the wealth calculations, the most generic structure is shown below (reproduced from figure 5). In this section, the decomposition formulae for this base case are derived.



The "first-tier" of the calculation is based on the resource rents and lifetime (which is part of the overall discounting part of the equation (see section 2.3).

$$V_t = \bar{R}_t \cdot F_t$$

Where

$\bar{R}_t$ – 5-year moving average of total rents

F_t – Lifetime factor $= 1 + \left(\frac{1}{r} \cdot \left(1 - \frac{1}{(1+r)^{T_t - 1}}\right)\right)$

The first-tier decomposition formula for the change from year 0 to 1, using Sun-Dietzenbacher-Los weights, is therefore:

$$D^{\Delta\bar{R}} = \Delta\bar{R}_{0,1} \cdot F_0 + \frac{1}{2} \cdot \Delta\bar{R}_{0,1} \cdot \Delta F_{0,1}$$

$$D^{\Delta T} = \Delta F_{0,1} \cdot \bar{R}_0 + \frac{1}{2} \cdot \Delta\bar{R}_{0,1} \cdot \Delta F_{0,1}$$

Where

$D^{\Delta\bar{R}}$ – Decomposition effect of changes in rent $\bar{R}_t$

$D^{\Delta T}$ - Decomposition effect of changes in quantity factor F_t (dependent on lifetime T_t)

The "second-tier" decomposition of the left-hand side of the figure (rents) distinguishes a volume (which may be production, area or another unit) and a unit rent component. The "third tier" for rents is when the unit rent is decomposed into a unit price and unit cost:

$$D^{\Delta\bar{R},q} = \left(\Delta\bar{q}_{0,1} \cdot \kappa_0 + \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot F_0 + \frac{1}{2} \cdot \left(\Delta\bar{q}_{0,1} \cdot \kappa_0 + \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot \Delta F_{0,1}$$

$$D^{\Delta\bar{R},\mu} = \left(\Delta\mu_{0,1} \cdot \bar{q}_0 + \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot F_0 + \frac{1}{2} \cdot \left(\Delta\mu_{0,1} \cdot \bar{q}_0 + \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot \Delta F_{0,1}$$

$$D^{\Delta\bar{R},\kappa} = \left(-\Delta\kappa_{0,1} \cdot \bar{q}_0 - \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot F_0 + \frac{1}{2} \cdot \left(-\Delta\kappa_{0,1} \cdot \bar{q}_0 - \frac{1}{2} \cdot \Delta\bar{q}_{0,1} \cdot \Delta\pi_{0,1}\right) \cdot \Delta F_{0,1}$$

Where

$D^{\Delta\bar{R},q}$ – Decomposition effect of changes in volume q_t via rents $\bar{R}_t$
$D^{\Delta\bar{R},\mu}$ – Decomposition effect of changes in unit price μ_t via rents $\bar{R}_t$
$D^{\Delta\bar{R},\kappa}$ – Decomposition effect of changes in unit cost κ_t via rents $\bar{R}_t$

To get the "second tier" effects on the right-hand side of the figure one simply uses the same formula's by inserting data on the stock and production figures. It is beyond the scope of this paper to reproduce all the decomposition formulae for all CWON natural capital stocks, but they simply follow the same logic. The other decompositions are variations on the above nested decompositions (an internal document is available as well as Stata scripts).

Data Treatment

A couple of things were assumed in the decomposition calculations:

- The wealth calculations use the five-year moving average for rents. For the decomposition assumptions need to be made because the moving average of production multiplied by the moving average of unit rent is not the equivalent of the moving average of rents. For this decomposition it is assumed that the moving average of rents are divided by the volume in the year in question.
- Decomposition run into issues when volume starts up (i.e. the first year of production where there was none in the year before). The question arises whether this is a production effect, a unit rent effect or a stock effect. The change in wealth from zero to the value in year t is assigned to the production effect. Similarly, in years where exploitation of a natural resource stops, it is deemed to be a production effect.

Data Validation Benefits of Decomposition Analysis

A decomposition drills down on the underlying annual increments of variables. It thereby also uncovers unrealistic annual jumps, data gaps which have not been imputed properly, variables that are assumed constant due to lack of data or even problematic sign changes. The decomposition helps to uncover such errors in the wealth calculations because they lead to extreme high or low decomposition effects, no

decomposition effects or the Stata program crashing. During the project, the decomposition led to questions about the quality of the preliminary wealth calculations. In quite a few cases this led to improvements in data processing, interpolation or missing values. Given the enormous amount of data being produced in the CWON it is useful to see decomposition as a useful way of validating the data and assumptions underlying the wealth calculations.