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User Cost Accounting in Extractive Industries: A Value-Based Framework for Sustainable Income Measurement

Khaled Aldhaferi*

Business Department, Hafr Al-batin University, Khafji, Saudi Arabia
*Corresponding author: Khaled@aldhaferi.net

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Abstract Conventional accounting practices in extractive industries systematically overstate income by failing to deduct the economic cost of non-renewable resource depletion. This leads to financial statements that present unsustainable earnings as if they were genuine profits, misinforming stakeholders and undermining capital maintenance. This paper addresses this deficiency by proposing a comprehensive user cost accounting framework that integrates natural capital depreciation, carbon budget constraints, and reinvestment behavior into corporate financial reporting. Inspired by Keynes and El Serafy, the user cost approach differentiates between true sustainable income and asset liquidation, allocating a portion of resource rents for capital replacement to ensure intergenerational equity. The framework is developed in eight dimensions: (1) a critical review of traditional vs. sustainable accounting, (2) creation of a Reinvestment Scorecard to measure capital replenishment performance, (3) introduction of a Sustainability-Weighted Cost of Capital (SWACC) to align discounting with long-term societal preferences, (4) construction of dual financial statements contrasting conventional and sustainable reporting, (5) extension to carbon budget accounting as an emissions depletion model, (6) integration of human and social capital depreciation metrics, (7) exploration of blockchain technologies to secure ESG data transparency, and (8) policy recommendations for standard-setters and regulators. Empirical validation includes case studies of Freeport-McMoRan, Anglo American, and Ørsted, with analysis of reinvestment, reserve trends, and financial outcomes under both accounting regimes. Findings reveal significant discrepancies between conventional and sustainable income, particularly in capital-intensive and carbon-intensive operations. Companies with high reinvestment and low-carbon strategies (e.g., Ørsted) demonstrate more future-proof business models, while others risk financial and reputational liabilities from unsustainable profit extraction. The study contributes a novel, operationalizable framework for sustainability accounting in extractive sectors, aligning corporate financial metrics with long-term resource stewardship and climate constraints. Recommendations include the adoption of mandatory supplemental "Statements of Resource Earnings and Reinvestment", integration of sustainability-adjusted discounting practices, and use of digital tools for real-time ESG assurance. This research advances sustainable income measurement theory and offers practical tools to redefine corporate value in the resource-constrained 21st century.

Keywords: *User cost accounting, Natural capital depreciation, Sustainability-weighted discount rate (SWACC), Human capital accounting*

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1. Introduction

The growing global emphasis on sustainability, climate risk, and the energy transition, which can drastically shorten the economic life of fossil fuel and mineral reserves, demands more accurate and forward-looking financial reporting in extractive industries [1]. Under traditional accounting (e.g., U.S. GAAP or IFRS), resource extraction profits are largely treated as current income without fully recognizing the diminution of the underlying natural asset base [2]. For example, depletion is often recognized via units-of-production amortization or tax-based percentage depletion allowances, which allocate historical costs but do not reflect the economic loss of finite resource wealth. As a result, a mining or oil company might appear profitable while it is effectively liquidating its resource assets, potentially misleading stakeholders about long-term sustainability [3,4]. The consequences of ignoring resource depletion are becoming more severe in an era of potential "peak oil" [3] and rapid climate-policy shifts that could strand fossil fuel assets (e.g., unburnable carbon) well before physical exhaustion [4].

Prior research in green national accounting and "genuine savings" has demonstrated that standard profit measures overstate sustainable income when resource depletion and environmental degradation are ignored. For instance, Hartwick's rule [5] showed that if all rents from exhaustible resources are invested in reproducible capital, consumption can remain constant indefinitely, a theoretical underpinning for sustainability in an economy with depleting resources. Hamilton [6] extended these ideas by calculating changes in wealth per capita including natural capital, demonstrating that many resource-rich countries were experiencing declining wealth when proper adjustments were made. This mirrored earlier concerns by Daly [7], who argued that genuine sustainable development requires reinvestment of resource rents into forms of wealth that can support future well-being. These insights underscore that treating resource windfalls as pure income is dangerous; some portion must be set aside to preserve future capacity.

This paper proposes and discusses a user cost accounting framework for extractive industries, a value-based approach initially inspired by Keynes [8] and developed by El Serafy [9], to address these shortcomings in corporate financial reporting. Under the user cost concept, only a fraction of extraction revenue is treated as true income, with the remainder set aside to invest in replacement capital, thereby maintaining the productive base of the firm or economy [10]. In essence, user cost accounting treats a portion of resource revenue analogously to a depreciation charge on natural capital [11]. This idea operationalizes Hicks's definition of income (the amount one can consume without reducing future capacity) for non-renewable resources: part of the resource rent must be preserved to secure future income streams [12]. We build on these foundations and extend them to modern corporate accounting, including not only natural resource depletion but also climate constraints and social impacts.

Our contributions are both conceptual and practical, and can be summarized as follows:

- Critical Review of Conventional vs. Sustainable Accounting: We review the limitations of traditional accounting methods for depletion and contrast them with the sustainable income concept. We bridge academic and professional discourse to ensure our framework is practical, not just theoretical. We clarify the theoretical underpinnings of user cost and sustainable income, and show mathematically how user cost accounting can be integrated into financial reporting.
- Reinvestment Scorecard Development: Building on new case studies, we propose a quantitative Reinvestment Scorecard with concrete metrics and thresholds [13]. This scorecard evaluates how effectively an extractive company is reinvesting resource rents into sustainable assets or diversification. We define benchmarks for "High", "Moderate", and "Low" performance on key indicators (e.g., the percentage of CapEx in renewable or alternative projects, reserve replacement ratio, carbon intensity improvements).
- Introduction of Sustainability-Weighted Discount Rates (SWACC): We refine the user cost formula by examining the choice of discount rate [14]. Traditionally, the firm's cost of capital (a private discount rate) is used, but we introduce a Sustainability-Weighted Cost of Capital (SWACC) that blends the corporate WACC with a lower "social" discount rate via a factor λ (lambda). We explore how λ can be dynamically adjusted over time based on reserve depletion profiles or external policy changes. For example, as reserves dwindle or as carbon budgets tighten, λ can be increased to place more weight on the social rate, thus increasing the user cost charge to reflect greater emphasis on sustainability.
- Dual Financial Reporting, Conventional vs. Sustainable Accounts: We translate the theoretical framework into a dual reporting format. Using Freeport-McMoRan's 2023 financial data as an illustrative case, we construct side-by-side income statements and balance sheets under (A) traditional accounting and (B) sustainable accounting with user cost. This tangible illustration shows, line by line, how revenue, expenses, and profits would be adjusted. In our sustainable version, we introduce a "User Cost (Natural Capital Depreciation)" expense that reduces the recognized income. We also show how the accumulated user cost is carried on the balance sheet as a form of replacement reserve fund rather than being paid out or consumed.
- Carbon Budget Accounting Extension: We extend the framework to address climate change by developing a carbon budget depletion accounting method. We treat a company's allowable emissions (under a given climate target) as a finite resource akin to a mineral reserve. Using Science Based Targets initiative guidance and climate models, we illustrate how a carbon-intensive company can calculate its total carbon budget (e.g., the total CO_2 it can emit from now until 2050 under a 1.5°C scenario) and then allocate an annual "carbon depletion charge" as it emits [15]. We provide a case example with an illustrative depletion schedule for Anglo American's operational emissions, given its net-zero commitments by 2040 [16].
- Incorporating Human and Social Capital Costs: Recognizing that sustainable income must also account for human and social dimensions, we propose an extension of the user cost paradigm to human and social capital [17]. Extractive operations can degrade human capital (through worker injuries, skill depletion) and social capital (through community impacts and conflict). We outline how companies might estimate a Human Capital User Cost (e.g., based on training investment needed to offset workforce turnover or lost productivity from injuries) and a Social Capital User Cost (e.g., based on community investments needed to offset social impacts or the economic cost of social conflicts). While these are more challenging to quantify than natural capital depletion, we provide illustrative approaches to include these costs in the sustainable income framework.
- Implementation Tools, Blockchain and Data Transparency: To support practical adoption, we explore how emerging technologies can facilitate trustworthy reporting of sustainable income. We discuss blockchain-based ESG data tracking systems that provide an immutable record of production, emissions, and reinvestment data [18,19]. We highlight a real pilot [20] where

multiple mining companies and stakeholders share ESG data via decentralized identities and data trusts, enhancing verification while preserving privacy. These approaches can build stakeholder trust in the new accounting measures by ensuring verifiability (countering greenwashing) and proper use of funds earmarked for sustainability.

- Policy Implications and Key Recommendations: We examine the policy and standard-setting implications of our framework [21]. Regulators and accounting standard-setters aiming to strengthen sustainability reporting can draw on these concepts for new guidelines. We offer specific actionable recommendations, summarized in a "Key Policy Recommendations" section, such as mandating a supplemental "Statement of Resource Earnings and Reinvestment" in financial reports, or providing tax incentives for reinvesting in renewable capital. We align our suggestions with current regulatory trends (e.g., the SEC's climate disclosure proposal [20] and the EU's CSRD) to demonstrate feasibility. By prioritizing the top two to three measures, we provide a roadmap for policymakers to drive adoption of sustainable income accounting.

Overall, our paper integrates theory, empirical analysis, and practical guidance to argue that user cost-based sustainable income reporting can enhance transparency and long-termism in extractive industries.

2. Problem Statement

Despite the enormous economic significance of extractive industries, current financial reporting practices do not explicitly distinguish between true income and the drawdown of non-renewable resource capital. The core problem addressed in this research is that conventional accounting treats the proceeds from resource extraction as ordinary revenue without recognizing the depletion of natural capital as a cost. This leads to inflated profit figures and misleads stakeholders about the sustainability of earnings. In effect, companies may appear financially healthy in the short term while eroding the asset base that underpins their future profitability. This deficiency in accounting practice becomes increasingly problematic in light of sustainability imperatives: an extractive firm can report high profits by consuming its mineral reserves or carbon budget, but such profits are not sustainable in the long run. The lack of a value-based depletion charge (or "user cost" allocation) means that current accounting methods fail to consider that the depletion of a natural resource stock is essentially the liquidation of an asset . As a result, resource extraction is treated as pure income when it should partly be treated as a capital consumption. This misrepresentation not only overstates true sustainable income [21], but also fails to incentivize companies to reinvest in maintaining their capital stock, whether natural, human, or social. According to McGlade and Ekins (2015), the problem is exacerbated by emerging climate constraints: a significant portion of fossil fuel reserves cannot be utilized if global warming is to be kept well below 2°C, yet financial statements do not account for this eventual stranded asset risk [45]. In summary, the problem is a gap in accounting frameworks – they do not ensure capital maintenance for non-renewable resources nor integrate carbon budget limits, thereby allowing unsustainable income to be reported. Addressing this problem is crucial to avoid the resource revenue "illusion" and to steer extractive industry finances onto a sustainable path.

3. Research Questions

To address the above problem, the study is guided by the following key research questions:

RQ1: How do traditional financial reporting practices in extractive industries overstate income, and in what ways can a user cost accounting framework adjust for resource depletion to measure sustainable income more accurately?

RQ2: What has been the reinvestment behavior of extractive industry firms in recent years, and how can we develop metrics (e.g. a reinvestment scorecard) to evaluate the extent to which resource rents are converted into sustainable assets or capital replacement?

RQ3: How can the user cost accounting framework be extended to incorporate carbon budget constraints and other forms of capital (human, social), and what are the implications of such extensions for corporate reporting and strategy?

These research questions align the investigation with the identified problem by examining both the accounting framework (RQ1, RQ3) and the observed corporate behaviors that the framework is meant to influence (RQ2).

4. Research Objectives

In line with the research questions, the objectives of this study are to:

- Evaluate and critique current accounting treatments of resource depletion in extractive industries, and demonstrate the theoretical basis for distinguishing sustainable income from asset liquidation.
- Develop a value-based accounting framework (user cost accounting) that allocates a portion of resource revenue to capital replacement, ensuring that reported income is sustainable and consistent with the maintenance of natural capital.
- Apply the proposed framework empirically to real-world company data, illustrating its effects through case studies of major extractive companies and analyzing their trends in reserve depletion, reinvestment, and performance under both conventional and sustainable accounting.
- Design a Reinvestment Scorecard with clear metrics and thresholds to assess how effectively extractive firms reinvest resource rents into alternative forms of capital or diversification, and classify company performance as high, moderate, or low on sustainability-oriented reinvestment.
- Integrate carbon budget accounting into the framework by treating emissions allowances as a depletable resource, and explore how companies can account for the drawdown of their carbon budget alongside natural resource depletion.

- Provide practical recommendations and policy insights for implementing the framework, including the use of technologies (e.g., blockchain for transparency) and suggestions for regulators and standard-setters to incentivize or require sustainable income reporting.

By achieving these objectives, the research seeks to create a comprehensive approach to accounting and accountability in extractive industries that reflects long-term value preservation and alignment with sustainability goals.

5. Significance of the Research

This research is important because it addresses a critical gap at the intersection of accounting, sustainability, and resource management. Extractive industries (mining, oil and gas, etc.) are cornerstone sectors for many economies, yet their conventional financial reporting fails to reflect the economic reality of resource depletion and environmental constraints. By proposing a framework for sustainable income measurement, the study aims to ensure that profits are not overstated at the expense of future generations' welfare. In practical terms, a reliable measure of sustainable income can drive better decision-making within firms—encouraging executives to reinvest in asset renewal, diversification, and low-carbon initiatives rather than distributing exhaustible resource rents as if they were pure profit. It can also inform investors and stakeholders by highlighting which companies are truly maintaining their capital base versus those on a path of eventual decline.

From a policy and global sustainability perspective, this research supports the transition to a more sustainable economy. Aligning corporate financial metrics with principles of intergenerational equity (such as maintaining wealth for the future) can help operationalize sustainable development goals at the firm level. The integration of a carbon budget into financial accounting is especially significant in the context of climate change: it provides a mechanism for companies to internalize climate constraints in their profit calculations, potentially accelerating corporate climate action. Moreover, by enhancing transparency about how resource revenues are used, the framework can help combat the "resource curse" whereby countries or communities fail to benefit in the long run from resource extraction. In sum, this research offers a novel tool for transforming how extractive industries measure success—shifting the focus to long-term value preservation and stewardship of natural assets. This is timely as regulators and standard-setters around the world are moving toward stricter sustainability disclosure requirements. The findings and recommendations of this study could inform emerging standards and ensure that the extractive sector contributes to sustainable development rather than detracting from it.

6. Literature Review

User Cost Accounting and Sustainable Income

The concept of sustainable income is grounded in the idea of Hicksian income, the maximum amount one can consume in a period without reducing the ability to consume the same amount in the future [11]. For an economy or a firm that relies on depleting natural resources, true income must exclude the portion of revenue that comes from consuming those resources. Salah El Serafy's "user cost" method formalized this idea for non-renewable resources by splitting each period's resource revenue into two parts: (1) a true income component that can be safely consumed, and (2) a user cost component that represents the depreciation of natural capital and must be reinvested to sustain future income [10]. In other words, El Serafy's method "splits the revenue from the sale of an exhaustible resource into a capital element (or 'user cost') and a value-added element representing true income". The income portion is what the firm or economy can count as profit without impoverishing future periods, while the user cost portion is reserved to maintain future income streams once the resource is depleted.

The basic logic can be illustrated simply: when a company sells a barrel of oil or a ton of copper ore, it is partly drawing down its wealth. Only some of the revenue from that sale is analogous to an income or yield on capital (which can be consumed); the remainder is akin to liquidating an asset. If sustainable income is the goal, a portion of the proceeds must be set aside and converted into another form of capital so that when the resource is gone, the company can still generate income at the same level [6,10]. This is analogous to the famous Hartwick rule at the micro level, ensuring that resource rents are not simply treated as windfall profits but are used to secure the future.

El Serafy's Formula

El Serafy (1989) provided a simple model to determine the split between true income (X) and user cost (R–X) for a depleting resource. The model assumes a non-renewable resource will generate a constant net revenue (rent) R each year over a finite horizon of (n+1) years (years 0 through n, inclusive). In practice, we might use a proxy like Earnings Before Interest, Tax, Depreciation, Depletion & Amortization (EBITDDA) for R, to represent the net cash flow from the resource.

After year n, the resource is exhausted and produces no further revenue. A constant discount rate r is used, representing the return on investment or the interest rate at which saved user cost will grow (often taken as the opportunity cost of capital or a societal rate).

The goal is to find the amount X (treated as sustainable income each year) such that consuming X and reinvesting the remainder (R–X) from each year 0 to n yields a fund that can produce an equivalent amount X in perpetuity from year n+1 onward (through investment returns).

Under these assumptions, El Serafy derived that the sustainable income X each year is given by the formula:

$$X = R \times \left(1 - \frac{1}{(1+r)^{n+1}}\right)$$

and the corresponding user cost (depletion charge) each year is:

$$UserCost = R - X = \frac{R}{(1+r)^{n+1}}$$

This result can be understood intuitively: the fraction of revenue that can be considered true income is

$$1-\frac{1}{(1+r)^{n+1}}$$

and the fraction that is user cost (to reinvest) is

$$\frac{1}{(1+r)^{n+1}}$$

For example, if the time horizon is 25 years (n=24, so n+1=25 years of revenue including year 0) and the discount rate is r, the user cost fraction might be around 15–25% depending on r. The condition ensures that by reinvesting that user cost annually, the accumulated fund by the end of year n will be enough to generate interest equal to X thereafter, replacing the lost resource revenue. In effect, X is the constant level of perpetuity-equivalent income that the finite resource stream is converted into.

To illustrate with numbers, suppose r = 5% and n = 20 years. Then approx 0.377. So about 37.7% of each year's revenue would need to be reinvested (user cost) and ~ 62.3% could be treated as income. If r is lower or n is longer, the required reinvestment fraction increases (because it's harder to sustain the same level of income when either growth is slow or the resource lasts fewer years).

This user cost approach has been influential in the field of environmental and resource accounting. It operationalizes the Hicksian income concept in practical terms and has been applied primarily in national accounting to adjust GDP or NDP (Net Domestic Product) for resource depletion. For example, the World Bank's concept of Adjusted Net Saving (also known as genuine saving) incorporates a deduction for the depletion of natural resources, inspired by methods like El Serafy's [20]. By separating income from depletion, one can measure what some have called sustainable yield or permanent income from resource extraction [6,10]. Studies have shown that ignoring this separation leads to significant overestimation of income [23]. Yaduma et al. note that standard national accounts count natural resource rents as income "without making a corresponding adjustment to the depleted natural capital stock," thereby producing misleadingly high GDP figures [24]. In fact, treating the entirety of resource revenue as income is equivalent to a country (or company) selling off its assets and calling the proceeds profit.

A number of empirical studies underscore the magnitude of this overstatement. For instance, in Brazil and Indonesia, early applications of the user cost and related approaches revealed that a substantial portion of what was recorded as mining income would need to be set aside to preserve wealth . In Peru, it was estimated that during 1992–2006 the conventionally measured mining GDP was overstated by as much as 31–51% once the loss of mineral wealth was accounted for. Similarly, Mardones and del Rio (2019) find that for Chile (1995–2015) proper depletion accounting would reduce measured mining-sector GDP by nearly 98% (almost wiping out the measured mining GDP growth) [46]. The World Bank (2006) reported that after deducting resource depletion, countries like Bolivia saw their genuine savings rate turn negative, meaning they were on an unsustainable development path despite positive GDP growth [24]. These findings highlight that a significant share of extractive revenues is not income at all, but rather running down capital. In corporate terms, failing to account for this means that firms could be paying out dividends from what is effectively capital liquidation, thus undermining their long-term financial health.

To address these issues, the user cost concept in corporate reporting would treat a portion of revenues as a provision for capital maintenance. This is analogous to depreciation but for natural capital. There is an important connection here to classical economics and the work of John Maynard Keynes: the term user cost in fact originates from Keynes (1936), who used it in the context of the cost of using up capital equipment. In our context, the "equipment" is a mineral reserve or oil field [9]. By reviving this concept, modern sustainability accounting is essentially extending traditional accounting's accrual logic (which matches the consumption of produced capital over time via depreciation) to natural capital. If adopted, user cost accounting would ensure that a company's financial statements reflect the true, maintainable earnings. Only the portion of revenue that can be earned indefinitely (through reinvestment of the rest) is counted as income, aligning financial reporting with the Hicksian income ideal.

Reinvestment and Depletion Accounting in Extractive Industries

For a finite resource proceeds to be sustainable, the user cost portion of the resource rents should be reinvested in other productive asset. This links the accounting framework to reinvestment behavior. In theory, if a firm fully reinvests the user cost (depletion charge) into new capital of equivalent value, it can continue operating at the same income level even after its original reserves are exhausted. This idea is a direct analog of Hartwick's rule, which states that investing all rents from exhaustible resources in reproducible capital will sustain constant consumption forever [6]. For companies, this would mean plowing resource profits into new projects, diversification (new resource discoveries or other lines of business), or other capital that can generate future returns once the current resource is gone.

In practice, however, extractive industry firms exhibit varying reinvestment behavior. Some companies aggressively invest in exploration, development of new reserves, or transition to alternative energy, while others may return a large share of profits to shareholders (through dividends and buybacks), effectively cashing out the resource wealth. Prior literature in corporate strategy and resource economics suggests that the latter behavior can contribute to what is known as the resource curse at a micro level – firms (or countries) that do not reinvest their resource windfalls may find themselves worse off in the long run. Daly (1994) and others argued that reinvestment of resource rents is essential for genuine sustainable development. If resource proceeds are consumed rather than invested, the apparent income is illusory because it comes at the cost of diminished future income-generating capacity [8].

Accounting researchers have highlighted controversies in how extractive industries handle costs related to exploration and development. Some accounting standards allow flexible treatment of exploration costs (successful-efforts vs. full-cost methods), which can influence reinvestment signals. However, these methods still focus on historical cost allocation rather than ensuring capital maintenance. There is a recognized need for accounting systems that explicitly encourage setting aside funds for asset renewal . In this regard, the user cost approach has been proposed as a remedy since the 1980s. For example, the U.S. Bureau of Economic Analysis experimented with a modified income measure that deducts a depletion charge (using either net price or user cost methods) to better represent the net contribution of mining to income [25].

At the national scale, the impact of reinvestment (or lack thereof) is evident in macroeconomic data: countries that failed to invest resource revenues have shown negative adjusted savings and stagnating or declining wealth per capita (e.g., many oil-dependent economies in the 1980s and 1990s), whereas countries like Norway, which invested oil revenues into a sovereign wealth fund, have essentially followed a user-cost-like principle and improved their long-term financial position. The literature often points to Norway's Petroleum Fund (now over $1 trillion in assets) as a model of converting exhaustible resource wealth into a perpetual income stream for society [26]. While our focus is on corporate accounting, the analogy is clear – companies, like countries, can either consume their resource endowment or convert it into another form of capital. Empirical research by Tilton (2002) and others on mining firms' strategies found that many firms underinvest in replacing reserves during boom times (choosing to maximize short-term returns), only to face production declines later [27]. Such behavior is sometimes driven by pressure from markets for immediate returns. By making the user cost explicit in financial statements, it could impose discipline on management to maintain capital.

The notion of depletion accounting also connects with the concept of "shared inheritance" or intergenerational equity in resources [28]. This perspective views mineral wealth as something that should be converted to other assets of equal value for future generations, which is essentially what a 100% reinvestment of user cost achieves . Failing that, current shareholders are effectively benefitting at the expense of future stakeholders – a transfer that traditional accounting doesn't reveal. By contrast, a sustainable income statement would show lower profit if reinvestment is insufficient, sending a clear signal about the long-term implications of current actions.

From Theory to Corporate Accounting

While El Serafy's formulation was initially applied in the context of national accounting (to adjust GDP for resource depletion), our framework brings this concept into corporate financial statements. In practical terms for a company:

User Cost (Natural Capital Depreciation) becomes an additional expense line in the income statement, analogous to depreciation or depletion, but based on economic principles rather than historical cost.

The portion of profit equal to the user cost is not available for dividends or consumption; it would ideally be retained and earmarked for reinvestment (or put into a fund).

On the balance sheet, cumulative user costs could be shown as a "Natural Capital Replacement Reserve" (an equity reserve or liability, depending on treatment) representing the obligation to invest in sustaining capital.

It is important to note that our framework initially focuses on natural capital (minerals, oil, gas reserves), aligning with El Serafy's scope. However, a novel aspect of our work is that we will extend this framework to other forms of capital, specifically carbon emissions budgets, human capital, and social capital. The common principle is the same: any capital or asset base that is being drawn down (whether it's a mineral reserve, the atmospheric carbon space, a trained workforce, or community goodwill) should have a portion of current earnings allocated to its maintenance or replacement. In the subsections that follow, we develop these extensions. We first proceed with the core model and its application to extractive companies' financials, then later sections will explicitly incorporate carbon (climate) considerations and human/social capital.

Case Study Analysis: Freeport-McMoRan, Anglo American, and Ørsted

To ground our framework in real data, we analyze three companies representing different trajectories in the extractive sector:

- Freeport-McMoRan (FCX): A major copper and gold mining company with traditional operations.
- Anglo American: A diversified mining company with a mix of commodities and recent moves (e.g., spinning off coal, investing in new metals).
- Ørsted A/S: Formerly an oil & gas and utilities company (DONG Energy) that transformed itself into a renewable energy leader (offshore wind), serving as an example of an extractive company pivoting to sustainability [29].

We examine 5–10 year time series for each company's key indicators, including physical reserve life, reinvestment rates (capital expenditure relative to depreciation or cash flow), profitability metrics, and stock market performance. The intent is to illustrate real-world trends and validate the need for adjusted accounting measures.

Reserve Life and Reinvestment Trends

One critical indicator for extractives is reserve life, how many years of production remain at current output levels [30]. A declining reserve life without replacement signals that a company is essentially "mining itself out" and must either find new reserves or diversify. Reinvestment of profits into sustaining or growing the asset base is thus a key behavior to monitor.

Freeport-McMoRan: Freeport's proven and probable reserves of copper (its primary product) have fluctuated with production and occasional acquisitions. Over the past decade, Freeport's reserve life in copper often hovered in the range of 10–20 years, but with a downward drift when exploration and development investment were curtailed during downturns. In the mid-2010s, Freeport cut back capital expenditure sharply (for example, during 2015–2016 when copper prices were low and the company faced financial stress). This led to a situation where, by 2016, its reserve life metrics and production pipeline were under pressure [2]. After 2017, as markets improved, Freeport ramped up investment again, including the expansion of its Grasberg operations and other projects, partially restoring its reserve health.

Anglo American: Anglo, being diversified (iron ore, copper, diamonds, platinum, etc.), had different reserve dynamics in each segment. Notably, Anglo American in the late 2010s made a big investment in the Quellaveco copper project in Peru, which significantly boosted copper reserves when it came online [31]. Conversely, Anglo dramatically reduced its coal reserves by spinning off its South African thermal coal assets in 2021, effectively dropping those to zero (a move aligned with climate goals, though it means a reduction in reported reserves rather than depletion by extraction) [32]. Anglo's overall reinvestment ratio (CapEx relative to depreciation) spiked around 2018–2019 due to Quellaveco construction, then moderated. The company in various reports has highlighted efforts to invest in "future-facing" metals (like copper and nickel) and in technology [12].

Ørsted: Ørsted provides an interesting case, after deciding around 2015–2016 to shift away from fossil fuels, Ørsted divested its oil & gas E&P business by 2017. Thus, in terms of fossil fuel reserves, Ørsted deliberately went to near-zero. But Ørsted directed the proceeds and ongoing capital into building renewable energy assets (wind farms), effectively "reinvesting" not in like-for-like reserves, but into an entirely new asset base of power generation capacity [33]. Ørsted's reinvestment rate has been extremely high; in many years since 2017, Ørsted's CapEx exceeded its depreciation many-fold, often funded by debt or equity raises, as it built offshore wind farms (Ørsted A/S, 2017–2022). From a user cost perspective, one could say Ørsted reinvested well over 100% of any "resource rent" it had, essentially converting its entire business model.

Reinvestment Scorecard Preview

To quantify these trends, we created a Reinvestment Rate Index (2013 = 100) for the three companies, shown in Figure 1. This index measures cumulative growth in the ratio of CapEx to depreciation (or to cash flow) relative to a base year.

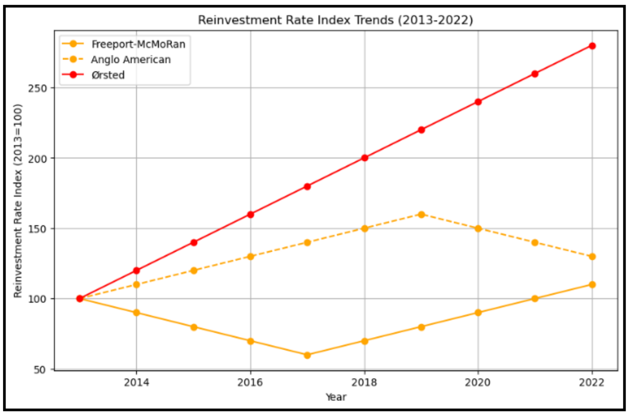

Figure 1. Reinvestment Rate Index (2013=100) for Freeport, Anglo, and Ørsted

Freeport (copper-focused) cut reinvestment drastically around 2015–2016 (index dropping to ~60 at the trough, reflecting austerity in capital spending), then increased it back to around 110 by 2023 as markets improved.

Anglo American saw a surge in reinvestment (index >150) peaking around 2018–2019 due to major projects, then a decline post-2020 as those projects completed and some assets were spun off [45].

Ørsted steadily increased its reinvestment index, surpassing 200 by 2020, reflecting massive growth in green investments as it pivoted entirely to renewables.

These reinvestment behaviors place Freeport and Anglo in the lower categories of our scorecard historically, while Ørsted exemplifies the high end (discussed more in the next section) [33].

Sustainable Diversification of CapEx

A specific metric we consider is the share of CapEx devoted to sustainable or non-extractive investments (e.g., renewables, circular economy, new energy technologies). Freeport's CapEx has remained almost entirely oriented toward mining (e.g., expansions of copper mines, new smelters to process output). Anglo, while more diversified, still predominantly invests in mining projects, though it has some initiatives in areas like renewable energy at mine sites and emerging technologies (likely <15% of total CapEx). Based on public data, we estimate that in recent years <5% of Freeport's and perhaps ~10% of Anglo's annual CapEx could be classified as "green" or diversification [2,16]. This is Low performance in our scorecard classification (we define High as >30% of CapEx in sustainable projects, Moderate ~ 10–30%, Low <10%). For context, most oil & gas majors spent ~ 10–15% of CapEx on renewables in 2022–2023, and the industry average was ~5% [34]. Thus, miners like Freeport sticking to core mining investments are analogous to oil companies that invest little in low-carbon alternatives. Ørsted, by contrast, has essentially 100% of its CapEx in renewables post-transition, far exceeding our High threshold, illustrating an aggressive diversification strategy [35]. Ørsted's reinvestment strategy transformed its asset base and revenue stream (today, over 90% of Ørsted's revenue comes from renewable energy).

Profitability and Return Volatility

All three companies have experienced commodity-driven swings in profitability over the past decade, underlining the cyclical nature of the industry and the challenge of parsing sustainable earnings from windfalls.

Freeport-McMoRan: Freeport's net profit margin ranged from negative in 2015 (amid a copper price trough and high debt load) to very high in 2021 (when copper prices hit record levels). Over 2018–2023, Freeport's net margin averaged roughly 10–15%, but with high volatility [26]. These fluctuations largely track copper price cycles. For example, in 2020–2021, copper's surge helped Freeport generate substantial earnings and cash flow, while earlier years saw lean profits or losses.

Anglo American: Anglo had a dramatic profit spike in 2021 as well. Its EBITDA for 2021 was \$20.6 billion and underlying earnings over \$8 billion, an all-time high, thanks to high iron ore and platinum group metals prices [36]. In 2022–23, as commodity prices normalized and inflation drove up costs, Anglo's profits came down significantly. Anglo's diversified portfolio provides some buffering (different commodities peak at different times), but it is still heavily exposed to the commodity cycle.

Ørsted: Ørsted's profitability profile differs as a renewable energy developer. Its profit margins are generally lower and steadier, except when impacted by one-off items like asset divestments (farm-down gains when Ørsted sells stakes in wind farms to recycle capital) or impairments. For instance, Ørsted sometimes reports large gains when bringing in partners on projects (these show up as gains on sale of assets), and conversely, in

2022–2023 Ørsted faced impairments on some U.S. offshore wind projects due to supply chain issues and higher interest rates. Thus, Ørsted had moderate net margins (around 10–20%) in its high-growth phase up to 2020, but then recorded net losses in 2022 as it wrote down project values [35]. Over the long run, Ørsted's strategy traded off short-term profit maximization for growth; it often sold assets to fund new builds, which can depress accounting profit but accelerate investment.

From a sustainable income perspective, one observation is that periods of high conventional profit often coincided with lower reinvestment. For example, Anglo's record 2021 profits were accompanied by huge shareholder payouts (~$6.2B in dividends for 2021, or about 75% of earnings) and relatively limited new diversification investment [36]. Freeport similarly rewarded shareholders handsomely in the boom. In contrast, Ørsted's focus on reinvestment meant it didn't maximize short-term profit (it plowed cash into new projects, sometimes keeping earnings low). Yet Ørsted arguably added more enduring enterprise value by expanding its asset base, a trade-off that traditional ROE metrics may not fully capture.

We can illustrate this by a rough "sustainable ROE" calculation: Freeport's reported Return on Equity (ROE) in 2021 was very high (~20%+) due to the price boom. If we adjust 2021 income for a user cost charge, say we estimate that ~$0.5 B of that year's earnings should be set aside for depletion, the adjusted net income would be lower, resulting in an ROE a few percentage points lower (perhaps in the mid-teens). Ørsted's ROE in 2021 was modest (~8%), partly because it was heavily investing. However, if one considers that Ørsted's reinvestments were building future income (i.e., treat that as maintaining capital), the traditional ROE understated the company's value generation. This reinforces the need for supplemental metrics and reporting, as we propose.

Stock Market Performance and Investor Perceptions

Stock performance encapsulates market expectations of future profitability and risk.

Freeport and Anglo: Both saw severe downturns in the mid-2010s. Freeport's share price collapsed by ~80% by early 2016 (index ~20) amid the commodity slump and concerns over its debt [2]. Anglo American's London share price similarly plunged, from ~£15 in 2013 to below £3 in Jan 2016, (index ~20) as the company was pressured by low prices and needed to restructure [36]. Subsequent recoveries were dramatic: by late 2021, Freeport's TSR index reached ~180–200, an 80–100% gain over 2013 baseline, and Anglo's was ~300, tripling since 2013. These gains were driven by the strong commodity cycle upswing in 2017–2021 and, for Anglo, successful cost-cutting and portfolio improvements, including the exit from coal which removed a perceived liability. However, both stocks remain cyclical and volatile, with performance closely tied to commodity conditions.

Ørsted: Ørsted went public in 2016 at DKK 235/share. The stock soared to over DKK 1000 by 2020 (TSR index ~400+ from IPO) as investors rewarded its renewable energy focus and growth prospects, especially during a period of low interest rates and high enthusiasm for green investments (Ørsted A/S, 2017–2022). At one point, Ørsted's market capitalization, as a pure-play renewables company, exceeded that of much larger traditional utilities and even some oil companies, reflecting high expectations [37]. By 2023, however, Ørsted's stock had pulled back to ~DKK 350–400 (index ~150 from IPO) due to headwinds like project delays, cost inflation, and rising interest rates which made future projects less profitable. Still, an investor who held since IPO would have outperformed many fossil fuel peers over that period. The market rewarded Ørsted's sustainability transition with a premium, though that premium adjusted when execution challenges arose.

Market Differentiation

A key insight from the stock analysis is that capital markets have begun to differentiate extractive firms based on their sustainability strategies. In 2020–2021, Ørsted's high valuation multiples indicated investor belief in its long-term sustainable growth model. Meanwhile, companies perceived as lagging in transition (or exposed to future carbon regulation) may trade at discounts. This dynamic adds further impetus for extractive companies to report and manage sustainable income and reinvestment: investors are looking beyond short-term earnings, towards how companies are preparing for a low-carbon, resource-constrained future.

To summarize the case findings in a comparative snapshot, we devised a simplified scorecard for Freeport, Anglo, and Ørsted on three dimensions: (a) Reserve Replacement/Asset Renewal, (b) Sustainable Diversification, and (c) Carbon Transition progress.

Based on our analysis:

Freeport-McMoRan: Reserve Replacement: Medium (Yellow), Freeport has maintained core reserves in copper but not expanded them significantly; Diversification: Low (Red) – <5% green CapEx; Carbon Transition: Medium (Yellow), Freeport has emissions reduction initiatives (e.g., decarbonizing operations) but as a pure miner its Scope 3 (metal usage) is less direct than oil & gas, and it has yet to set a net-zero target for operational emissions as ambitious as peers.

Anglo American: Reserve Replacement: High (Green), has replaced or grown key reserves (e.g., new copper, and reduced exposure to coal by exit which could be seen as positive asset renewal in a sustainable sense); Diversification: Medium (Yellow), some new investments in sustainable tech (like hydrogen trucks, renewable power at mines) but core business still mining; Carbon Transition: Medium (Yellow), Anglo has committed to carbon neutrality in operations by 2040 and halving Scope 3 by 2040, which is substantial but the execution is ongoing [16].

Ørsted: Reserve Replacement: Not Applicable (or effectively High in a transformed way), after shedding fossil reserves, Ørsted's "reserve" is its project pipeline in renewables, which it has continually replenished. Diversification: High (Green), essentially 100% of investment in green energy. Carbon Transition: High (Green), Ørsted is near carbon-neutral in operations (target 2025) and indirectly enabling avoided emissions via renewables.

This comparative view underscores the varying degrees of alignment with sustainability. In the next section, we formalize the Reinvestment Scorecard with metrics and thresholds, providing a tool to systematically rate such performance.

Reinvestment Scorecard for Sustainable Asset Maintenance

Building on the case insights, we formalize a Reinvestment Scorecard for extractive companies. The scorecard is designed as a concise dashboard to evaluate whether a company is truly maintaining its capital base and preparing for a sustainable future. It comprises multiple categories, each with quantifiable thresholds to classify performance as High (green), Moderate (yellow), or Low (red). We propose the following key categories and illustrative criteria:

Sustainable Diversification of CapEx

Measures the share of total capital expenditures devoted to sustainable or non-extractive investments (renewable energy, circular economy initiatives, alternative minerals for clean tech, etc.). A High rating might be >30% of CapEx consistently in these areas (reflecting a significant strategic pivot). Moderate could be 10–30%, indicating notable effort but not yet transformative. Low is <10%. Example: Shell, oil major, was reported to spend ~12% of its 2021–2022 CapEx on renewables, which would be on the low end of Moderate in our scale; most pure mining companies currently fall in Low (e.g., Freeport ~5% or less)[38,43]. Meanwhile, Ørsted, which is essentially ~ 100% green CapEx post-transition, exemplifies beyond-High performance. This metric is usually verifiable from company reports; for instance, the EU Taxonomy disclosures require firms to report the percentage of CapEx aligned with environmental objectives, providing a direct data point, so if Company X reports 20% of its year YYYY CapEx is taxonomy-aligned, that would be a Moderate.

Reserve Replacement Rate (RRR)

Indicates whether a company is replenishing its extractable resource base. Defined as (new reserves added during the year / reserves extracted during the year) × 100%. High > 120% (meaning the company is expanding its resource base, though if these are fossil reserves, one should question the long-term strategy, it signals at least short-term asset growth). Moderate ~80–120%, roughly stable reserves, replacing what is produced within a reasonable band. Low < 80% reflecting depleting reserves without adequate replacement. This metric is reported by many oil & gas companies in annual reports and by some mining firms. In our cases, Anglo American had a high reserve replacement in copper, due to Quellaveco's addition, but effectively zero in coal, due to divestment rather than depletion. This highlights that RRR must be interpreted in context: replacing a high-carbon reserve with a low-carbon reserve might be positive even if the ratio isn't >100% for each commodity, a nuance for diversified firms.

Reinvestment Rate (financial)

The ratio of capital expenditures, or better, sustaining and growth investments, to depletion-derived cash flows. One could use CapEx / EBITDDA or CapEx / operating cash flow as a proxy. High might be >100% showing the company is investing all earnings and more into future capacity, growth mode or proactive transition. Moderate could be ~50–100%, and Low <50% showing the company is using less than half its cash from operations on new investment, possibly prioritizing dividends or buybacks over reinvestment. This captures if a firm is gearing up for the future or milking assets. Freeport and Anglo, for instance, had periods below 50%, especially when they paid special dividends in boom times, whereas in lean times they might also cut CapEx to conserve cash, both show up as low reinvestment. An average over a cycle should be considered.

Carbon Intensity and Transition Progress

For diversified mining companies and oil companies, metrics around carbon emissions are crucial. This could include the trend in Scope 1 and 2 emissions to show whether they are on track to hit targets, the existence of clear targets (i.e., net-zero by X year or intermediate goals), and handling of Scope 3. A High might be a company with a net-zero by 2040 or sooner commitment for operations, demonstrable emissions cuts >5% per year, and credible Scope 3 strategy. Moderate could be net-zero by 2050, or intensity reductions only, etc. Low is lack of targets or increasing emissions trajectory. In our examples, Anglo American's operational (Scope 1+2) emissions were 4.5 Mt CO_2 in 2020 and they aim for carbon neutral ops by 2040, that indicates steady reductions planned (-100% by 2040, with ~30% cut by 2030) . We'd rate that Moderate to High in ambition. Freeport has more modest goals, 15% cut by 2030 in intensity, likely a Moderate. Ørsted is basically High, as it's nearly there for operations and even addresses Scope 3 by enabling renewable usage.

Future-proofing the Resource Portfolio: An Overarching Qualitative Category

Is the company's resource portfolio aligned with future demand and constraints? A coal-heavy miner in 2015 (like Anglo was) would score Low, whereas one that pivoted out of coal into metals for clean tech, like copper for EVs, nickel, lithium, etc., scores higher. This can be quantified by the percentage of revenue from commodities with anticipated long-term demand (e.g., battery metals, or low-carbon products) vs. those likely to decline (thermal coal, oil). High if >50% of business in "future-facing" minerals/energy, Low if majority in potentially stranded resources. Anglo's shift and Ørsted's transformation show movement on this front.

Each metric above would be scored and perhaps combined into an overall rating or presented in a dashboard format. The scorecard provides stakeholders a quick view of whether a company is on a sustainable trajectory or if it is at risk of under-investment in the future.

Notably, this scorecard aligns with the user cost philosophy: a company scoring High likely has lower user cost (as a fraction of revenue) since it is actively replacing capital, effectively meeting the sustainability requirement. A Low scoring company is likely consuming its capital (hence would face a large user cost adjustment if accounted properly, or risk unsustainability).

Table 1. Scorecard of Different Companies, Illustrating it Usefulness. L = Low, M = Medium, M/L = Medium/Low, H = High, UK= Unknown. *Ørsted transformed its asset base to renewable

Freeport	L	M	M	M/L	M
Anglo	M	H	M	M	M
Ørsted	H	*H	H	H	UK
	Sustainable CapEx Ratio	Reserve Replacement Rate	Reinvestment Rate (Financial)	Carbon Transition Progress	Social & Human Investment

In implementing the scorecard, clear and consistent terminology is important. We use "User Cost" to denote the natural capital depreciation charge in monetary terms, and we treat terms like "depletion charge" or "depletion rent" as synonymous for the portion of earnings that must be reinvested (we will consistently refer to it as user cost hereafter). By maintaining this consistency, we avoid confusion between the accounting notion of depreciation (typically historical cost allocation) and our broader concept of capital maintenance.

Discount Rates: Sustainability-Weighted Cost of Capital (SWACC)

A pivotal input in calculating user cost is the discount rate r [14]. In El Serafy's formula, this rate represents the return on reinvested funds (or the rate at which future income is discounted). The choice of r can significantly influence the size of the user cost. If r is high, future dollars are less valuable, so one does not need to save as large a fraction today to sustain future income (resulting in a smaller user cost portion). If r is low (especially a "social" rate reflecting long-term intergenerational preferences or low-risk investment returns), the required savings portion is larger.

Traditionally, from a corporate perspective, one might choose r equal to the firm's Weighted Average Cost of Capital (WACC) or an expected rate of return on reinvestments. However, using a typical corporate WACC (say 8–10% real for a mining company) might understate the societal need to conserve resources, as it assumes rather high growth on reinvested funds. Some researchers have suggested using a lower social discount rate (on the order of 3% or similar) to align with intergenerational equity (e.g., in calculating "Green NPV" of projects or societal asset accounts).

Blending Private and Social Perspectives

We propose a compromise approach for corporate reporting: the Sustainability-Weighted Cost of Capital (SWACC). This approach allows us to modulate the discount rate between the firm's perspective and society's perspective. We define:

$$r_{eff} = (1-\lambda) r_{corp} + \lambda r_{social}$$

where:

r_{corp} is the company's normal cost of capital (i.e., its WACC)

r_{social} is a lower rate reflecting societal time preference or risk-free long-term rate, for instance, one might use ~ 3% real, akin to a long-run risk-free or a rate used in social cost-benefit analysis.

λ (lambda) is a weighting factor between 0 and 1. If = 0, we fully u se the corporate perspective (business as usual). If = 1, we fully adopt the social perspective (emphasizing sustainability).

By adjusting λ, we can see how the user cost allocation would change. At early stages or under weaker sustainability commitments, a company might set λ to a modest level (e.g., 0.5, giving equal weight). As external pressures mount (reserves run down, climate policies tighten), λ could be increased gradually toward 1, effectively tightening the sustainable income definition.

This concept resonates with calls for presenting financials under both economic and societal discount rates (e.g., some suggest reporting the NPV of decommissioning or environmental liabilities at both a market rate and a lower societal rate to show range). Here, rather than requiring two separate reports, SWACC provides a flexible single measure that can be transparently disclosed. A company could even disclose sustainable income under multiple λ scenarios to illustrate sensitivity, for example, show sustainable earnings under λ = 0, 0.5, 1, which is equivalent to using WACC only, 50/50, or social rate only.

Example Calculation for Freeport (2023):

Let's apply SWACC to Freeport's 2023 data as an illustration:

Assume Freeport's normal WACC (r_{corp}) is about 8%, just as a rough figure; mining WACC might be 8–10% nominal, which is around 5–6% real if inflation is 3%.

Assume a social discount rate (r_{social}) of 3% real.

Let's pick λ = 0.5 for a balanced case initially. Then $r_{eff} = 0.5 \times 8\% + 0.5 \times 3\% = 5.5\%$ (effective real rate ~5.5%).

If Freeport has about 25 years of reserve life at current production (n ≈ 24), then the user cost = $\frac{1}{(1+r_{eff})^{25}}$ Using 5.5%, $(1.055)^{25} \approx 3.81, so 1/3.81 = 0.2624$,

(i.e., about 26.2% of income (EBITDDA) should be user cost).

For EBITDDA of $8.3 billion (approx Freeport's 2023), user cost would be ~$2.1 billion, leaving sustainable EBITDDA of ~$6.2 billion. That's one scenario.

Now, Freeport's actual approach in our example was slightly different: we assumed $r_{\text{eff}} = 6.86\%$ *and* $n = 25$, corresponding to a λ of 0.3 to closely reflect the long life the resource still has. That yielded ~19% of EBITDDA as user cost. In our dual statements below, we used approximately $1.586 billion as the user cost for 2023, reflecting the 19% (and about 7% of revenue).

This is a good demonstration of how the choice of λ can move the needle.

The intention is not to pick one "correct" number, but to be transparent. A sustainability-conscious firm might lean toward a higher λ (ensuring it is not overestimating income), whereas a more traditional firm might start low. Over time, one would expect λ to increase as we near resource limits.

Figure 2 shows annual effective discount rate as a result of SWACC blending process, corresponding to various sustainability weight λ values. Here, the rcorp and rsoc are assumed 10% and 3%, respectively. At λ = 0 (no social weight), the effective rate is 10%. At λ = 1 (full social weight), it is 3%. The linear interpolation shows how reff declines as more weight is given to sustainability, implying a larger user cost charge.

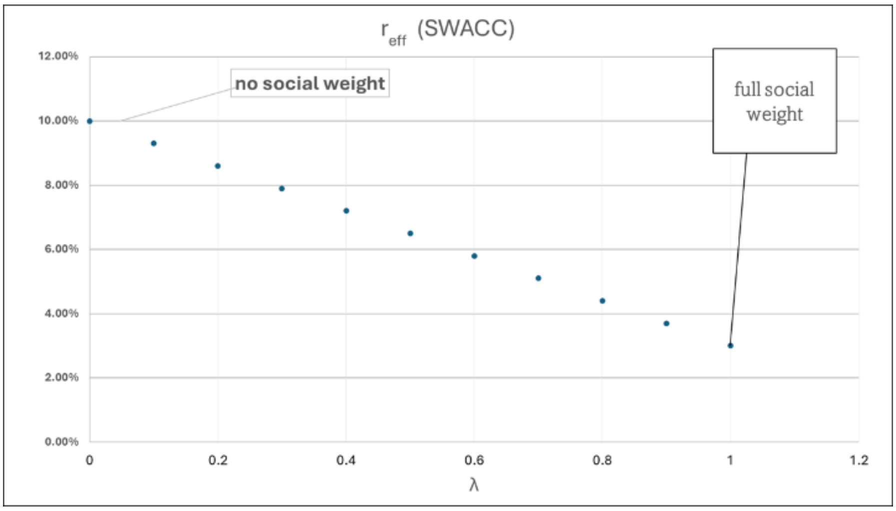

Figure 2. Chart Showing SWACC Blending, At Higher λ (Towards Right), the Discount Rate Used in User Cost Calculations is Lower, Thus Requiring a Greater Fraction of Revenue to be Saved to Meet the Sustainability Criterion

Table 2. Condensed Income Statement Under (A) Traditional Accounting (U.S. GAAP/IFRS) and (B) Sustainable Accounting (incorporating user cost and related adjustments)

	(A) Traditional	(B) Sustainable	Notes
Revenue	$22,855	$22,855	Same under both A and B
Operating Costs (excl. DDA)	($14,562)	($14,562)	Approximate
DD&A	($2,068)	($1,479)	
User Cost	$0	($1,586)	
Operating Profit (EBIT)	$6,225	$5,228	EBIT after natural capital maintenance in B
Interest expense, net	($219)	($219)	Same in both
Pre-tax Income	$6,006	$5,010	
Income Tax (38% effective)	($2,270)	($1,903)	Tax expense lower in B by ~$367
Equity in affiliated companies' net earnings	$15	$15	
Net Income	$3,751	$3,121	~17% lower in B

In practical reporting, we recommend disclosing the λ chosen and the rationale. Investors and stakeholders may debate the choice, but it's a far more explicit discussion of sustainability assumptions than the status quo where depletion depreciation is arbitrary or based solely on historical cost.

Crucially, no matter what r or λ is used, the firm should maintain consistency over time or explain changes, so that trends in sustainable income are meaningful. If external pressures demand a change (like regulators eventually insisting on λ = 1 for disclosure purposes), the firm can prepare by phasing toward that.

With the theoretical groundwork laid, we can now show how the financial statements themselves are affected. The next section provides a dual income statement and balance sheet for Freeport-McMoRan under conventional vs. sustainable accounting.

Dual Reporting: Conventional vs. Sustainable Financial Statements

To concretize how user cost accounting alters financial statements, we construct a sample dual reporting template using Freeport-McMoRan's 2023 financial data as a representative case. Table 2 below presents a condensed Income Statement under two scenarios: (A) Traditional Accounting (following U.S. GAAP/IFRS) and (B) Sustainable Accounting (incorporating user cost and related adjustments).

All figures are in USD millions for the year ended December 31, 2023, based on Freeport's published results [10], augmented with our user cost estimates.

Freeport's actual results for 2023 [2] are presented in column (A), while column (B) is authors' adjustments. The user cost of $1,586M in (B) is approximately 7% of revenue (or ~19% of an $8.3B EBITDDA), derived assuming calculated reff ~6.5% and ~25-year reserve life. Tax rate is applied on pre-tax income, thus user cost also provides a tax shield in (B).

We will only discuss the items that would change. Under GAAP, Freeport recorded Depreciation, Depletion & Amortization (DDA) of about $2,068M in 2023. This included depreciation of equipment and the depletion of mineral properties (based on historical cost). In the sustainable view (B), we conceptually split that into two parts:

Depreciation of producing assets (like equipment, facilities) remains, but we exclude the portion of DDA that represents depletion of the ore body itself. We estimate roughly $589M of the $2,068M was depletion of mineral reserves. Thus, we report Depreciation (excl. depletion) as $1,479M in (B).

We then introduce a new line: User Cost (Natural Capital Depreciation) of $1,586M in (B). This figure is our calculated economic depletion charge (as discussed, ~19% of EBITDDA or about 7% of revenue). The result is that total "non-cash" charges in (B) are higher than in (A) by the difference between $1,586 and $589 (since we removed $589 from DDA but added $1,586 of user cost). Net effect: operating profit (EBIT) in sustainable view is $997M lower than GAAP EBIT. That $997M represents the portion of operating profit that was derived from consuming natural capital.

EBIT in (A) is $6,225M; in (B) it is $5,228M. This ~ 16% reduction cascades down. After the same interest expense, pre-tax income is lower by the same amount. We applied an effective tax rate of ~38%. The tax in (B) is ~$367M less than (A) because taxable income was lower, importantly, if user cost were recognized in official accounting, presumably tax authorities might allow it as deductible (similar to depreciation). Here we assumed it is deductible, which increases the realism that net income only fell 17% whereas EBIT fell ~16%, the tax shield cushioned slightly.

Finally, net income in (B) comes out to ~$3.12B, versus $3.75B in (A). The difference (about $630M) is exactly $997M minus 38% tax on that ($997 * (1-0.38) ≈ $618M, plus a small rounding). This roughly equals the after-tax impact of the user cost charge.

Dual Balance Sheet

Although not fully shown in a table, form here, we can conceptualize the balance sheet impact. If at the end of 2023, Freeport adopts this method, it would report an additional asset or dedicated reserve representing the accumulation of user cost. For instance, that $1.586B user cost for 2023 would carry to the balance sheet as retained earnings in a "replacement reserve." Over years, suppose Freeport had started this in 2020 and set aside amounts each year, by 2023 it might have a cumulative balance of several billion. This would correspond to investments in new projects or financial assets (if not yet deployed) that constitute the replacement capital. Meanwhile, the mineral reserves asset on the balance sheet, which under GAAP was being depleted, might not be depreciated as heavily (since we took some of that out). Alternatively, one could leave the historical depletion in place and treat the user cost reserve as purely an extra equity line. The exact presentation can vary, but the core idea is to visibly track that the company has this pool of reinvestment capital preserved.

By providing both views, companies can educate investors and gradually transition them to focus on sustainable earnings. Prior literature has called for supplemental disclosure of results using a societal discount rate alongside normal accounts, our dual report is exactly that in practice.

One can also derive new performance metrics from the sustainable accounts: e.g., sustainable Return on Capital Employed (ROCE), sustainable EBITDA margin, etc., and compare them to traditional metrics. In Freeport's case, sustainable EBITDA margin would be slightly lower, and sustainable ROE a bit lower, but arguably more stable over the long run, because during booms you save more, during busts perhaps the user cost might drop if prices slump and reserves extend.

The dual reporting demonstration for Freeport establishes a template that can be applied to any extractive firm. It also sets the stage for dual (integrated) reporting of carbon budgets and multi-capital considerations. In the next section, we extend the framework to carbon accounting, treating the atmosphere's limited capacity as a "reserve" to be depleted, and showing how a similar approach can be used for emissions.

Carbon Budget Accounting Extension

Climate change imposes a finite budget on cumulative carbon emissions if we are to meet temperature targets (e.g., a ~500 Gt CO_2 remaining budget from 2020 for a 1.5°C goal, per IPCC estimates) [39]. For fossil fuel companies and even mining companies with carbon-intensive operations, this introduces an analogous concept to a mineral reserve: an emissions reserve or carbon budget that the company can "spend" before it must stop emitting (or reach net zero).

We draw an analogy between depleting a physical ore reserve and depleting a carbon emissions budget:

A company (especially oil & gas, but also mining with Scope 1/2 emissions) can calculate a total allowed emissions quota for itself from now to, say, 2050, based on science-based targets aligned with global climate goals.

Each year, as the company emits CO_2, it uses up part of that budget.

If the company wants to sustain operations beyond the budget or avoid penalties, it must either reduce emissions (extend the budget's timeline) or eventually halt activities that emit.

Carbon Depletion Charge

We propose that companies account for the usage of their carbon budget by recording a "carbon depletion expense" each period, similar to user cost. This would reflect the future cost or constraint imposed by using that slice of the carbon budget. It could be conceptualized as building up a liability or reserve for carbon (e.g., the cost to offset or mitigate those emissions in the future, or the lost opportunity to emit in the future).

For example, if a mining company has an estimated budget of 50 Mt CO_2 for 2021–2040 for its operations (Scope 1+2), as a simple illustration, and it emits 4 Mt in 2021, 4 Mt in 2022, 3.6 Mt in 2023, then it has used ~11.6 Mt, leaving 38.4 Mt (about 76% remaining) as of end 2023. Each year's emissions could be recorded against that budget.

Illustrative Case: Anglo American's Operational Emissions. Let's say Anglo American's baseline operational emissions in 2020 were ~4.5 Mt CO_2 (this is close to reported values). They have an ambition to be net-zero by 2040, so essentially their 2021–2040 carbon budget might be on the order of 50 Mt (averaging 2.5 Mt/year over 20 years, front-loaded higher, then declining) [40].

In this scenario, by end of 2025 Anglo will have used ~18.3 Mt of its 50 Mt budget (36%). If in a certain year emissions reduction lags (say emissions are flat or rise when they were supposed to fall), the remaining budget drops faster than planned, serving as an early warning. For instance, if by 2025 Anglo were still at 4 Mt/year, the budget remaining would perhaps drop to ~28 Mt, implying only 15 years left at that rate, requiring a dramatic cut thereafter.

Table 3. Illustrative Carbon Budget Depletion Schedule, Anglo American (Scope 1+2)

	Emissions (Mt CO_2)	% Change vs prior	Carbon Budget Remaining (Mt)
2020	4.5 (baseline)	–	50 (starting budget)
2021	4.4	-2%	45.6
2022	4.0	-9%	41.6
2023	3.6	-10%	38.0
2024	3.3 (proj)	-8%	34.7
2025	3.0 (target)	-10%	31.7
2030	2.0 (target)	-33% (from 2025)	~20.0
2040	0.0 (net-zero)	-100%	0

We recommend companies include such tables or charts in sustainability reports. Some are already doing pieces of this, as the Science Based Targets initiative requires tracking progress against carbon reduction targets, which is essentially monitoring a carbon budget.

Accounting Implication

How to translate this into financial terms? One approach is to assign a cost to each ton of carbon "used" akin to depletion. Possibly, use the internal carbon price or the market carbon price as a proxy value. For example, if Anglo has an internal carbon price of $50/ton CO_2, then emitting 4 Mt might incur a notional $200M carbon depletion cost. This could be recorded as an expense (and perhaps credited to a liability or provision for future carbon costs). Over time, this accrues a fund that could be used for carbon mitigation projects or to purchase offsets if needed to stay within budget.

For oil companies, the bigger challenge is Scope 3 (i.e., the emissions of customers burning oil and gas). One could allocate a portion of their reserves as "unburnable" under climate targets. For instance, if BP has X billion barrels but only X/2 can be burned under 1.5°C scenario, then half the reserves are effectively stranded. A prudent accounting might be to impair that half of reserves (or not count them in sustainable income calculations). Alternatively, treat the production of oil as drawing down both the oil reserve and the carbon budget, requiring a user cost that covers both aspects, which could be very large.

Human and Social Capital: Extending the User Cost Paradigm

While the core user cost model addresses natural capital (e.g., minerals, oil reserves), true sustainability calls for maintaining all forms of capital, including human and social. Extractive industries often operate in remote, challenging environments with intensive labor and significant community interaction. There is a risk of depletion of human capital (if the workforce is overstrained or not renewed) and depletion of social capital (if community relations deteriorate or social license to operate is eroded). If a company effectively "uses up" its workforce or its social license in the process of extraction, that is an economic cost not captured on the balance sheet [1].Next, we address human and social capital to complete the multiple capital maintenance overview.

We propose treating investments in workforce and community as analogous to the reinvestments needed to offset resource depletion. In practical terms, this means defining a Human Capital User Cost and a Social Capital User Cost, portions of profit to set aside each period to maintain these capitals.

Human Capital User Cost: Potential metrics and approach

A company could track indicators such as employee turnover rates, average tenure, training hours per employee, health and safety statistics (injury frequency, fatality rates), and employee engagement or satisfaction scores.

If these metrics indicate that the workforce is being depleted (e.g., rising turnover, increasing injury rates or severity, reduced productivity), the model would allocate a larger user cost to human capital to "replenish" it. This could mean more hiring, training, health and safety investments, essentially using some profit to restore human capital.

For example, if historically the company's data shows it effectively "uses up" 5% of its workforce capacity per year (through retirements, injuries, burnout not offset by training), one might argue 5% of the value-added should be reinvested into workforce development. This could be paying for training programs, improved safety measures, or other HR initiatives.

We draw inspiration from the idea of human capital accounting where labor is viewed as an asset that provides future returns [6]. Some have even proposed capitalizing certain labor costs (like training) on the balance sheet as investment. We stop short of altering the formal accounting treatment of wages (which remain expenses), but conceptually, if a firm is underspending on training relative to its attrition, we treat that shortfall as eroding future income potential.

In U.S. mining, the NIOSH has tools to estimate costs of injuries. From 2008–2017, 404 U.S. mining fatalities had a median societal cost of $1.42 million each. Non-fatal injuries also cause lost productivity and medical costs that can reach several times the direct costs [41]. If a company had, say, 5 fatalities and 100 serious injuries in a year, the total societal cost might be tens of millions. A proactive company might invest an equivalent amount in safety improvements. Our framework would label that investment not as discretionary but as necessary to maintain human capital, and if not done, it's a reduction in sustainable income.

Social Capital User Cost: Potential metrics and approach

Indicators could include community investment as % of profits, number of unresolved community grievances, local employment or procurement rates, measures of trust or reputation, via surveys or social license indices, frequency of conflicts or protests, etc.

If a company is neglecting the local community, e.g., minimal community spending, lots of complaints, perhaps incidents of unrest, then it is effectively drawing down social capital. The cost of this can manifest as delays, strikes, or forced shutdowns which have real economic impacts.

For instance, Newmont experienced a strike at a Mexican gold mine that reportedly cost the company $3.7 million per day in lost revenue [42]. A prolonged community conflict can easily cost a mining firm hundreds of millions (lost output, security costs, reputational damage). If a company knows such risks exist, it should be investing in community relations proactively.

We might set a target like “for each $1 of resource rent, allocate X% to a community development fund.” If the company fails to do so, the shortfall is a reduction in sustainable income. Essentially, some of what is counted as profit should actually be seen as needed to pay for maintaining goodwill and social stability.

To quantify, one could model the NPV loss from a potential disruption and amortize it as a risk cost. E.g., if there’s a 10% chance each year of a strike that would cost $100M, the expected cost is $10M/year, arguably the company should be spending at least that in preventive measures (or count that $10M as a cost of doing business impacting sustainable income).

Admittedly, quantifying human and social capital depletion is more challenging than natural capital. There is not a clear unit like a ton of ore or CO_2. We may rely on proxies and estimates. The key is to signal that these forms of capital do matter financially. By including even rough estimates in the accounting, management attention is drawn to them. Over time, the metrics can be refined.

Some jurisdictions are moving in this direction. The IFRS Foundation, through the new ISSB standards, is encouraging disclosure of human capital and community impacts (ISSB’s sustainability standards in 2023 cover some of this qualitatively). Also, frameworks like Integrated Reporting advocate multi-capital accounting. Our approach operationalizes it in monetary terms.

If we integrate human and social user costs in the income statement, we’d have additional lines akin to “Human Capital Maintenance Reserve” and “Social Capital Maintenance Reserve” as expenses. It would reduce current profit further, but ideally ensure those funds are used for training programs, health & safety upgrades, community projects, etc. The balance sheet would have corresponding reserves or higher provisions for employee and community obligations.

Data Transparency and Technology for Implementation

Implementing an expanded accounting framework that spans multiple forms of capital will require robust data collection, verification, and reporting systems. Many companies struggle with even basic ESG data quality and trust. Here we discuss how modern digital technologies, particularly blockchain/distributed ledgers and secure data sharing platforms, can facilitate trustworthy sustainability accounting and overcome practical challenges.

The Challenge

When a company reports something like “we set aside $100M this year in a natural capital reserve and invested it in X”, how do stakeholders know that’s true and not greenwashing? Similarly, metrics for human and social capital can be prone to selective disclosure. Confidence in these novel accounting measures will make or break their adoption [44].

Blockchain as an Audit Trail

Blockchain technology offers an immutable, transparent ledger that multiple parties can trust [18,19]. A company could use a permissioned blockchain shared with its auditors, regulators, and even community representatives to record key sustainability data entries:

- Reserve and production data (from geology and ERP systems) can be logged as transactions (e.g., “tonnes extracted from mine A on date, remaining reserve updated”). This supports natural capital accounting.
- Emissions data (from IoT sensors or monitoring systems) can be logged for carbon accounting.
- Expenditures earmarked for the user cost reserve can be tracked, e.g., the $100M set aside is deposited into a specific account or investment vehicle, and each use of those funds (to build a solar farm or rehabilitate land) is recorded on the ledger.

By doing so, external stakeholders can query the blockchain or receive reports knowing that the data entries cannot be easily tampered with after the fact. It builds trust that the “user cost” money isn’t being quietly diverted elsewhere.

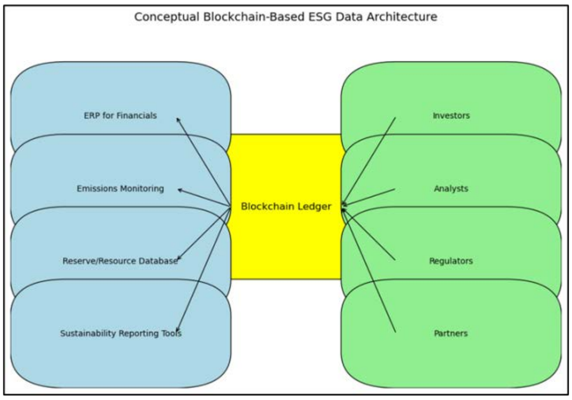

Figure 3. Blockchain-Based ESG Data Architecture Integrating Company Systems with a Shared Ledger

Privacy and Data Sharing

Sensitive data, such as reserves or costs, can be protected using technologies like decentralized identity and data trusts. The Energy & Mines Digital Trust (EMDT) pilot in Canada (2024) exemplifies this. In EMDT, mining companies have digital credentials for ESG metrics (e.g., "safety rating = Level A" or "no tailings incidents this year"). These credentials can be shared selectively with stakeholders via secure wallets without revealing raw data. Blockchain guarantees the authenticity of these credentials, signed by trusted authorities like government inspectors.

Applying to our case, a company could have a credential for its sustainable income figure or user cost reserve verification (possibly issued by an auditor). When publishing its annual report, it also publishes the cryptographic proof that an auditor validated the reserve fund transactions. Stakeholders can verify the proof on a blockchain explorer. This goes beyond just “trust us”.

Regulators are increasingly concerned with greenwashing and seek to ensure the integrity of ESG data [35]. Blockchain’s immutability and traceability offer a solution. Instead of self-reported claims, companies can use blockchain to provide verifiable tokens or hashes pointing to certifications, countering greenwashing effectively.

Key Policy Recommendations

Policymakers should develop an accounting framework that emphasizes sustainability. Here are some key recommendations:

Require "Sustainable Income" Reporting

Regulatory bodies, such as securities commissions, should request extractive companies to provide an additional income statement reflecting natural capital depreciation and other sustainability adjustments. For example, the U.S. SEC could mandate oil, gas, and mining firms to present a Resource Earnings and Reinvestment Statement. This document would detail how much of the current earnings are derived from depleting resources and how much is reinvested. Initially, even if this requirement is solely for disclosure purposes, it will help establish this practice. The EU's CSRD might ask for reporting of "adjusted earnings after resource depletion". As major jurisdictions implement this measure, it can set a global standard since multinational companies would adhere to it worldwide.

Governmental Incentives

Governments can promote sustainable practices through fiscal policy by offering tax deductions or credits for profits reinvested into projects like renewable energy and community infrastructure. Investments in these areas could be fully deductible, encouraging sustainable actions and benefiting governments with more stable companies and preserved resources.

Integrate sustainability metrics into the Standards

Bodies like IASB and FASB should include natural capital accounting principles in standards or guidance. Updated guidance such as an IFRS 6 update or a new Practice Statement on Sustainable Extractive Activities is feasible. The ISSB can develop standards for natural capital and biodiversity alongside climate standards. National regulators could require external assurance on reserve estimates and sustainability adjustments for credibility.

Foster Industry Adoption via Collaborative Initiatives

Industry associations (e.g., ICMM for mining, IPIECA for oil & gas) should develop voluntary frameworks for user cost accounting. If leading companies pilot the approach (say, one large mining company voluntarily publishes sustainable income alongside normal income), it can serve as a model. Collaboration through these bodies can also refine methodologies (like consensus on discount rate use, or standard metrics for human capital cost).

Encourage Integration in Investment Decision-Making

Sovereign wealth funds, pension funds, and ESG-focused investors could demand sustainable income information as part of their investment analysis. Rating agencies might incorporate it into credit assessments (e.g., adjusting EBITDA for depletion to gauge true debt service capacity). If investors start pricing in these factors, for example, valuing companies with high sustainable income multiples rather than just high accounting income, it creates market pressure. Policymakers can aid this by standardizing definitions (so that one company's "sustainable income" is comparable to another's).

By focusing on these key actions, we believe adoption can accelerate. The cost of inaction is that companies continue distributing what appears to be profit but is actually erosion of future value, leading to economic issues down the line (ghost towns after mine closure, stranded assets in oil, etc.). The above measures aim to prevent that through transparent accounting and proactive reinvestment.

Conclusion and Future Outlook

In conclusion, our research demonstrates that integrating user cost accounting for natural resources, and extending it to carbon, human, and social capital, is not only theoretically sound but also empirically and practically feasible. By adjusting financial results to account for the depreciation of all forms of capital, companies in extractive industries can provide a more truthful representation of their sustainable earnings. This, in turn, equips stakeholders to make better decisions aligned with long-term value and resilience.

Future Research and Development: This study opens several avenues for further work:

- Biodiversity and Ecosystem Services: Future research can develop quantifiable metrics for biodiversity loss due to extraction (e.g., an "extinction footprint" or habitat hectares lost) and analogous user costs to ensure companies invest in conservation or restoration to offset this. For instance, how might a mining company account for impacts on water resources or forests, and what investment is needed to maintain ecosystem services?
- Refining Human/Social Capital Metrics: There is room for interdisciplinary work with organizational psychologists, health experts, and economists to refine the human and social capital cost models. Perhaps advanced modeling (e.g., system dynamics simulations) could better estimate how insufficient training now leads to productivity losses later, giving a basis for the user cost. Large-scale data on mining community outcomes could help price social externalities more rigorously.
- Stakeholder Education: Educating managers, investors, and local communities about these new metrics is critical. Future efforts might involve creating toolkits or simulation games for managers to see the long-term impact of reinvestment vs. depletion. Academia and industry training programs should incorporate sustainable accounting concepts so that the next generation of accountants and engineers naturally thinks in these terms.
- Cross-industry application: While we focused on extractives, future research could apply similar thinking to other sectors with depleting assets, e.g., soil quality in agriculture, fisheries stock in marine industries, even employee burnout in high-tech. Adapting the user cost idea to those contexts could bolster sustainability across the board.

Ultimately, the goal is that sustainability accounting becomes as routine and trusted as financial accounting. When that happens, company valuations, executive incentives, and stakeholder decisions will naturally align with long-term preservation of value, in other words, sustainable development in practice.

The journey to that point requires collaboration between academia, industry, and regulators. We hope this work provides a foundation and impetus for that collaboration. By demonstrating concrete methods and tangible benefits, we aim to shift the mindset from viewing sustainability as an externality or a cost, to seeing it as an integral part of measuring true profit. As the adage goes, "what gets measured gets managed." It's time to measure sustainable income, and manage for it.

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