DOCTORAL THESIS

Economics of Mineral Resources and the Environment

Studies from Mozambique

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Economics

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LULEÅ UNIVERSITY OF TECHNOLOGY

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To William and Willmya

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José Jeremias Ganhane

Abstract

This thesis consists of studies of the economics of mineral resource exploitation and their environmental impact, reported in four papers. **Paper I** replicates two seminal papers from the early 2000s which indicated that the correlation between genuine savings and future consumption was weaker than theory predicted, at least when genuine savings were measured using the World Bank estimates. The aim of this paper was to examine whether the correlation has become stronger over time, on the back of policy changes in resource-rich countries and of revisions to the World Bank estimates. The results indicate that the correlation between genuine savings and future consumption growth may be stronger for poorer countries than for richer, and for sub-Saharan Africa, the theoretical predictions appear to hold. **Paper II** estimates resource rents for Mozambican coal mining using company-level data employing the residual value method devised by SEEA-Energy (the multi-purpose conceptual framework for organizing energy related statistics) and compares the findings with the World Bank's estimates of coal rents. The latter estimates are often used in the resource curse literature and guide the World Bank's policy notes, forming the baseline of their policy advice on resource exploitation. On average, the results show that the World Bank overestimate overstates coal rents for Mozambique considerably. The main driver of this overestimation is the World Bank's underestimation of extraction costs. The results suggest that studies employing resource rent estimates should consider sensitivity analyses and greater use of local data, and that the World Bank's policy advice should be interpreted cautiously to avoid unreasonably high expectations. **Paper III** implements a choice experiment to examine the willingness to pay for improved water supply and forest use currently degraded due to mining activities, with a specific focus on how different household groups near coal mines value these services. The survey sample comprised 419 households in Moatize, Mozambique. Overall, the estimation results obtained via a latent class conditional logit model indicate that four classes of households exist, with different preferences across classes. The main drivers of class membership include gender, income, education and age. All classes express dissatisfaction with the status quo, and improvements in water supply is generally highly valued. However, the four groups in some cases express quite different valuations of the proposed improvements. Development interventions attempting to address the environmental impacts of mining should therefore consider the heterogeneous preferences of the intended beneficiaries, and how experiences from previous interventions are likely to affect attitudes toward new interventions. **Paper IV** uses the contingent valuation method to estimate displaced and resettled Mozambican households' willingness to pay (measured in labour) to restore the landscape where they used to live before mining began there. The study results indicate that, on average, households were willing to contribute about nine working days per month. The results further indicate that resettled respondents had been adaptive and had used the monetary compensation they were given for resettlement to buy productive land to offset that lost due to resettlement. However, they still saw themselves as worse off than before their relocation. One explanation for this is that they are now far from marketplaces and the river, making it difficult to develop new sources of income and have access to water. Mitigation interventions and future resettlements should therefore think more carefully about selecting resettlement sites.

List of Papers

Paper I: Ganhane, JJ & J Stage, Resource rents, Genuine Savings and sustainable development: Revisiting the evidence. *Sustainability*, 2024. **16**(15): 6535 https://doi.org/10.3390/su16156535

Paper II: Ganhane, JJ & J Stage, Estimating resource rents for Mozambique. *Resources Policy*, 2024. **94**: 105137 https://doi.org/10.1016/j.resourpol.2024.105137

Paper III: Ganhane, JJ, Heterogeneity in preferences for water supply and forest use near a coal mine. 2025. *Manuscript.*

Paper IV: Ganhane, JJ, Willingness to pay for post-mining landscape restoration. 2025. *Manuscript*.

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Preface

Section 1

Introduction

Natural resources from the extractive industry provide raw materials for various key sectors for global economic development, including manufacturing, construction, transportation and energy. A country's extractive industry can stimulate economic growth through job creation as well as through generating tax revenue that can be invested in economic and social infrastructure, education, healthcare and productive industries [1, 2].

Despite their positive effects, however, extractive industries are also responsible for many adverse environmental impacts, particularly on the biodiversity, ecosystems and landscape where the exploitation of the resources occurs. These environmental costs include habitat destruction, air and water pollution, and soil erosion [1–5].

This thesis studies economic aspects of mineral exploitation, focusing on Mozambique. About 40 different mineral resources are known and over 350 deposits or occurrences are included in Mozambique's industrial mineral database. So far, however, commercial mining has played a relatively minor role in the development of the country and improvement of social welfare [6].

Many natural-resource-rich countries in Africa and elsewhere face the challenge of harnessing their resources for sustainable economic development. They usually share the struggle with factors such as mismanagement, rent-seeking and, at times, conflicts over natural resources. This can hinder economic development and exacerbate poverty and inequality [7].

Hence, it is important to ensure that the benefits that a country experiences from its extractive industries are enough to offset the associated costs of mining, so that the country gains from such industries. The process of exploiting natural resources should therefore be guided by the principles of sustainable development to ensure that social, economic and environmental aspects are considered while those resources are exploited.

The trade-off between benefits and costs created by the extractive industry calls for measurement of both. On the one hand, there is a need to accurately assess the benefits, examine whether or not the gains from extraction are reinvested in the economy and identify the impacts of such reinvestment. On the other hand, information about the costs, including the negative environmental impacts for local communities and other stakeholders, is required to assess the country's net gains from natural resource exploitation. Ignoring environmental costs risks underestimating the role of the environment in supporting human welfare [4, 5].

Over time, the gains accrued from the depletion of one of type of capital (e.g. by extracting natural resources) should be reinvested in other forms of capital. The concept of *weak sustainability* entails maintaining the total wealth of a country, measured as a sum of its different capital stocks, including natural, human and produced capital [8]. Given these stocks of capital, an economy is developing in a sustainable manner if it ensures a non-declining total capital stock over time. If weak sustainability holds in an economy, the satisfaction of current consumption needs will not compromise the satisfaction of the consumption needs of future generations. Hence, future generations will have consumption possibilities similar to or greater than those of the current generation [9].

A *sustainable development path* is one along which intergenerational, non-decreasing welfare is maintained at constant levels [10]. Reliable indicators of sustainable economic development are an important starting point from both a research and a policy perspective. At any particular time, researchers and policymakers need to be able to examine whether an economy is developing sustainably at that point. Such examinations guide economic policies for maintaining an economy's development on a specified path, monitor whether such development is in line with sustainability, and are used for proposing timely intervention measures to achieve a sustainable path if the economy is deviating from it.

One indicator of country's sustainable development path is the change in its capital stocks over time [10]. Traditional measures of saving and investment focus on produced capital – without, however, accounting for natural or human capital. Thus, a more comprehensive indicator is required: one that also accounts for other forms of capital that could be used to measure sustainability. In an attempt to fill this gap, the economics literature has proposed a composite indicator known as *Genuine Savings* (GS) [11]. GS entails enlarging the concept of net savings to account not only for the depletion of, but also the investment in, natural resources, pollutants and human capital [12].

The interpretation of GS is straightforward. Countries with negative GS rates are currently depleting their overall capital stocks and need to redirect their development path towards sustainable levels of such stocks; conversely, those with positive rates are assumed to be achieving sustainable development [13]. Countries with a positive GS rate should, therefore, experience non-declining future consumption [10].

The World Bank has computed and published GS estimates on a regular basis for more than 100 countries since the early 2000s. Given the popular use of these estimates in both research and policy advice, assessing their empirical accuracy is important.

Ferreira and Vincent [14] were the first to test the accuracy of the World Bank's estimates of GS as a forward-looking indicator of sustainability. They found that these estimates failed to explain the difference between current consumption and average future consumption. The correlation between these two variables was positive and significant only when the sample was limited to countries who were not members of the Organisation for Economic Co-operation and Development (OECD). However, even then, the correlation was weaker than what theory would have predicted.

Hamilton and Hartwick [15] extended the analysis to consider the wealth dilution effects of population growth on per capita wealth. Ferreira et al. [16] expanded Ferreira and Vincent's [14] approach to account for this, but found no substantial changes when they compared the results of the original [14] and expanded [16] analyses.

However, there are important shortcomings in the World Bank's estimates of GS which may help explain this apparent discrepancy with theory. For example, the use of data on current expenditure on education as a proxy for investment in human capital does not allow deductions of losses from human capital [12–14, 17, 18].

The accuracy of the World Bank's GS data also depends on the quality of the indicators used to measure the gains from extracting exhaustible resources. An important question that arises here is how to calculate those gains. It is a given that the economic value of natural capital is the present value of future sales from the attained resources after deducting extraction costs. This economic value of natural resources – the net price – is defined as the *resource rent* [19]. Resource rents are measured as the surplus revenue accruing to the owners (or extractors) of the resource after deducting the cost of capital and variable inputs [20].

The accuracy of resource rent estimation is important to the evaluation of sustainable economic development. Accurate calculations of resource rents are not only a fundamental component of GS estimates, but they are also essential for economic planning and for decisions about the proper management and reinvestment of revenues accrued from the extractive sector. However, calculating such rents is a complex exercise: it requires knowledge of prices, marginal extraction costs, discount rates, extraction rates, reserves, and the expected lifetime of the deposits concerned [19, 20].

Another useful World Bank publication in this regard are its estimates of resource rents for most countries. These estimates are also used in calculating GS as a measure of non-renewable-resource depletion. The World Bank uses the same method for all countries, the net price method, and relies on standard international data sources. To calculate natural resource rents, the World Bank collects data on the average unit production cost of each resource, if such data are available, and estimates the production cost where no data exist. The average export price per unit of each commodity in the international market is then estimated, and data are collected on the country-specific physical quantities of each resource extracted. From there, the unit of resource rent is calculated as the difference between the average unit cost and the average export price [18].

When production costs are not available for a specific year in a specific country, depending on data availability, the World Bank uses one of three methods to estimate year-by-year extraction costs. The first method, adopted for countries where no extraction cost data are available at all, consists of assigning a surrogate extraction cost from another country or from the entire region based on geographic proximity. In the second method, used for countries that only have extraction cost data for a single year, extraction costs are calculated from that single data point under the assumption that production costs remain constant in real terms. The third method, applicable to countries with extraction cost data for at least two different years, estimates extraction costs as a linear interpolation between the two years [18].

The use of extraction cost data based on regional and international average estimates may, however, lead to an estimation error of the resource rent compared with what country-specific cost estimates would show. That is, the total cost in a specific country encompasses both capital and operating costs. With respect to mining, the capital cost estimation is affected by the size and nature of the mines concerned, their ore quality and their plant sites. These may vary between countries, leading to errors if regional or international averages are used. Similarly, the estimation of operating costs depends on a range of different costs that may vary considerably from country to country [21–23]. Also, on the revenue side, mining activities may exploit mixed deposits with resources of different market value, such that the average export price may not be a good guide to the revenue from an individual mining operation.

In addition, World Bank resource rent estimates rely on market prices and data on average costs of extraction available in standard international data sources. These data may differ from country-specific revenues and costs. Finally, only a very small sample of exhaustible natural resources is included. Thus, for countries having a variety of resources, the estimate of total resource rents may differ considerably from the true estimate that would be obtained if all resources were included in the calculation per country [12–14, 17, 18].

SEEA-Energy – the United Nations' multi-purpose conceptual framework for organising energy-related statistics – recommends that, rather than use the net price method as the World Bank does, resource rents should be estimated through the residual value method. In the latter method, rents from non-renewable resources are calculated by deducting the total user cost of the produced asset used for the extractive activity, the specific subsidies on extraction, and specific taxes on extraction, from the gross operating surplus. The advantage of this method is its greater use of data that can be collected at mining company level [24].

As noted, even the costs of the mining companies themselves can be complex to estimate. Another important consideration in designing policies for extractive industries are the external costs from the environmental impacts caused by the extraction of mineral resources. Many of these impacts are borne locally and can be significant, and they may sometimes leave local communities worse off than before mining activities began. To minimise these negative impacts while ensuring mineral extraction remains sustainable, key tools such as environmental regulations and sustainable mining practices can be implemented [1, 4, 25]. Measures that mitigate impacts and even possibly reverse them once mining operations cease can also help to achieve sustainable development. It is therefore important to keep track both of what the environmental impacts are, and what costs these impacts impose on local communities.

However, the standard measures of market consumption exclude the non-market values that the environment contributes to welfare [26]. Furthermore, the non-existence of (or limitations in) market transaction data makes the measurement of environmental values for use in applications such as cost–benefit analysis more difficult [27, 28]. Thus, to assess how changes in the environment affect human welfare, non-market valuation methods are frequently used.

The advantage of non-market valuation methods is that they help to assess the shadow monetary value of environment-related services. This shadow value can also be used to manage the trade-offs between market activity and the environmental quality implicit in the process of production and consumption. Moreover, non-market valuation studies can provide information on the roles of the environment in supporting human welfare [26].

The value of non-market goods can be estimated either by direct or indirect methods. Direct methods include discrete choice experiments and contingent valuation, while indirect methods determine these values from indirect sources such as averting behaviour, travel cost, demand dependency, and hedonic pricing [29, 30]. This thesis will apply only direct methods, for reasons explained below.

Both discrete choice experiments and contingent valuation have their theoretical ground in Lancaster's [31] approach to consumer theory, where goods and services comprise sets of attributes that consumers value. The difference between these two direct methods is that discrete choice experiments are appropriate in studies that aim to value changes in environmental goods or services that are functions of multiple attributes, while contingent valuation is suitable to estimate values for a change considered as an indivisible whole when the studied object cannot be easily defined in terms of attributes [28].

The discrete choice experiment (or simply *choice experiment*) is a preference-based valuation method which creates hypothetical scenarios in which respondents are asked to complete a series of choice sets (also called *choice tasks*) consisting of several multi-attribute alternatives, based on their preferences [27, 28]. The respondents' choice information allows the analyst to estimate economic values for attributes of an environmental good or service under analysis by including price or cost as an additional attribute [27, 32].

In the contingent valuation method, a hypothetical scenario is created, and respondents are asked to vote for or against the scenarios. This approach can entail a single-bounded referendum (where participants vote on a single value presented to them) or a double-bounded one (where respondents are asked questions about initial and follow-up bids) [33–40].

In this regard, a Pareto principle has an important contribution to make in the valuation estimates. The principle states that a change will provide a net gain in welfare if the losers are fully compensated for their losses and the gainers still feel that they gained from the transaction [41]. This principle leads to two monetary measures of the utility changes associated with changes in the quality or quantity of environmental goods, namely the willingness to pay (WTP) and the willingness to accept (WTA) [41]. According to the theory of environmental valuation, a household's *compensating surplus* (CS) for an increase in the quality or quantity of an environmental good can be defined as the maximum amount that that household is willing to pay (WTP) to enjoy such an increase. Conversely, the CS for a reduction in the environmental good in terms of its quality or quantity can be defined as the minimum compensation that would make the household willing to accept (WTA) such a reduction and keep its initial level of utility. The same theory defines *equivalent surplus* (ES) as the maximum WTP to avoid a quality or quantity reduction in the environmental good or, conversely, the minimum WTA compensation in lieu of a quality or quantity increase in the environmental good [30]. Hence, environmental valuation methods are critically linked to the concepts of WTP and WTA [26].

Another factor to consider in contingent valuation is that individuals have a well-being reference status – which is not necessarily the status quo – to which they compare the outcome of a change in their well-being due to an intervention. This reference status is linked to what the individuals themselves consider to be an acceptable level of well-being. Individuals consider positive changes in well-being in ranges that exceed above their reference status as gains, while changes in ranges below that status are considered as losses [41, 42].

The WTP concept is appropriate for measuring gains, including these. The tool is especially useful when respondents can be asked questions about their maximum WTP to acquire such gains or their WTP to avoid a reduction in them [28, 41, 43]. The principal advantage of this measuring tool is that the maximum WTP amount is bounded by the respondent's budget [43].

The WTA concept, on the other hand, is appropriate for measuring losses, particularly in situations where respondents can be asked questions about what minimum compensation would make them WTA incurring a loss or foregoing a reduced loss [28, 41–44]. One of the drawbacks of the WTA in practical research, however, is that it is unbounded, as respondents have few incentives to answer with their true minimum acceptable value; this is especially the case when they face open-ended questions [43]. This unboundedness permits respondents to ask for extremely large amounts of compensation. Another disadvantage of the WTA is that offers of compensation to respondents can be perceived as bribes [42].

A final factor to take into account in employing the WTP and WTA concepts is the individual's aversion to loss. Due to individuals' loss aversion, even where losses and gains are equivalent in magnitude, losses are valued more than gains [41, 42, 45]. Hence, WTA values are generally greater than their WTP counterparts [42, 45, 46]. Due to this disparity, and the empirical issues with WTA estimation discussed above, WTP is generally recommended as the default approach to measuring welfare impacts [28].

Section 2

Overview of Mozambique's Extractive Industry

Mozambique's extractive industry is composed of the hydrocarbon and minerals subsectors. While the hydrocarbon subsector deals with the country's oil and gas, the minerals subsector is concerned with its mineral resources. A significant characteristic of this industry is its relatively high share of foreign capital, which is linked to the large number of so-called megaprojects spanning both subsectors. One such megaproject involves exhaustible natural resources including coal, natural gas and heavy mineral sands. [47].

This section presents an overview of Mozambique's extractive industry and its relation to sustainable development via policies based on converting exhaustible natural capital into reproducible capital to sustain the country's consumption needs over time. In practice, this conversion process entails four main components: i) the discovery and evaluation of resource deposits; ii) the extraction of those resources; iii) the appropriation of related resource rents, and iv) the reinvestment of such rents in reproducible capital [48]. The following sections discuss these components.

2.1 Resource discovery and evaluation

In the discovery phase, the government grants exploration licences to companies to conduct geological surveys of resource deposits. This phase lasts until such licences expire, giving way for the government to grant extraction licences [48]. In the last two decades, Mozambique has seen a rapid growth of investments in the exploration and exploitation of exhaustible natural commodities. Companies have made discoveries that have increased the country's resource base, and the country is now poised to become a major exporter of natural gas, coal and valuable natural resources.

For instance, in the early 2000s a massive coal deposit was discovered in Tete Province, in the country's west-central region. The confirmed deposit is estimated to hold over 32 billion tonnes [49]. Moreover, in 2009, companies discovered enormous gas fields in the Rovuma Basin in the northern part of the country along its border with Tanzania. The Basin is estimated to hold 130 trillion cubic feet of confirmed gas reserves, which could allow Mozambique to become one of the world's top 15 countries in this regard, potentially making it a major exporter of liquid natural gas and other hydrocarbon fuel products [49–51]. Many other resources have been discovered and are currently being exploited [47].

As mentioned in section 1 of this chapter, the World Bank's resource rent estimates, besides being used as indicator of resource depletion in GS calculations, are also used to estimate the monetary value of a country's stock of natural capital. Thus, the already discussed shortcomings in resource rent estimation also have implications for the estimated value of countries' natural wealth. If one nonetheless uses a country's unit rent as a simple estimate of the value of the physical quantities of a discovered resource, the value of natural capital at any point in time is the total value of all that country's known deposits, estimated as the product of its total reserves and unit rents (see **Figure 1** for some selected exhaustible resources). The change of a country's capital stock value over time can therefore be due to a change in physical quantities as a result of new discoveries; a change in market price due to changes in demand and/or supply; and fluctuations in extraction costs caused by technological advances and other factors.

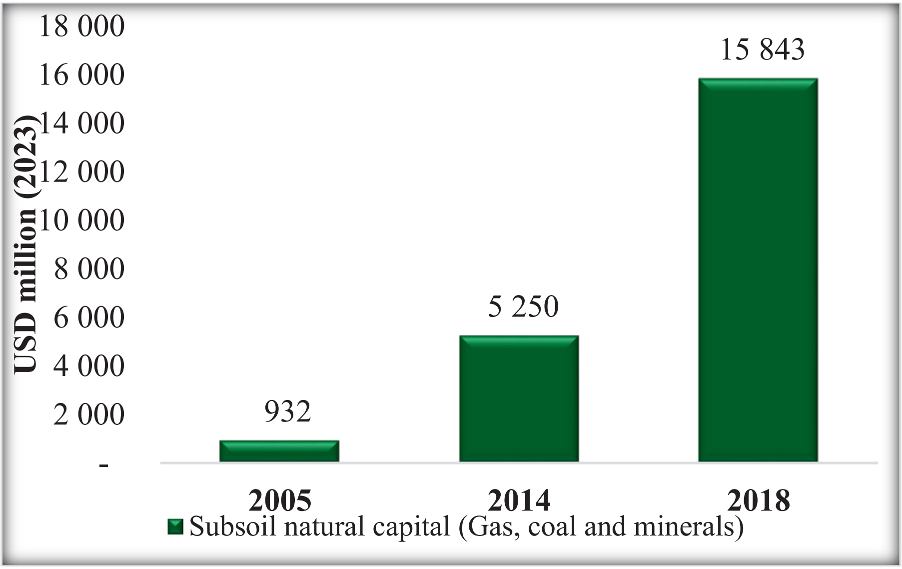

Figure 1. Mozambique's Subsoil Natural Capital
Sources: [52-54]
Note: other minerals include bauxite, gold, and lead.

Figure 1 shows that Mozambique's exhaustible natural wealth increased significantly between 2005 and 2018, thanks to an increase of confirmed deposits resulting from new discoveries. Notably, the estimates reported in **Figure 1** are not comprehensive, as they include only a few exhaustible minerals. Difficulties in estimating resource rents per se as well as a lack of data are part of the reason why many other natural resources are excluded from these estimates. Nonetheless, the information presented in **Figure 1** is sufficient to show the effects of these discoveries on the value of Mozambique's capital stock. Another point to note is the importance of accurately estimating resource rents, given their relevance in determining the monetary value of the natural capital that makes up the value of economic wealth at a given time.

In theory, reserves include confirmed reserves, currently subeconomic and hypothetical reserves, and speculative or hypothetical resources [55]. However, only confirmed reserves are included in natural capital stock value estimations, because of the uncertainty associated with the other reserve types. Given that the value of natural capital depends on three main factors – physical quantities, market commodity prices, and extraction costs – the value of depletion of resources that should be saved and reinvested to sustain the total capital value for future generations depends on the dynamics of these three variables over time.

2.2 Resource extraction

Once exploration is completed and if economic viability is confirmed, the government grants the mining company in question an extraction licence. These licences entitle companies to start extracting, producing and monetising the resources concerned. The extractive industry in

Mozambique is currently dominated by the hydrocarbon subsector, principally coal (see **Table 1**). The extraction of natural gas began in 2004 at the Sasol gas-processing plant in Inhambane, in southern Mozambique [48, 49].

Mozambique also plays a significant role in the global production of mineral commodities. For example, the country was ranked as the world's fourth producer of ilmenite – accounting for 11% of global production in 2017. Its graphite production accounted for 10% of global output in 2019, ranking the country second in the world (after China) as regards this commodity. In the same year Mozambique was the third-largest producer worldwide of beryllium and the fourth-largest producer of zirconium, accounting for 6% and 7%, respectively. More comprehensive production data on the extractive industry for the period 2008–2023 are presented by commodity in **Table 1** [56].

Extracting natural resources requires technical expertise and capital – which Mozambique lacks. Consequently, the country relies on large foreign-owned mining companies to do so, thus holding a relatively weak bargaining position when extraction contracts are negotiated. Moreover, contract negotiations make it possible to reach contract terms that may deviate from the applicable legal framework, and in some cases this may harm society at the local level [48].

Table 1. Mozambique's extractive industry production: 2008–2023

Name	Unit	2008	2009	2010	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023
Aquamarine	tonne	2.55	0.59	1.58	0.06	0.59	0.65	na	na	0.34	0.51	0.01	0.01	0.06	0.03	3.14	0.31
Bauxite	10^3 tonne	5.44	3.61	8.56	10.35	8.63	6.19	3.33	4.99	1.45	3.18	9.91	8.02	6.49	7.85	14.58	5.48
Bentonite	10^3 tonne	18.28	92.68	11.88	0.92	25.46	22.10	28.42	74.22	73.85	88.28	98.55	77.73	80.19	118.69	113.99	71.59
Beryllium	tonne	8	45	57	58	532	103	3	35	181	53	381	45	80	330	1 285	882
Cement, hydraulic	10^3 tonne	744	777	884	976	1 184	1 299	1 502	1 585	2 446	2 350	2 400	2 700	2 800	3 000	na	na
Clay	10^3 tonne	80	16	43	254	47	939	1 116	589	646	329	477	1 834	1 664	1 980	1 814	2 328
Coal	10^3 tonne	42	61	79	680	4 993	6 605	6 979	7 276	7 836	16 639	17 742	11 991	8 211	11 695	14 806	14 976
Diatomite	10^3 tonne	0.38	0.21	0.12	0.05	0.54	0.38	0.08	0.16	1.31	4.54	66.43	72.44	80.19	72.91	51.45	29.63
Garnet	tonne	1	3	4	25	171	2	363	384	125	159	155	129	299	172	241	526
Gas, condensed	10^3 bbl	696	na	328	398	408	416	20	458	553	409	380	302	281	266	337	1 611
Gas, natural	10^3 TJ	4	0.11	0.13	132	147	164	177	190	194	192	193	174	186	180	242	385
Gold	Tonne	0.24	0.51	0.11	0.10	0.18	0.09	0.20	0.24	0.20	0.17	0.51	0.43	0.49	0.76	1.26	1.67
Granite	10^3 tonne	5.40	0.34	na	17.22	0.08	1 267.23	74.05	1.94	0.16	0.45	0.43	2.19	2.34	0.83	4.18	7.45
Graphite	10^3 tonne	na	na	na	na	na	na	na	na	na	1.04	106.77	113.80	18.16	77.12	165.93	97.35
Gravel	10^3 tonne	114	2 890	772	846	990	1 267	1 669	2 803	1 247	3 608	3 629	4 219	3 921	2 118	2 156	1 464
Ilmenite	10^3 tonne	329	472	678	637	574	720	855	829	1 340	1 327	1 283	1 443	1 608	2 071	2 553	3 373
Lead	10^3 tonne	na	0.40	0.60	0.80	0.89	1.70	1.93	2.31	2.49	3.83	3.42	3.94	4.20	4.59	na	na
Limestone	10^3 tonne	48	234	264	947	1 322	523	901	844	728	3 246	1 053	915	1 320	1 620	1 777	2 404
Quartz	Tonne	157	141	707	839	52	57	57	1	1	0.20	361	124	163	1 189	3 511	4 188
Ruby	Tonne	na	na	na	na	na	0	1	2	1	5 503	2 964	2 261	1 599	5 012	4 215	2 711
Rutile	10^3 tonne	8.78	1.80	0.20	6.46	3.71	7.85	14.83	5.98	7.78	9.14	8.83	8.26	5.96	8.92	8.87	8.38
Sand, building	10^3 tonne	706	1 237	1 129	1 649	2 100	3 179	1 200	1 909	2 565	5 471	5 482	3 463	3 374	5 439	3 161	2 688
Tourmaline	tonne	34	6	15	26	486	514	520	20	1	4	6	4	107	127	229	99
Tantalite	10^3 tonne	0.53	0.55	0.07	0.19	0.51	0.26	0.14	0.09	0.11	0.13	0.15	0.13	0.21	0.18	0.21	0.20
Zirconium	10^3 tonne	33	21	37	37	47	37	56	58	215	160	202	122	104	123	134	144

Source: [56–58]

Note: bbl = barrel; na = data not available; α = 1 cubic metre (0.98200557276378);

2.3 Appropriation of resource rents

Mozambique's extractive industry is export-oriented (see **Figure 2**). In this regard, coal accounts for the major share of total mining exports. The two next-largest mining exports are natural gas and heavy sands.

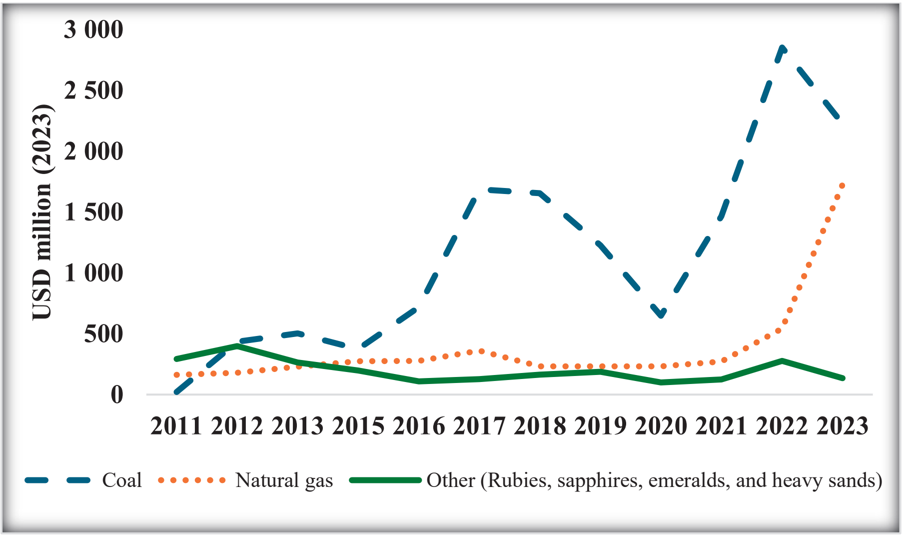

Figure 2. Resources Export from Mozambique
Source: [59]

Given that mining companies are privately owned and that production is export-oriented, the Mozambican government has attempted to design an appropriate scheme composed of tax and non-tax instruments to capture mining revenues generated from the trade of natural resources. However, limited power and knowledge around taxing firms can affect the government's ability to appropriate resource rents [48].

Mozambique's resource-rent capturing scheme currently consists of tax and non-tax instruments. Besides general taxes such as personal income tax and corporate income tax, which are also applied in the non-extractive sector, there are other taxes specific to the extractive industry, such as resource rent tax, surface tax, and royalties. The minerals royalty is termed a *production tax* [60].

Apart from various instruments the government uses to capture resource rents, it also offers tax exemptions as an incentive to encourage investment in the mining sector. The typical tax-exemption package contains general incentives for which companies can apply, such as exemptions from value added tax, customs duties, specific consumption tax and municipal taxes. Investors can also negotiate reductions in the various instruments that aim to capture the rents. In practice, therefore, rent capture is lower than what the official rates would imply. Consequently, a contract-based analysis is required to accurately estimate resource rents and their capture.

Figure 3 displays the revenue collected from the mining industry through taxation. It is clear from **Figure 3** that revenues from the mining sector are very volatile.

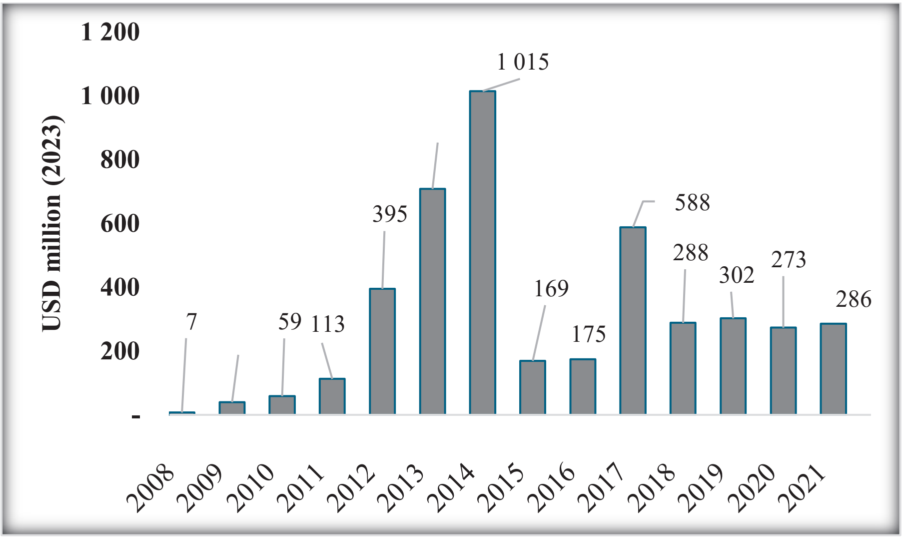

Figure 3: Extractive industry revenues (State-confirmed revenues)
Source: [61]

To give an overview of the importance of the extractive industry to Mozambican government finances as a whole, **Figure 4** presents the revenue from this sector as a share of the country's total tax revenues. The volatility and uncertainty of gains from the mining industry have in practice made it difficult for policymakers to plan and allocate revenues into long-run projects to offset the depletion of exhaustible resources. For example, high revenues can induce the government to consider the revenue increase as permanent and increase spending accordingly, and then struggle when revenues drop.

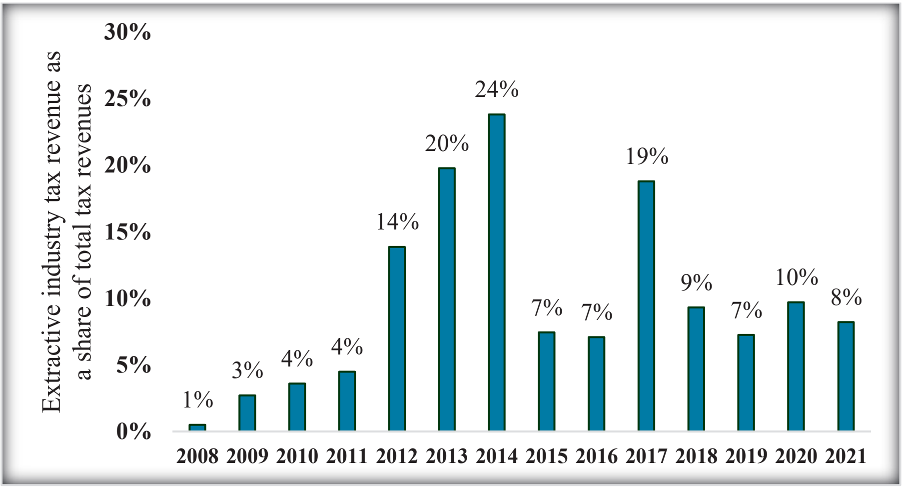

Figure 4: Extractive industry tax revenue as share of total tax revenues
Source: [57, 61]

2.4 Reinvestment of resource revenues

How the revenue from mineral exploitation is spent, and to what extent it is reinvested within the country, is of key importance. The government decides how to allocate resource revenues between current and future generations by funding current spending needs or by investing in human capital and other capital assets [48]. Historically, Mozambique has not earmarked revenue from natural resources for investment purposes, unlike the practice in many other countries. It is therefore difficult to determine to what extent natural resource revenue, specifically, is being invested.

In late 2023, the government's plans to address this issue by establishing a Sovereign Wealth Fund were approved by Parliament. Implementation of the Fund is slated to start soon. The regulation of this Fund defines the share of revenues from natural resources that may be spent versus the share that should be saved on behalf of future generations. The saved revenues in the Fund will be channelled to the state budget to cover the deficit between the projected and the effective revenues from non-renewable natural resources. Thanks to the Fund, the full projection of such revenues can be used to finance economic and social development projects, macroeconomic stabilisation, and disaster or emergency relief responses.

Beyond the allocations in Mozambique's state budget, there are two additional policy measures that can help align with the reinvestment of rents, community development requirements, and corporate social responsibility. Both follow international best practices and require legislative amendment, as detailed below.

It is a given that the management of resource revenues at central government level does not ensure a fair distribution of costs and benefits within the host country. To deal with this challenge, international best practices for the management of mining revenues advise resource-rich countries to incorporate community development requirements into their mining laws so that communities affected by mining can also benefit directly from it. This resource-sharing approach is intended to improve the redistribution of resource revenues and mitigate the negative effects of mining on communities where resources are extracted [62]. Countries who observe global standards such as these are expected to have the added benefit of attracting international mining stakeholders by their offer of a quality investment climate [62].

In Mozambique's case, the government adopted a community development component added to its mining law of 2002 [62]. Further changes were made in 2007 (Laws 11/2007 and 12/2007), which mandated that a certain percentage of mining royalties be earmarked for community development in areas where extractive-industry projects were located [63].

This revenue-sharing approach began to be implemented in 2013 (see **Figure 5**), when the government budget incorporated into the affected communities some 2.75% of mining royalties that had been collected two years before. As stated by the government in guidance on the use of such transferred revenues, they were to be managed by the members of the community hosting the resource. In terms of the law, those communities were obliged to devote the funds to suitable projects that would boost local growth and reduce poverty, e.g. by building socioeconomic infrastructure in the domains of education, healthcare, agriculture, forestry, markets, transportation and water [49].

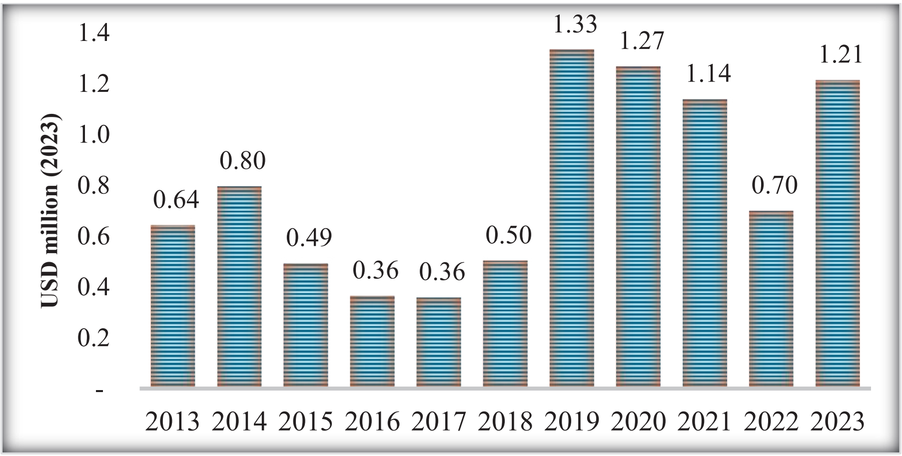

Figure 5: Resource revenues transferred to resource-hosting communities
Source: [49, 64]

Under this revenue-sharing system, the central government redistributes a portion of its mining revenues directly to the affected communities instead of implementing community development projects itself. The effectiveness of this system relies on the expenditure capacity and financial management efficiency of the local community [62].

Besides reinvesting these accrued resource revenues, the government also promotes corporate social responsibility in line with international standards. To this end, it implemented a corporate social responsibility policy for the extractive industry of natural resources (Resolution number 21/2014 of 16 May 2014) that required each mining licence holder to establish its own specific social investment targets. The policy further mandates that mining companies should not only report on such investments annually, but also that the accounting and accountability related to their social investment targets be carried out in accordance with prevailing international standards and best practices.

Since then, some mining contracts have begun incorporating development programmes. Mining companies who adopt initiatives such as these to deliver social and economic benefits to local communities have demonstrably improved their reputation in both the international and domestic mining stakeholder arena [62].

Section 3

Summary of papers

Four articles compose this thesis and are summarised below. **Papers I** and **II** were co-written by José Jeremias Ganhane (JJG) and Jesper Stage (JS). The author contributions for both papers are as follows: conceptualisation, data curation, investigation, methodology, software management, writing, original draft preparation – JJG; project administration, supervision, validation, formal analysis, writing, review and editing – JS. JJG is the sole author of **Papers III** and **IV**.

Paper I
Ganhane, JJ & J Stage, Resource rents, Genuine Savings and sustainable development: Revisiting the evidence. *Sustainability*, 2024. **16**(15): 6535.

The research reported in **Paper I** evaluates whether the World Bank's GS estimates can be used to predict the difference between current and average future consumption. According to theory, a correct estimate of GS can be effectively used as a predictor of whether a country's consumption will be higher or lower in the future compared to today's. This allows one to investigate whether a country is or is not complying with the weak sustainability theory.

The World Bank's estimates of GS are widely available comprehensive measures of countries' net investment across all forms of capital. The paper follows the approaches used in Ferreira and Vincent [14] and

Ferreira et al. [16], but uses the more recent and more comprehensive data now available to examine whether the fit with theory has improved as a result of the revisions in the data.

This study defines four alternative measures of a country's investment in produced capital, namely gross investment; net investment; net investment adjusted for depletion of natural capital; and GS. This is followed by testing three hypotheses on the correlation between GS and future consumption, namely positive and perfect correlation; positive and increasing correlation as the net investment become more comprehensive to include more types of capital; and positive correlation. The hypotheses were tested assuming both 10 and 20 years as the period over which present values were calculated to, as well as with and without considering the effects of population growth.

The first, most stringent, hypothesis was rejected in all estimated models. The estimated positive correlation, however, remained positive and significant in all estimated models. The estimates were higher in absolute values for the 20-year estimates than for their 10-year counterparts. No significant predictive power was added by adjusting for population growth. In general, little change in the results was found in comparison to the studies carried out in the early 2000s. The predictive power of GS was substantially stronger for sub-Saharan African countries than for richer countries. However, countries' levels of investment could still not be regarded as good predictors of their future consumption levels.

Paper II

Ganhane, JJ & J Stage, Estimating resource rents for Mozambique. *Resources Policy*, 2024. **94**: 105137.

Instead of country-specific data, the World Bank uses international averages to estimate natural resource rents for many countries. It is very important from both a policy and a research perspective that these rent estimates do not suffer from important measurement errors, because many studies in the literature use the World Bank's estimates of natural resource rents to test the contribution of natural resources to economic growth. Furthermore, the World Bank advises governments around the world on policies aimed at exploiting non-renewable mineral resources and on how to manage the income from such exploitation, based on the resource rent estimates for the country concerned. However, since a single coal deposit, for example, may contain different qualities of coal and, hence, be sold at different prices, the use of one global price to estimate coal rents for all countries may lead to such rents being misestimated for individual countries. Similarly, as discussed in section 1.1, the cost estimates used may also lead to misestimation of rents for individual countries.

To test for possible misestimation of resource rents, Paper II used higher-quality data gathered at company level from Mozambique's coal industry to estimate resource rents. The paper then compared its findings with the World Bank estimates for that industry. The residual value method endorsed by SEEA-Energy – and preferred to the net-price method used by the World Bank – was employed to obtain reliable estimates.

The estimates of resource rents in Paper II were found to be much more stable and consistently smaller than those published by the World Bank for the entire period under analysis. This result indicates that the World Bank overstates coal rents for Mozambique considerably. The main driver of this discrepancy is the data. The method effect – which is captured by specific taxes and subsidies on extraction not explicitly accounted for in the World Bank estimates – is negligible in this specific case. These results mean that the World Bank overstates coal rents for Mozambique by underestimating the associated mining costs.

Paper III

Ganhane, JJ, Heterogeneity in preferences for water supply and forest use near a coal mine. 2025.

Paper III estimates the WTP of various households living in the vicinity of coal mining in the Moatize District, Mozambique, for improved water supply and forest use. The previously available water and forest resources have been degraded, or access to them denied, because of the establishment of mining activities. This research focused specifically on how different household groups near coal mines value these services.

It is already well documented that the population in Mozambique's coal mining region is being negatively affected by the environmental impacts that mining imposes. Less well known, however, is what impacts are considered most important, and to what extent this varies across different groups in the population. Communities in mining regions are made up of people of diverse cultural, social and economic characteristics – and, hence, different preferences. Information about how different households value water and forest services is therefore needed to help set priorities in designing and implementing policies to mitigate the related environmental impacts.

The choice experiment method, which allows the relative importance of different attributes to be examined, was used to assess preferences of households residing near mines in respect of mitigating the impacts of mining. A latent class conditional logit model, which allows for heterogeneity among respondents, was used to fit survey data from a sample of 419 households.

The estimation results indicate that four classes of households existed, with different preferences across classes. The main drivers of class membership included gender, income, education and age. All classes expressed dissatisfaction with the status quo, and improvements in water supply was generally highly valued. However, the four groups in some cases expressed quite different valuations of the proposed improvements.

Water supply and forest use clearly have strong impacts on local welfare, and this study reveals considerable support for their improvement. At the same time, preference heterogeneity is important for how projects aimed at mitigating mining impacts are likely to be perceived.

Paper IV

Ganhane, JJ, Willingness to pay for post-mining landscape restoration. 2025.

Paper IV examines some of the long-term impacts of resettlement, firstly, by comparing resettled people's current living conditions to those before resettlement and, secondly, by estimating their WTP to restore the landscape where they once lived before coal mining began and to move back to their place of origin.

The literature on the short-term impacts of involuntary resettlements induced by mining has pointed out that resettlement has worsened the welfare of the resettled people, as the compensation packages offered smaller and less fertile farmland compared to what they had owned in their home areas. Moreover, such relocations have not only disrupted the income sources that the people affected had once enjoyed in their areas of origin, but have also led to reduced access to water and worsened dwellings compared to their former places of residence. However, less is known about the long-term impacts of involuntary translocations such as these. For example, resettled people may adapt well and even improve their welfare over time, thus reducing the negative impacts of the forced move. They may also become less likely to prefer the restoration of the landscape of their former home areas.

The WTP for a programme to restore the landscape in resettled persons' places of origin was valued using the contingent valuation method. This technique is widely used in the field of environmental economics to examine how people value non-market goods and services. In a contingent valuation method, a double-bounded dichotomous choice setup was also adopted.

The study findings indicate that, on average, households were willing to contribute about nine working days per month for landscape restoration. Among the studied potential determinants of WTP for landscape restoration, namely changes (compared to before resettlement) in farmland size, farmland quality, water access, dwellings, and availability of sources of income, only changes in water access and available sources of income were strong determinants of WTP. The results further indicate that resettled respondents have been adaptive, using the monetary compensation they received to buy more productive land to offset the land lost due to resettlement. As the survey data showed, most respondents (57%) had enjoyed use of a nearby river as their main source of water before resettlement; access to water was therefore a key determinant of WTP since those with better access to water showed a significantly lower WTP.

An overall possible explanation of the study findings is that households are now far away from the marketplaces and the river, making it difficult to develop new sources of income and to get access to water.

Section 4

Findings and policy implications

Overall, this thesis found that the benefits from the extraction of natural resources are not calculated accurately, at least when the calculations are made by the World Bank. A policy implication of these results is that the lack of accurate estimates can induce errors in the design and implementation of sustainable natural resource management policies. This calls for the need to invest in human resources and institutions that can ensure the quality of relevant statistics for countries rich in natural resources can be improved. Improved statistics will in turn enhance the indicators of benefits of the extractive industries for such countries.

Further findings of this thesis indicated that households affected by the extraction of natural resources revealed a high willingness to pay for mitigation of the negative environmental impacts caused by the extractive industry. These results suggest that countries rich in natural resources need to devote more attention to environmental costs in their decision-making when it comes to the sustainable exploitation of those resources. Moreover, such countries could adopt appropriate legal instruments to minimise the environmental costs to the communities affected by resource extraction, because the costs involved can outweigh the benefits obtained from this industry's activities.

Findings from **Paper I** show that the correlation between GS and future consumption growth is substantially stronger for sub-Saharan Africa countries than for richer states. However, the various countries' levels of investment are still not good predictors of their future consumption levels.

Given the concerns about the long-run consequences of natural resource depletion and environmental degradation, policymakers in developing countries in general should prioritise the sustainable management of their natural resources and the reinvestment of resource rents. In theory, resource rents can be invested in industries that can create jobs. Such rents can also be used to finance economic development programmes, strengthen national institutions, improve the delivery of public goods, and enhance the quality of regulation. However, the resource rents estimated in **Paper II** are consistently smaller than the World Bank's estimates for the entire period considered.

The United Nations Sustainable Development Goal 6 (SDG 6) aims at ensuring the global availability and sustainable management of water and sanitation by 2030. In respect of water supply, the main targets are to achieve access to safe and affordable drinking water. SDG 6 will potentially address water scarcity and reduce the number of people affected by insufficient supplies. In this context, **Paper III** addresses improvements in water supply in regions near mining activities, since mining activities are both water consumers and polluters.

High preferences for forest use and water supply improvements, as well as the respondents' high WTP for such improvements, call attention to both the government and the mining companies that people in the area value projects to improve these two sets of natural-resource-based services. Hence, implementing projects aiming to improve forest use and water supply is very likely to improve the welfare of resettled persons. Public policies and mining companies' corporate social responsibility programmes are therefore strongly encouraged to implement projects in these domains.

Another key finding in **Paper III** concerns the heterogeneities in respondents' preferences in respect of forest use and water supply. This implies that any projects – whether financed by the Mozambican government or by the relevant mining companies – which aim to mitigate the negative impacts of mining in the region concerned should therefore select carefully what is offered to improve the situation. They also need to consider how different groups of people feel about the proposed improvements, how those groups may have changed over time, and how experiences from previous interventions are likely to affect attitudes toward new ones.

SDG 15 is devoted to protecting, restoring and promoting the sustainable use of terrestrial ecosystems, sustainably managing forests, combatting desertification, halting and reversing land degradation, and halting biodiversity loss. The expected results to achieve this goal include ending deforestation and restoring degraded forests; restoring degraded land; protecting biodiversity and natural habitats; and integrating ecosystems and biodiversity in governmental planning. **Paper IV** examines post-mining landscape restoration in this context.

Paper IV found two main results. The first finding was that households were willing to contribute about nine working days per month for landscape restoration if the mine in question closed. The second finding was that mining-induced displacement and resettlement worsened resettled persons' well-being. The survey data show that, prior to resettlement, many income sources had been linked to a nearby river, market and road. Resettling people far from these three elements disrupted their income from those sources.

The policy implication of this result is that interventions aiming to improve resettled households' welfare should target access to water and sources of income. Resettling the respondents far from the river, the highway and the city meant they lost their previous unlimited access to water and various related sources of income. This probably explains why, even 15 years after resettlement, they still preferred their village of origin. Future mining-induced resettlements are therefore advised to be very careful in selecting the sites to resettle people if it means losing access to water and sources of income. These attributes are difficult to recover, even in the long term.

In general, developing countries rich in non-renewable natural resources, when designing and implementing policies for managing their resources, as well as while developing projections of resource gains to guide decision-making, should prioritise the use of domestic data rather than data available in international databases. Furthermore, mining contracts should ensure that the environmental costs of mining and its effects on local communities hosting the resources are internalised by mine owners at all stages of mining, with a greater focus on pre-mining resettlements, pollution during mining, and post-mining restoration of degraded landscape. This requires fortification of the institutions responsible for producing relevant statistics on exploitation of natural resources, as well as strengthening institutions that can ensure the monitoring of compliance with the terms of the mining contracts.

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Paper I

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Article

Resource Rents, Genuine Savings and Sustainable Development: Revisiting the Evidence

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Abstract: Economic theory on sustainable development suggests that resource-rich countries should reinvest the rents from natural resource extraction in other forms of capital to ensure that future consumption level of the economy can be greater than or at least equal to the level of their current consumption. Several seminal papers in the early 2000s indicated that the correlation between genuine savings and future consumption was weaker than theory predicted, at least when genuine savings were measured using the World Bank estimates. This paper revisits the issue and replicates two of these earlier studies to see whether the correlation has become stronger over time, on the back of policy changes in resource-rich countries and of revisions to the World Bank estimates. The results indicate that the correlation between genuine savings and future consumption growth may be stronger for poorer countries than for richer, and for sub-Saharan Africa, the theoretical predictions appear to hold.

Keywords: sustainable development; genuine savings; World Bank; natural resources

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1. Background

Genuine savings (GS) can be defined as a country's net investment in all types of capital. This paper studies the link between countries' GS and their consumption levels over time. The purpose of the study is to re-examine results from previous research, which found that the correlation between GS and consumption over time was weaker than predicted by green accounting theory.

Green accounting theory is concerned with the impact of natural resource depletion and environmental degradation on long-term welfare. According to an important version of this theory, countries should aim to follow a development path where the gains derived from exploiting natural resources and the ecosystem are reinvested in such a way that their future consumption can be greater than their present consumption. The extant literature predicts that with positive GS, future consumption will be greater than today's, while with negative GS, it will be less.

This literature has contributed to considerable interest in empirical work on green accounting and GS, both in terms of case studies of individual countries (see, e.g., [1–15] for various countries in Sub-Saharan Africa and elsewhere) and cross-country comparisons (see, e.g., [16–21]). As part of the interest in the latter, the World Bank [22] began publishing data on estimated GS as part of its World Development Indicators database.

Soon after the first edition of the World Bank's GS estimates, a series of seminal studies—notably by Ferreira and Vincent [18] and Ferreira, Hamilton and Vincent [19]—were conducted to see whether the connection between GS and future consumption was as green accounting theory predicted. These studies found that the correlation was far weaker than estimated. One likely explanation for this was that limitations in the World Bank's estimates had weakened the link between the theory and the measured empirical outcomes. For example, Ferreira and Vincent [18] highlighted the weaknesses of the World Bank method in its calculation of the initial estimates of the GS. These shortcomings notably included the large number of natural capital types that were only partially covered or not covered at all (To give some key examples, the World Bank estimates exclude (1) changes in the quality of farmland and the availability of freshwater on it; (2) fisheries; the increased availability of farmland when forestland is converted into cropland; and (3) the net increase in forest capital when forest regeneration exceeds forest depletion); the problems with estimating the value of produced capital using the perpetual inventories method with a constant depreciation rate; the exclusion of new discoveries of natural resources; the effect of price changes on the value of reserves; and the inability to account for human capital losses.

Ferreira and Vincent [18] explained that their own findings were based on initial data, suggesting that the results they had generated could be improved over time with future updates of World Bank estimates. However, an additional explanation of those findings, discussed briefly (and fairly diplomatically) in Ferreira and Vincent [18], was that the capital stocks built up through the measured investments might not generate subsequent consumption streams, at least not that part of a country's consumption measured in the World Bank data.

Obvious explanations for the discrepancy found by Ferreira and Vincent would include unrecorded capital flight; private investments that generated poor returns on paper because actual returns to private owners went unreported; or poor public investment decisions based mainly on political considerations, and which generated poor returns.

An additional explanation could be that, at least in richer countries, consumption may be reaching saturation levels where additional investment does not translate into increased consumption and where increased economic activity is less dependent on natural resources (see, e.g., [23,24]). If this is the case, the correlation between GS and future consumption should be higher in poorer countries than in richer countries.

Several studies have proposed extending the World Bank's GS estimates by including relevant new items to make them more consistent with green accounting theory. For example, Biasi et al. [25] suggested adding degradation in water and land; McLaughlin et al. [26] proposed adding the present value of technological change; Fink and Ducoing [27] suggested adding negative resource incomes, fish incomes and technological change over time; and Yamaguchi [28] showed the need for GS estimates to account for change in neighbouring resource stocks. McGrath et al. [29,30] proposed further extension of the estimates to include changes in agricultural land value as well as in local air pollutants (sulphur dioxide, non-metallic volatile organic compounds, nitrogen oxides and ammonia) and non-greenhouse gases.

Boos [31], on the other hand, suggested modifying the GS estimates by, e.g., adding health expenses when calculating investment in human capital; covering a wider range of natural resources in calculating their depletion; excluding military investment from gross national investment; using five-year averages of resource rents to reduce the effects of the volatility of natural resource prices on GS estimates; and separating the forest from the rest of the non-renewable natural capital to avoid forest growth being interpreted as reinvestment of natural capital rents in further natural capital.

During the two decades since the release of the initial GS estimates, the World Bank has announced four major revisions, namely in 2006 [32], 2011 [33], 2018 [34], and 2021 [35]. It would be reasonable to assume that these updates have improved the estimates' accuracy. Hence, it is of interest to revisit the findings by Ferreira and Vincent [18] in 2005 and Ferreira, Hamilton and Vincent [19] in 2008 to determine whether their results still hold.

Moreover, the debate around GS and green accounting has spurred several initiatives aimed at improving not only the management of natural resources per se, but also the rents derived from them—especially as regards developing countries, and especially those in sub-Saharan Africa. This provides further motivation to revisit the two earlier studies mentioned to see whether the correlation between GS and future consumption has strengthened over time. Moreover, if one considers how much attention is being devoted to improving resource management in sub-Saharan Africa, it is of particular interest to examine the correlation between GS and future consumption there. For this reason, the hypothesised links for this region are calculated separately for the current study.

This article proceeds as follows. The next section outlines the relevant sustainable development theory and establishes its connection with the World Bank's GS estimates. Sections 3 and 4 describe the econometric specification and data, respectively. Section 5 presents the results, while the last section presents a discussion of them.

2. Theory

2.1. Measuring Genuine Savings

The weak sustainability concept underlying green accounting theory assumes complete substitutability between physical capital, natural capital and human capital. Thus, when one form of capital, e.g., natural capital, is depreciated, the depreciation can be replaced by an increase in other forms of capital, i.e., physical or human capital, and production and consumption can be maintained if the overall capital stocks do not decline.

Based on the weak sustainability theory, Hartwick [36] defined the value of the net change in total capital stocks—physical, natural and human—at any given point in time as the sum of the changes in each of these three forms of capital. Hartwick's rule states that, if this value is equal to (or greater than) zero, it means that a country is maintaining (or increasing) its level of capital so that it can sustain (or increase) its level of consumption [37,38].

The World Bank was inspired by the concept of weak sustainability and by the Hartwick rule to measure the *GS* as follows [18]:

$$GS = \underbrace{\underbrace{\underbrace{GNI + NITA}_{CGI} - \delta K}_{CNI} - \Sigma Rn, j - CO_2D}_{GrNI} + IHC \quad (1)$$

where *GNI* is gross domestic savings; *NITA* is net income and net current transfers from abroad; δ is the rate of depreciation of the produced capital stock (K); Rn,j is rent from depletion of natural capital j; CO_2D represents damages from carbon dioxide emissions; and *IHC* is investment in human capital measured as current (non-fixed-capital) expenditure on education. *CGI* is the conventional gross investment or gross savings, *CNI* is conventional net investment or net savings, and *GrNI* is green net investment or green net savings.

In line with Hartwick [36], the depletion of natural resources is included in the GS estimates by including energy rents (from the depletion of the three major fossil fuels—oil, natural gas and coal); mineral rents (including the depletion of a set of ten mineral resources, namely bauxite, copper, gold, iron, lead, nickel, phosphate, silver, tin and zinc) whose data are available; and forest rents (measured as a reduction in wood stock through the difference between forest growth and deforestation). Furthermore, the damages from carbon dioxide emissions (CO_2D) are assumed to be USD 20 per metric ton of carbon emitted.

Detailed descriptions and explanations of the assumptions made by the World Bank and the sources of data used in their initial estimates of GS can be found in [39–41].

2.2. Genuine Savings as a Predictor of Future Consumption

Although the theoretical model underlying the research by Ferreira and Vincent [18] and Ferreira, Hamilton and Vincent [19] is expressed slightly differently in the two studies, the theory underlying the model is the same. The relevant theory and its model were outlined in Weitzman [42], who showed that, under a number of restrictive assumptions, the change in average future consumption in an economy relative to its current consumption should be given by that economy's net change in capital stocks. This net change has subsequently been referred to as the economy's genuine savings rate. If we refer to this rate at time t as $G(t)$ and the consumption at time t as $C(t)$, Weitzman's result can be written as

$$G(t) = \frac{\int_t^\infty C(s)e^{-r(s-t)}ds}{\int_t^\infty e^{-r(s-t)}ds} - C(t) \quad (2)$$

where the first term on the right-hand side of the equation is an average of future consumption weighted by the discount rate r.

Weitzman's seminal work has subsequently been revisited in several theoretical papers that have developed generalised results that hold under less restrictive conditions. Of particular interest here is the study by Hamilton and Hartwick [43], who show that

$$G(t) = \int_t^\infty \frac{dC(s)}{ds} e^{-\int_t^u r(u)du} ds \quad (3)$$

and Ferreira, Hamilton and Vincent [19], who bring in varying population growth $\gamma(t)$ and show that

$$g(t) = \int_t^\infty \left(\frac{dc(s)}{ds} \frac{d\gamma(s)}{ds} w(s) \right) e^{-\int_t^s (r(u)-\gamma(u))du} ds \quad (4)$$

The lower-case letters (e.g., g in respect of G) denote per-capita values. Thus, $w(s)$ represents the economy's per-capita overall capital stocks (W) at time s.

3. Econometric Specification

Shortening the time period from ∞ to T gives us predictions that can be tested empirically. Writing the second and fourth equations in discrete form gives us the respective predictions that, for country i,

$$G_{it} = \frac{\sum_{s=t+1}^{t+T} C_{is}(1+r)^{-(s-t)}}{\sum_{s=t+1}^{t+T} (1+r)^{-(s-t)}} - C_{it} \quad (5)$$

and

$$g_{it} = \sum_{s=t+1}^{t+T} \left(\frac{\left(\frac{C_{is+1}}{N_{is+1}} - \frac{C_{is}}{N_{is}} \right) + (\gamma_{is+1} - \gamma_{is}) \frac{W_{is}}{N_{is}}}{\prod_{j=t+1}^{s} (1 + \rho_{ij} - \gamma_{ij})} \right) = PV\Delta C_{it} + PV[(\Delta\gamma_{it})w_{it}] \quad (6)$$

In Equations (5) and (6), G_{it} represents various measures of net capital investment, ranging from gross physical investment to GS, while g_{it} is the per-capita counterpart of G_{it}; C_{it} is consumption, while c_{it} is per-capita consumption; r is the discount rate; ρ_{it} is the interest rate; γ_{it} is the population growth rate; W_{it} represents the produced and natural capital stocks and w_{it} their per-capita counterparts; PV is present value; and N_{is} is the total population of country i in time s. These are all measured using data from the World Development Indicator (WDI) database.

Thus, if one calls the right-hand side of Equation (5) (the difference between average future and current consumption) Δ_{it}, and one runs the regression

$$\Delta_{it} = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \quad (7)$$

One should get $\beta_0 = 0$ and $\beta_1 = 1$.

Similarly,

(a) if one calls the term $PV\Delta C_{it}$ the present value of future consumption changes, one assumes constant population growth rates γ in Equation (6), and one runs the regression

$$PV\Delta C_{it} = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \quad (8)$$

(b) if one assumes that population growth rates γ_{it} vary over time in Equation (6) and one runs the regression

$$PV\Delta C_{it} + PV[(\Delta\gamma_{it})w_{it}] = \beta_0 + \beta_1 g_{it} + \epsilon_{it} \tag{9}$$

(c) if one includes the ratio of the population growth rate to the total population as an additional explanatory variable to control for omitted wealth components from the GS variable in Equations (8) and (9), and one runs the regressions

$$PV\Delta C_{it} = \beta_0 + \beta_1 g_{it} + \beta_{2i}\frac{\gamma_{it}}{N_{it}} + \epsilon_{it} \tag{10}$$

and

$$PV\Delta C_{it} + PV[(\Delta\gamma_{it})w_{it}] = \beta_0 + \beta_1 g_{it} + \beta_{2i}\frac{\gamma_{it}}{N_{it}} + \epsilon_{it} \tag{11}$$

one should obtain $\beta_0 = 0$ and $\beta_1 = 1$ in all of these regressions, with the fit improving the closer the regression assumptions correspond to the theoretical model.

Both model versions used, respectively, in the studies in [18,19] give testable implications, provided one is willing to accept a shorter time horizon than theory requires. However, when actually running these regressions, neither Ferreira and Vincent [18] nor Ferreira, Hamilton and Vincent [19] found the predicted values for β_0 or β_1. It is, therefore, of interest to examine whether the subsequent improvements in the data set have led to results that are more in line with theory. Hence, these regressions are re-estimated here using more recent data.

Ferreira and Vincent [18] used the median of the lending and deposit interest rates to calculate a uniform discount rate of 3.5% for all countries. If one adopted the same approach and used the updated data instead, that rate would then be 2.7%. Ferreira, Hamilton and Vincent [19] also followed that approach, but they used country-specific discount rates while estimating the models. In the current study, the discount rates used in Ferreira and Vincent [18] and in Ferreira et al. [19], respectively, were employed to maintain comparability with the latter study's results.

In Ferreira, Hamilton and Vincent [19], the labour force is used as a proxy of population, whereas Ferreira and Vincent [18] used the total population. The GS indicator used in estimating models (8)–(11) is defined as $GS = GrNI + \gamma w$, i.e., population-adjusted savings. In estimates of Equation (7), however, GS is calculated as in Equation (1).

Since *CGI*, *CNI*, *GrNI*, and *GS* are measures of savings which are determined at the same time as consumption, they were tested for endogeneity. In line with Ferreira and Vincent [18] and Ferreira, Hamilton and Vincent [19], the results showed that the *p*-values of both Wu–Hausman *F*-statistic and the Durbin χ^2 statistic were insignificant. The null hypothesis that *CGI*, *CNI*, *GrNI*, and *GS* were exogenous was rejected, therefore, and they were treated as endogenous.

In the replication of Ferreira and Vincent [18], the endogeneity issue was addressed by using lagged savings (*CGI*, *CNI*, *GrNI*, and *GS*, respectively) and the lagged proportion of the working-age population as instruments. The instrument set used to replicate Ferreira, Hamilton and Vincent [19] included lagged values of green savings, produced capital, the percentage of the population of working age, the population growth rate, and the time trend. Time dummy variables were employed to control for other unobserved factors. The first-stage regression statistics, which showed small and insignificant partial R^2 as well as *F*-statistics that were much larger than any of the critical values, validated the current study's instruments. The results of overidentifying tests showed that the models had been correctly specified.

4. Data

A constraint in replicating both studies was that the names of the countries included in their sample was not disclosed. This constraint was overcome for the replications, as explained below.

Ferreira and Vincent [18] estimated Equation (7) using data from the World Bank's WDI database, updated until 2001, covering 136 countries. Where T was equal to 10 years, their sample constituted only 93 countries; 43 were excluded because the database did not contain complete data for all needed variables to estimate the models. Out of these 93 countries, 22 were members of the Organisation for Economic Co-operation and Development (OECD) and 71 were not. Where T was equal to 20 years, their sample constituted only 83 countries.

For the current study, the relevant data set from the WDI database, as updated on 26 October 2023, was uploaded. The data set contains information on 217 countries. Countries that had complete data series for the period 1970–2001 were selected from this set to constitute the final sample of 93—the same number as in the Ferreira and Vincent [18] sample. Of these 93 countries, 22 were OECD members before 2001, also matching the number in the Ferreira and Vincent [18] sample. Thus, regression (7) estimated by Ferreira and Vincent [18] was replicated using data from the same countries and from the same period as their study, but employing the updated data. This entails that any differences between the current study's results and those generated by Ferreira and Vincent [18] (Table 1 in each case) should be due to changes in the data after the data sets were updated by the World Bank.

In the Ferreira, Hamilton and Vincent [19] study, they estimated Equations (7)–(11) using data from 64 developing countries from the WDI, updated until 2003, with a data range of 1970–2002. They assumed a time horizon (T) equal to only 20 years. In the current study's replication, the 64 developing countries that matched the Ferreira, Hamilton and Vincent [19] sample were selected. Again, any differences between the current study's results in estimating models (7) to (11) and those generated by Ferreira, Hamilton and Vincent [19] (Table 2 in each case) should also only be due to changes in the data after their World Bank updates.

The replication of Ferreira, Hamilton and Vincent [19] focused on developing countries and on estimation procedures that not only accounted for changes in population growth rates, but that also adopted the present value of future consumption changes instead of the difference between average future consumption and current consumption as dependent variables. Moreover, the current study used country-specific interest rates as discount rates. It also employed a generalised two-stage least squares (2SLS) regression analysis method, which allows for full information estimations of a system of simultaneous equations but with an error component structure, as proposed by Balestra and Varadharajan-Krishnakumar [44] to reduce possible estimate bias.

After the pure replications of the Ferreira and Vincent [18] and Ferreira, Hamilton and Vincent [19] studies, the same models were estimated in a complementary way, using only data from sub-Saharan African countries.

Table 1. Replication of Ferreira and Vincent (2005) [18].

Variable	Per Ferreira and Vincent (2005) [18]						Replication of Ferreira and Vincent (2005) [18], with Same Sample of Countries and Same Time Span But with Updated Data						Replication of Ferreira and Vincent (2005) [18] with Updated Data, More Countries and Longer Time Spans					
Estimate number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**	**16**	**17**	**18**
Countries	93 world-wide	93 world-wide	93 world-wide	83 world-wide	22 OECD §	71 non-OECD	93 world-wide	93 world-wide	93 world-wide	83 world-wide	22 OECD	71 non-OECD	141 world-wide	141 world-wide	141 world-wide	141 world-wide	37 OECD	104 non-OECD
Country fixed effects (Yes/No)	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes	No	Yes	Yes	Yes	Yes	Yes
Time horizon (*T*)	10 years	10 years	10 years	20 years	10 years	10 years	10 years	10 years	10 years	20 years	10 years	10 years	10 years	10 years	10 years	20 years	10 years	10 years
Discount rate	3.5%	3.5%	Country-specific	3.5%	3.5%	3.5%	3.5%	3.5%	Country-specific	3.5%	3.5%	3.5%	3.5%	3.5%	Country-specific	3.5%	3.5%	3.5%
Time period	Former 1970–2001	Former 1970–2001	Former 1970–2001	Former 1970–2001	Former 1970–2001	Former 1970–2001	Updated 1970–2001	Updated 1970–2001	Updated 1970–2001	Updated 1970–2001	Updated 1970–2001	Updated 1970–2001	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022
Estimated equation	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)	(7)
Savings measure:																		
Gross	0.263 ***	−0.002	−0.004	0.095	−0.274 ***	0.169 ***	−0.036 ***	−0.039 ***	−0.037 ***	−0.039 ***	−0.040 ***	0.089 ***	−0.047 ***	−0.081 ***	−0.045 ***	0.163 ***	−0.036	0.111 ***
	(0.007)	(0.025)	(0.025)	(0.064)	(0.067)	(0.018)	(0.011)	(0.013)	(0.014)	(0.018)	(0.015)	(0.022)	(0.012)	(0.011)	(0.012)	(0.013)	(0.163)	(0.013)
Net	0.551 ***	0.128 ***	−0.132 ***	0.214 ***	−0.001	0.282 ***	−0.094 ***	−0.102 ***	−0.095 ***	−0.102 ***	−0.002	0.201 ***	−0.112 ***	−0.188 ***	−0.111 ***	0.285 ***	−0.093	0.419 ***
	(0.015)	(0.035)	(0.036)	(0.068)	(0.078)	(0.027)	(0.012)	(0.020)	(0.033)	(0.043)	(0.321)	(0.041)	(0.037)	(0.016)	(0.015)	(0.024)	(0.148)	(0.127)
Green net	0.534 ***	0.129 ***	0.133 ***	0.250 ***	−0.029	0.349 ***	0.098 ***	0.105 ***	0.098 ***	0.206 ***	−0.016	0.374 ***	0.071 ***	0.083 ***	0.076 ***	0.389 ***	0.096	0.619 ***
	(0.016)	(0.034)	(0.035)	(0.055)	(0.073)	(0.028)	(0.018)	(0.028)	(0.044)	(0.019)	(0.874)	(0.093)	(0.012)	(0.013)	(0.034)	(0.095)	(0.815)	(0.205)
Genuine	0.416 ***	0.037	0.038	0.215 ***	−0.274 ***	0.322 ***	0.232 ***	0.250 ***	0.235 ***	0.353 ***	−0.253 ***	0.443 ***	0.113 ***	0.133 ***	0.140 ***	0.762 *	0.225	0.821 ***
	(0.011)	(0.034)	(0.034)	(0.065)	(0.078)	(0.026)	(0.015)	(0.041)	(0.075)	(0.089)	(0.126)	(0.088)	(0.017)	(0.018)	(0.029)	(0.079)	(0.724)	(0.341)

Note: Robust standard errors corrected for serial correlation are given in brackets. * Estimate is significantly different from 0 at the 10% level. *** Estimate is significantly different from 0 at the 1% level. § Organisation for Economic Co-operation and Development.

Table 2. Replication of Ferreira et al. (2008) [19].

Variable	Ferreira et al. (2008) [19]					Replication of Ferreira et al. (2008) [19] with Same Sample of Countries and Same Time Span But with Updated Data					Replication of Ferreira et al. (2008) [19] with Updated Data, More Countries and Longer Time Spans				
Estimate Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**	**13**	**14**	**15**
Countries	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	64 non-OECD	104 non-OECD	104 non-OECD	104 non-OECD	104 non-OECD	104 non-OECD
Country fixed effects (Yes/No)	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No	Yes	Yes	Yes	No	No
Time period	Former 1970–2002	Former 1970–2002	Former 1970–2002	Former 1970–2002	Former 1970–2002	Updated 1970–2002	Updated 1970–2002	Updated 1970–2002	Updated 1970–2002	Updated 1970–2002	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022	Updated 1970–2022
Estimated equation	(7)	(8)	(9)	(10)	(11)	(7)	(8)	(9)	(10)	(11)	(7)	(8)	(9)	(10)	(11)
Savings measure:															
Gross	−0.597 **	−0.642 *	−0.764 *	−0.084	−0.106	−0.139 ***	−0.236 ***	−0.389 ***	−0.031 ***	−0.0137 ***	−0.046 ***	−0.078 *	−0.081 ***	−0.008 ***	−0.010 *
	(0.268)	(0.365)	(0.415)	(0.255)	(0.258)	(0.035)	(0.045)	(0.096)	(0.015)	(0.017)	(0.022)	(0.013)	(0.029)	(0.002)	(0.002)
Net	−0.533 **	−0.610 *	−0.729 *	−0.200	−0.234	−0.102 ***	−0.092 ***	−0.100 ***	−0.080 ***	−0.095 ***	−0.050* **	−0.081 ***	−0.075 ***	−0.011 ***	−0.012 ***
	(0.274)	(0.364)	(0.412)	(0.316)	(0.324)	(0.022)	(0.011)	(0.036)	(0.021)	(0.021)	(0.011)	(0.027)	(0.018)	(0.004)	(0.007)
Green net	0.801 **	0.425 **	0.558 **	0.405 **	0.504 **	0.606 ***	0.395 ***	0.103 ***	0.283 ***	0.198 ***	0.278 ***	0.181 ***	0.279 *	0.148 ***	0.250 ***
	(0.362)	(0.203)	(0.274)	(0.178)	(0.197)	(0.202)	(0.097)	(0.025)	(0.071)	(0.098)	(0.089)	(0.088)	(0.069)	(0.073)	(0.083)
Genuine	0.788 ***	0.413 **	0.560 **	0.392 **	0.496 ***	0.553 ***	0.425 **	0.243 *	0.294 ***	0.335 ***	0.137 ***	0.299 *	0.188 ***	0.253 ***	0.462 ***
	(0.287)	(0.163)	(0.213)	(0.165)	(0.182)	(0.094)	(0.281)	(0.121)	(0.048)	(0.167)	(0.071)	(0.103)	(0.075)	(0.052)	(0.051)

Note: Robust standard errors corrected for serial correlation are given in brackets. * Estimate is significantly different from 0 at the 10% level. ** Estimate is significantly different from 0 at the 5% level. *** Estimate is significantly different from 0 at the 1% level.

5. Results

Regressions (7)–(11) from the previous studies were re-estimated and β_1 estimates (Tables 1–3) were reported. Thus, β_1 was estimated and reported for the four versions of savings indicators (*CGI*, *CNI*, *GrNI* and *GS*) derived in Equation (1).

Columns 7 to 18 in Table 1 contain the range of the current study's estimates. For comparison purposes, the estimates in columns 1 to 6 are from Ferreira and Vincent [18]. The estimates in columns 7 and 13 are directly comparable with estimates in column 1, while the estimates in columns 8 and 14 are comparable with estimates in column 2, and so on. In estimates 13 to 18, updated data were used. Moreover, the time range was updated to consider all data available until 2021, while the data set itself covers 141 countries.

For the estimates reported in Table 1, the current study followed strictly the same estimation procedures as Ferreira and Vincent [18]. This included checking for stationarity for all time series by examining the autocorrelograms instead of formal testing, due to the shortage of observations in our sample. As is evident from Table 1, the results of the current study are largely similar to the results reported in Ferreira and Vincent [18]. Repeating the analysis for the same countries and the same time spans, but with revised data (columns 7–12 in Table 1), there is very little change compared to the original analysis (columns 1–6 in the same table). For the more limited savings measures, the fit with theory is, in most cases, even worse with the newer data than with the older data. With the most comprehensive savings measure, genuine savings, the fit does become better with the newer data, at least with the longer 20-year period of analysis, but remains far from the fit predicted by theory. Comparing OECD and non-OECD countries, the fit with theory is even worse for OECD countries, suggesting either that technological progress is more important there (in line with [18]) or that consumption is more saturated there.

Exploiting the additions to the dataset and bringing more countries and longer time spans into the analysis could, in principle, affect the outcome either way. The new countries added to the dataset presumably were excluded before because their economic statistics are worse than those in the original countries originally in the dataset, which should worsen the fit with theory further. On the other hand, the longer time spans in the updated dataset should improve the fit. Looking at the empirical results (columns 13–18 in Table 1), the outcomes are, indeed, mixed. The fit with theory is, in most cases, comparable to or worse than the results for the smaller data set. However, it deserves to be mentioned that when the analysis is restricted to non-OECD countries (column 18), the fit with theory improves, and for the most comprehensive genuine savings measure, we can in fact not reject the theoretical prediction that the coefficient is 1.

Table 2 displays the results of the estimation for developing countries, replicating the Ferreira, Hamilton and Vincent [19] study. Again, the current study's estimates range from columns 6 to 15, with estimates in columns 1–5 being from Ferreira, Hamilton and Vincent [19] shown for comparison. Estimates 6 and 11 are directly comparable to estimate 1, while estimates 7 and 12 are comparable to estimate 2, and so on. Looking at these estimates, the picture is mixed. For the less comprehensive savings measures (conventional gross savings and net savings), the fit with theory improves somewhat with the better data and with the addition of more countries and longer time spans in the data set, but all the estimated coefficients are far from the value predicted by theory. However, for the more comprehensive savings measures (green net savings and genuine savings), the fit with theory is in almost all cases even worse than in the original study. Adding better data does not improve the fit with theory for any of the estimates for the original set of countries (columns 6–10 in Table 2), and bringing more countries and longer time spans into the analysis (columns 11–15) makes the fit even worse in almost all cases.

The general picture of the results in Tables 1 and 2 is that the data of the World Bank's GS framework still fail to predict the difference between average future consumption and current consumption accurately, as theoretically proposed. As the adjustment of savings indicators is extended from CGI to GS, the quality of the fit improves; however, as in the previous studies, the fit remains poor.

Table 3. Replication of Ferreira and Vincent (2005) [18] and Ferreira et al. (2008) [19] for sub-Saharan Africa.

Variable	Replication of Ferreira & Vincent (2005) [18]						Replication of Ferreira et al. (2008) [19]			
Estimate Number	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**
Country fixed effects (Yes/No)	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes	No	No
Time horizon (T)	10 years	10 years	10 years	20 years	10 years	20 years	20 years	20 years	20 years	20 years
Discount rate	3.5%	3.5%	Country-specific	3.5%	3.5%	Country-specific	Country-specific	Country-specific	Country-specific	Country-specific
Time period	Updated 1970–2022	Updated1970–2022	Updated 1970–2022	Updated1970–2022	Updated1970–2022	Updated1970–2022	Updated1970–2022	Updated1970–2022	Updated1970–2022	Updated1970–2022
Estimated equation	(7)	(7)	(7)	(7)	(7)	(7)	(8)	(9)	(10)	(11)
Savings measure:										
Gross	−0.046 ***	−0.078 ***	−0.080 ***	−0.008 ***	−0.019 ***	−0.083 ***	−0.084 ***	−0.007 ***	−0.007 ***	−0.048
	(0.023)	(0.013)	(0.016)	(0.002)	(0.008)	(0.041)	(0.009)	(0.003)	(0.002)	(0.024)
Net	−0.050 ***	−0.081 ***	−0.075 ***	−0.011 ***	−0.010 ***	−0.057 **	−0.055 ***	−0.012 ***	−0.032 ***	−0.036 ***
	(0.011)	(0.018)	(0.031)	(0.006)	(0.005)	(0.012)	(0.027)	(0.006)	(0.016)	(0.017)
Green net	0.078 ***	0.081 ***	0.079 ***	0.548 ***	0.150 ***	0.376 ***	0.375 ***	0.446 ***	0.647 ***	0.771 ***
	(0.026)	(0.041)	(0.039)	(0.274)	(0.054)	(0.185)	(0.187)	(0.223)	(0.308)	(0.327)
Genuine	0.137 ***	0.199 ***	0.168 ***	0.753 ***	0.262 ***	0.482 ***	0.680 ***	0.550 ***	0.751 ***	0.794
	(0.047)	(0.091)	(0.011)	(0.371)	(0.125)	(0.230)	(0.295)	(2.683)	(0.366)	(0.397)

Note: Robust standard errors corrected for serial correlation are given in brackets. ** Estimate is significantly different from 0 at the 5% level. *** Estimate is significantly different from 0 at the 1% level.

Table 3 presents the estimates for sub-Saharan African countries only. These estimates use all data available until 2022, which was the most recent data period recorded. Comparing the results for the regressions from Ferreira and Vincent [18] (i.e., comparing the results in columns 1–5 in Table 3 with those in Table 1), the fit with theory is in most cases even worse for sub-Saharan Africa than it is for the full sample or for the full developing country sample. The fit does become better, however, for the most comprehensive genuine savings measure and the longer twenty-year period of analysis (column 4), the only one of these estimates where the theoretical prediction cannot be rejected.

Comparing the results for the regressions from Ferreira et al. [19] (i.e., comparing the results in columns 6–10 in Table 3 with those in Table 2), for the less comprehensive savings measures, the fit with theory is just as poor as for the full developing country sample, but for the more comprehensive savings measures, the fit with theory is better than for the full sample. For several of the estimates using the full genuine savings measure, the theoretical prediction cannot be rejected.

The general picture of the results in Table 3 is, nonetheless, that the data of the World Bank's GS framework do not accurately predict the difference between average future and average current consumption, nor do the data accurately predict the present value of changes in future consumption, as expected by the theory. However, as the adjustment of savings indicators is extended from CGI to GS, the quality of fit does improve considerably.

6. Discussion

The classic earlier studies showed that the World Bank data of the time did not provide results in line with theory; countries' levels of GS were not good predictors of future consumption. At the time, the main explanation suggested for this was that the World Bank data were not comprehensive enough and did not capture the full picture. Another explanation that was suggested was that poor investment decisions might mean that, even when there was investment, it did not lead to the future income streams for the country that were theoretically predicted—whether due to capital flight, poor public investment decisions, or other reasons.

Revisiting and replicating these results almost 20 years later, it is notable how little has changed. Running the same regressions on the supposedly more accurate data that are available now produced no real difference in the results. Thus, countries' levels of investment are still not good predictions of their future consumption levels. Poor data and poor investment decisions may both still be plausible explanations for this outcome. However, despite the current data being better than that of 2005 or 2008, it yielded little change in the results.

Economic theory predicts that the change in a country's capital stocks should determine changes in its future consumption. As in the previous studies, our results in general showed a positive and significant correlation between savings and future consumption, with estimated coefficients that have greater magnitudes when the savings measures are extended to include broader capital measures. One noteworthy finding is, however, that the fit with theory is generally better for poorer countries than for the richer countries. In particular, for sub-Saharan Africa and for the most comprehensive savings measures, the fit with theory is relatively good. This result should not be overstated, as countries in sub-Saharan Africa generally have quite poor economic statistics, but it does suggest that more research in this area could be fruitful.

The worse fit with theory in richer countries could be due to, e.g., technical progress being a more important factor for consumption growth in richer countries, or a less clear-cut link between increased production and increased material consumption in the richer countries. Most of the studies that seek to combine estimates of genuine savings with estimates of technological progress have been conducted in richer countries, so it could be worthwhile to carry out similar studies in poorer countries to see if the results are different. It could also be the case that the link between increased economic capacity and increased material consumption is weaker in richer countries than in poorer countries because a greater share of the increased economic capacity is used for other purposes. This suggests that using more comprehensive welfare measures than material consumption in future GS studies could be fruitful. Both possibilities deserve further investigation.

Investment does, thus, seem to lead to higher future consumption, but not to the extent that the theory predicts. However, if—as our results suggest—the fit with theory is indeed better for poorer countries than for richer countries, using the results from GS theory as a guide for national investment decisions can still be useful for developing countries. A remaining challenge in these countries is then to ensure that the economic statistics are good enough to permit this.

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Paper II

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Estimating resource rents for Mozambique

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ABSTRACT

This paper estimates resource rents for Mozambican coal mining using company-level data employing the residual value method devised by SEEA-Energy (the multi-purpose conceptual framework for organising energy-related statistics) and compares the findings with the World Bank's estimates of coal rents. The latter estimates are often used in the resource curse literature and also guide the World Bank's policy notes, forming the baseline of their policy advice on resource exploitation. On average, the results show unit coal rents for the 2011–2020 period that are less than half of the World Bank estimates, suggesting that the World Bank overstates coal rents for Mozambique considerably. The main driver of this discrepancy is the World Bank's underestimation of extraction costs. The results suggest that studies employing resource rent estimates should consider sensitivity analyses and greater use of local data, and that the World Bank's policy advice should be interpreted cautiously to avoid unreasonably high expectations.

1. Introduction

The purpose of this study is to empirically estimate Mozambique's natural resource rents based on data collected at mining-company level and to compare such rents to those estimated for the country by the World Bank. The latter rent estimates are widely used by researchers as a proxy for abundance to empirically test the resource curse hypothesis that natural resource abundance slows down the relevant host country's economic performance. Since the World Bank uses its estimates as a baseline in developing its policy note (Armas et al., 2014) for advising many of its member countries on sustainable natural resource management, whether these estimates are accurate or not is, thus, a matter of some importance.

The World Bank rents are estimated as the difference between the world average export price and the average regional extraction costs. These export prices may not reflect those that a specific mine is able to get from higher-quality deposits. Similarly, these extraction costs may differ from those faced in a specific country, and a regional average may mix costs for both developing and developed countries. Moreover, production in the latter countries is frequently cheaper than in the former. This discussion therefore raises the question: Is there a gap between locally based and World Bank estimates of resource rents?

To empirically answer this question, company-level data were collected from the coal industry in Mozambique. Coal rents were calculated from these, using the residual value method recommended by the System of Environmental Economic Accounting, namely SEEA-Energy, a multi-purpose conceptual framework for organising energy-related statistics. This method is supported by the concept of *resource rents* given by Harold Hotelling (1931) (therefore, resource rents are also commonly known as *Hotelling rents*). Such rents, which correspond to economic profit, can be referred to as *net price* as well.

Mozambique, in addition to having the best quality coal deposits in Africa, is an interesting case study for four main reasons. Firstly, according to World Bank estimates, the country has the highest coal rents in Africa, relative to its gross domestic product (GDP) (World Bank, 2022b), and ranks fourth in the world in this respect (Adedoyin et al., 2020). Secondly, Mozambique is the second largest coal-producing country on the African continent (U.S. Energy Information Administration, 2022), with a reserves-to-production ratio corresponding to about 120 years at current production rate. This qualifies Mozambique as both a developing and resource-rich country. Thirdly, at the domestic economy level, coal is the most important mineral. In 2021, for example, it accounted for 26% of export revenues (Banco de Moçambique, 2022a). Fourthly, sufficient data are available to make locally based estimates possible.

If the World Bank estimates of Mozambique's coal rents differ from those calculated here, it would have implications for the empirical results of research on the resource curse hypothesis using coal rents – or indeed any other resource rents – as a proxy for resource abundance, as under- or overestimates have an effect on the estimated regression

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coefficients. Moreover, such a difference would imply that the World Bank's policy notes are based on over- or underestimates of rents, which may mislead policymakers assessing future rents to be obtained from resource exploitation. If the World Bank overestimated such rents, for example, policymakers might be more prone to subsidising local mining companies and increasing public debt in the short run, with the expectation of paying with future resource revenues. In such a case, the expectations of future resource wealth end up exacerbating the resource curse.

The rest of this discussion is therefore structured as follows. Section 2 addresses the resource curse hypothesis underlying the empirical studies in this topic, while section 3 elaborates on the notion and calculation of resource rents. Section 4 provides an overview of Mozambique's coal industry, with section 5 covering the methodology and data used for the study. Section 6 depicts the results and the last section concludes the paper.

2. The resource curse hypothesis

Countries that have natural resource deposits have access to a natural capital that can be profitably converted into other types of capital. The earnings from mining, for example, are consumed to increase present welfare and can be invested in other forms of capital (including physical or human capital) to increase future welfare. This accumulation of capital and knowledge should generate efficiency and growth (Davis et al., 2005). Thus, an endowment of natural resources should be a blessing for the host country concerned.

However, empirical studies suggest instead that an abundance of resources slows economic growth, entailing what is known as the *resource curse paradox*. The oldest explanation given for the phenomenon, also called the *Dutch Disease*, is that, when a boom in natural resource exports (such as oil exports in the Dutch case) leads to real appreciation in the exchange rate, it makes manufacturing less competitive and increases the economy's dependence on the resource sector. When the resource boom ends, the country becomes economically vulnerable. Another suggested driver of the resource curse is the volatility of resource prices, making tax revenues from profits unpredictable and making public planning difficult (Davis et al., 2005).

Furthermore, the controlling power that political elites have over resource rents can increase inequalities, creating winners and losers across regions and within affected communities (Betz et al., 2015). This, in turn, can worsen the quality of institutions – and may even lead to civil war. In other cases, production is processed abroad with no value added domestically; thus, if most senior workers also come from abroad, there is little gain for the country from its own resources.

Another complication is that, while the secondary sectors often enjoy some market power that allows them to split the gains from cost reductions between wages and dividends, the resource market is often quite competitive. Hence, the gains from cost reductions are passed on to consumers through prices, causing the terms of trade to deteriorate. As a result, countries that produce specialised resources have to export more and more in return for the same bundle of processed goods (Davis et al., 2005).

Table 1 displays an overview of literature testing the resource curse hypothesis in many countries, employing different econometric methodologies. The divergent results show that nearly half of the studies confirm the resource curse hypothesis – especially in developing countries.

A common feature of the studies presented in Table 1 is that they all used the World Bank's estimates of natural resource rents rather than calculating their own from local data. The advantage of the World Bank data is they are always available, easy to access, and useful in making cross-country comparisons, whereas calculating such rents using local data is difficult. However, the World Bank's macroeconomic estimates have been called into question in general (see, e.g. (Jerven, 2013; Jerven, 2014; Jerven, 2016),). It is therefore somewhat worrying that so

Table 1
Resource curse studies.

Author	Location	Abundance proxy	Finding	Data source
Inuwa et al. (Inuwa et al., 2022)	Nigeria	Coal, forest, minerals, natural gas, and oil rents	• FRs and ORs affect growth negatively • CRs, MRs and NGRs affect growth positively	World Bank
Korkmaz (Korkmaz, 2022a)	China & USA	Coal, natural gas, and oil rents	• China: No effect on growth • USA: NGRs and CRs have no effect on growth, while ORs affect it negatively	World Bank
Korkmaz (Korkmaz, 2022b)	Russia	Coal, natural gas, and oil rents	• ORs affect growth positively • CRs and NGRs affect growth negatively	World Bank
Zhou et al. (Zhou et al., 2022)	4 South Asian countries	Coal, forest, natural gas, oil and total resource rents	• FRs and TRs affect growth negatively • CRs, NGRs and ORs affect growth positively	World Bank
Hordofa et al. (Hordofa et al., 2022)	G7 economies	Natural gas, oil and total resource rents	• ORs and NGRs affect growth positively • TRs affect growth negatively	World Bank
Dogan et al. (Dogan et al., 2020)	11 developed countries	Coal, forest, natural gas, and oil rents	All affect growth positively	World Bank
Epo & Nochi Faha (Epo et al., 2020)	44 African countries	Total resource rents	Affect growth negatively	World Bank
Khan et al. (Khan et al., 2020)	China	Total resource rents	Affect growth negatively	World Bank
Shahbaz et al. (Shahbaz et al., 2019a)	USA	Total resource rents	Affect growth negatively	World Bank
Marques & Pires (Marques et al., 2019)	25 gas-producing countries	Natural gas rents	Affect growth positively	World Bank
Zallé (Zallé, 2019)	29 African countries	Total resource rents	Affect growth negatively	World Bank
Shahbaz et al. (Shahbaz et al., 2019b)	35 countries	Total resource rents	Affect growth negatively	World Bank
Damatte & Seghir (Damette et al., 2018)	26 oil-exporting countries	Oil rents	Affect growth positively	World Bank
Dwumfour & Ntow-Gyamfi (Dwumfour et al., 2018)	38 African countries	Total resource rents	Affect growth positively	World Bank
Badeeb et al. (Badeeb et al., 2016)	Malaysia	Oil rents	No effect on growth	World Bank
Jović (Jović et al., 2016)	European Union	Coal, forest, minerals, natural gas and oil rents	Affect growth positively	World Bank

Note: CR = coal rent; FR = forest rent, MR = mineral rent; NGR = natural gas rent; OR = oil rent; TR = total rent.

much of the resource curse literature is, essentially, dependent on a single set of estimates for its analyses.

3. Resource rents

Resource rent can be defined as the economic profit from extracting and marketing a natural resource, or the returns that resource extraction generate over and above the normal returns on invested capital. Formally, *resource rent* can be defined as the net price, that is, the difference between the gross price per unit of the resource and the marginal cost of extracting it (Hotelling, 1931). Therefore, this discussion adopts the notion that *resource rent* is the shadow price of the natural resources concerned (Conrad et al., 1990). Hence, a resource's scarcity and exhaustibility – the main features of its supply – are the sources of its rents (Prasad, 2018). The current discussion therefore focuses on extraction costs. Indeed, as Hotelling himself stated, accumulated production affects costs, as the smaller the remaining deposit, the higher the extraction cost (Hotelling, 1931).

The resource rent (*RR*) is theoretically a measure of the producer's surplus, where *producer* refers to the owners of the mining companies as owners of the factors of production. *RR* corresponds to the excess of gross receipts by the producer over the costs incurred in the extraction process. In this context, the resource rent is measured as the area above the resource supply curve and below the price line (Currie et al., 1971), as shown by the definite integral function in equation (1), –

$$RR_t = \int_{q_0}^{q_T} [p(q) - f(q)]dq \tag{1}$$

where *p(q)* is the marginal revenue function; *f(q)* is the marginal cost; *q* is the quantity of the resource extracted; q_0 and q_T are quantities extracted at the start and endpoints, respectively; and the time dimension measured in years is $t = 0, 1, 2, \ldots, T$. For a competitive industry with free entry and exit, *p(q)* is a constant from the perspective of the individual firm; in the long run, *f(q)* coincides with the industry's minimum average cost curve (including the cost of normal returns to invested capital) as well as with the market price. Thus, no economic profits would be expected to persist. However, in a resource sector such as mining, where access to the resource is a natural barrier to entry, economic profits – resource rents – can persist indefinitely for those agents who have access to it.

Equation (1) can be used to determine resource rents from individual resource-extracting firms or from an entire resource-extracting sector, but it should be noted that the calculation of resource rents based on model (1) is complex in practice. One reason for this complexity is that the functional form of the cost function is usually unknown, making it necessary to specify it in an estimable form. Another reason is that the nature of many variables in the mining process makes them difficult to measure. For example, in Mozambique, the State supplies energy services to mining companies. Thus, the State supply of such services includes a component of implicit or non-accounted-for resource rents by way of these State subsidies (Hughes, 1975). In other cases, mining companies also invest in other infrastructure, such as railways. This lowers their average costs relative to those faced by similar companies in the industry, since they can supply their own transportation services in addition to selling mineral resources. This supply of services is once again a source of implicit rents (Prasad, 2018). To sum up, the State receives implicit resource rents from mining companies by (a) supplying services to them, (b) allowing corporate investment by them in services the State usually provides, and (c) enabling relatively lower corporate costs overall as a result.

Given the aforementioned complexities, the World Bank has simplified model (1) to facilitate estimates of resource rents, and these estimates have become widely used in the literature. In the World Bank methodology, the marginal revenue function is estimated using the world market export price of the resource. The marginal cost function is then simplified to an average unit production cost (Cameron et al., 1998).

More precisely, to estimate non-renewable natural resource rents, the World Bank collects data on the average unit production cost of each resource, if such data are available, or it estimates the cost where no data exist. Such average unit costs are assumed to include the cost of extraction and transportation to port, the depreciation of fixed assets, and the normal return on capital (Bolt et al., 2002; Hamilton et al., 1999). The average export price per unit (*p*) of each commodity in the international market is then estimated, and data are collected on the country-specific physical quantities of each resource extracted. From there, either equation (2) (Cameron et al., 1998; Lange et al., 2018) or equation (3) (World Bank, 2005) is applied to calculate the resource rent, as follows:

$$RR_t = (p_t - c_t)q_t \tag{2}$$

$$RR_t = \left(\frac{p_t - c_t}{p_t}\right)\overline{p}_t q_t \tag{3}$$

A straightforward comparison between the World Bank method and the theorical model in equation (1) can be written as follows:

$$\begin{cases} p(q) \equiv p_t.q_t \\ f(q) \equiv c_t.q_t \\ \int_{q_0}^{q_T} \equiv \sum_{t=1}^{T} \end{cases} \tag{4}$$

In equation (3), $\overline{p}$ is the average price of the commodity in the international markets (World Bank, 2005). The expressions in parentheses in (2) and in (3) are the unit rent. By means of equations (2) and (3), resource rents are calculated as economic profits. Equation (3) is used only when data on $\overline{p}$ are available. Equation (2) is the most widely used since it requires relatively fewer variables.

Comparing models (1), (2) and (3), one sees that the theoretical model (1) is a dynamic function since it captures the changes and interaction of the functions *p(q)* and *f(q)* over very small-time intervals. Moreover, the functions *p(q)* and *f(q)* can take any functional form. The simplified models (2) and (3), on the other hand, are static as they only capture year-on-year changes. Also, the World Bank has assumed that the functions *p(q)* and *f(q)* are linear in *q*, which means they can be estimated easily.

What motivated this paper is the fact that the estimates of resource rents given by equations (2) and (3) have a number of weaknesses. The average extraction cost of the resource from a specific mining project is often U-shaped over time (Rademeyer et al., 2018), meaning that it varies throughout the project cycle. In the initial phase of the project, upfront expenses entail a high average cost. However, this cost begins decreasing once production starts, and it continues to decline until the project reaches peak production. As production decreases in the product depletion phase, the cost of clean-up and shutdown operations makes the average cost increase again (Lange et al., 2018). The estimates of rents given by equations (2) and (3) do not allow these dynamic phases to be reflected fairly as costs are measured at a fixed point in time and held constant (in real terms) in couple of years (Hamilton et al., 1999). Moreover, extraction costs vary with the location of the deposit concerned. The location matter across and within countries. For example, the average cost of extraction in an offshore project should be higher than that for an onshore deposit, which makes the average cost used in equations (2) and (3) reflect one case but not the other.

Moreover, fuel is a relevant input in determining costs. This means that fuel cost estimates should be constantly revised to reflect the volatility of fuel (especially oil) prices. It also means that the cost of access to fuel among miners located in oil-producing countries is likely to be lower than that faced by miners from deposits located in non-oil producing countries. In addition, an estimate of the average regional cost does not reflect this difference between countries in a region.

Mining, by its nature, involves incurring upfront costs before production begins. The combination of the proven physical mineral quantity and the mining plan selected by the company allows the useful life-of-mine to be determined, which in turn serves as the basis for determining asset amortisation. However, negative external shocks such as a significant increase in taxes or royalties, a mining accident, major changes in exchange rates, or reduced expectations about future commodity prices may result in impairment losses. These losses reduce the recoverable value of assets, with a negative effect on the value of amortisation, which consequently leads to overestimating resource rents during the period affected by the shock. Conversely, with positive external shocks, the opposite may occur. Hence, country-specific extraction cost adjustments need to be made for each mining deposit to avoid biases in World Bank rent estimates (Cameron et al., 1998), particularly in countries with large resource deposits (World Bank, 2005). In effect, estimating depreciation without using country-specific data on asset values completely ignores possible impairment gains or losses.

Regarding the normal return on fixed capital, which is another component of costs, it is not reasonable to assume a worldwide or regional average rate of return – as the World Bank does (Bolt et al., 2002; Hamilton et al., 1999) – because, in practice, this return is adjusted to the risk of investing capital in a specific country. Thus, while using an average increases the estimated cost in developed countries, using it would reduce the estimate in developing countries with relatively high risks. For developing nations, these artificially low estimates of capital costs risk lead to high estimates of rents. Consequently, the rents calculated by equations (2) and (3) should be interpreted as an upper bound of available rents (Lange et al., 2018).

Another aspect to consider is that, in the case of coal, metallurgical coal and thermal coal can be extracted at the same cost from the same deposit but sold in the market at different prices. Metallurgical coal, which is used in the steel production industry, is relatively more valuable due to the lack of substitutes; thermal coal, on the other hand, is sold in the power-generation market and at relatively lower prices. If world coal prices are used to calculate the rents via equations (2) and (3), the estimation of the rents from a specific deposit – depending on that deposit's composition – may be misleading. For example, the calculation would underestimate the rents for deposits mostly composed of metallurgical coal and overestimate the rent value for deposits mostly composed of thermal coal. In other words, since metallurgical coal is more valuable, then pricing it at the average coal price will underestimate rents, and vice versa for thermal coal.

Arguably, mines with deposits located in developed countries should have access to more modern technologies and maintenance facilities than those available to their counterparts in developing countries (Cameron et al., 1998). Hence, mining costs are likely to be comparatively higher in developing countries, which may also lead to rents being overestimated.

Another weakness of the World Bank method is that it ignores the effect of extraction taxes paid by mining companies – although this variable depends on the tax system applicable in each country. If such taxes affect extraction decisions, which often happens in practice, they are also likely to affect the size of rents and their distribution over time. In addition, the impact of such taxes on decisions could lead to production costs that differ from those estimated by the World Bank.

Nonetheless, despite the weaknesses mentioned in this section, the World Bank estimates of resource rents are useful – especially for making cross-country comparisons. They should, however, be interpreted with these weaknesses in mind. Indeed, although the World Bank acknowledges these weaknesses, it continues to maintain its estimates because the detailed data required to make more accurate estimates for each country are lacking (Cameron et al., 1998).

To correct or at least ameliorate all the problems of the World Bank method mentioned here requires the adoption of an alternative that allows using detailed data from a specific deposit. In this context, the United Nations released SEEA-Energy in 2019. Among its several virtues, this statistical framework allows the resource rent for mineral and energy resources such as coal, oil and natural gas to be calculated (United Nations, 2019). SEEA-Energy recommends that resource rents be estimated through the residual value method, where rents from non-renewable resources are calculated via equation (5), namely –

$$RR_t = GOS_t - Uc_t - Se_t + Te_t \tag{5}$$

where *GOS* represents the gross operating surplus, *Uc* is the total user cost of the produced asset used for the extractive activity, *Se* represents the specific subsidies on extraction, and *Te* denotes specific taxes on extraction. The gross operating surplus, in turn, is calculated using equation (6), which is presented as –

$$GOS_t = p_t' * q_t - \sum X_t \tag{6}$$

where p_t' represents the price at which the product was sold in period *t*; and X_t represents the vector of operating costs in period *t*, including the intermediate consumption or input cost of goods and services, compensation to employees, and other taxes on production which are net of subsidies. An apostrophe (′, as in p_t') was used to distinguish the prices and costs used in the SEEA-Energy approach from those used by the World Bank.

Equation (7) estimates the user cost of produced assets, which corresponds to the total cost of capital services. The assumption underlying equation (7), as set out below, is that coal mining companies are the owners and users of capital assets (Organisation For Economic Co-operation and Development – OECD, 2009):

$$Uc_0^t \approx \sum k_0^t p_0^t (r^{*t} + \delta_0) \tag{7}$$

In equation (7), *k* represents the number of capital assets of corresponding age; p_0^t is the acquisition price of a new asset at the beginning of year *t*; *r* is the real rate of return applicable during year *t*, which corresponds to the opportunity cost of the financial capital tied up with the acquisition of the asset; and δ is the new asset's rate of depreciation, which is its loss in value due to aging. Note that equation (7) still only approximates the total user cost of capital because it does not include revaluation, that is, the expected change in the price of the asset class under consideration (Organisation For Economic Co-operation and Development – OECD, 2009).

Thus, the method recommended by SEEA-Energy given by equations (5)–(7) also simplifies model (1), but there is less simplification than in the World Bank's models (2) and (3). Another upside of the SEEA-Energy method is that it enables mining companies' detailed data to be included in the rent calculus. The current study therefore strictly follows the SEEA-Energy method. The study also employs mining-company-level data from the coal industry in Mozambique to calculate coal rents for the country and compares these with the World Bank's rent estimates to show, empirically, the weaknesses of the latter estimates.

A straightforward comparison between the SEEA-Energy method and the theorical model in equation (1) can be written as follows:

$$\begin{cases} p(q) \equiv p_t . q_t \\ f(q) \equiv \sum X_t + Uc_t + Se_t - Te_t \\ \int_{q_0}^{q_T} \equiv \sum_{t=1}^{T} \end{cases} \tag{8}$$

4. Overview of Mozambique's coal industry

Coal was first discovered in Mozambique in the late 1850s (Hatton et al., 2012). Mining began over 50 years ago, although before 2011 it was done at low levels and transported by truck due to the civil war that destroyed the railway used for transporting coal to the port (Jourdan, 1986). In 2004, Vale Moçambique S.A. (Vale), a subsidiary of the multinational company Vale S.A., was granted a research and exploration licence by the Mozambican Government. This resulted in the discovery of marketable reserves, and Vale began investing in Mozambique in 2008 after having signed a mining contract for the Moatize Coal Mine concession in the Zambezi Valley the previous year (Ministério dos et al., 2007). Vale started production and exports in the third quarter of 2011 (Hatton et al., 2012; Lakshminarayana, 2015; Wiegink, 2018), extracting both metallurgical and thermal coal, which respectively accounted for 51% and 49% of its total production on average.

With the start of Vale's production, coal became Mozambique's most important mineral. Due to its coal reserves, the country is currently affectionately called the "El Dorado of coal". Not only are these reserves among the least explored in the world, they also place Mozambique among the top ten coal exporters globally (Wiegink, 2018), and enable coal to rank as the country's most economically important commodity (Lehto et al., 2008). Vale has dominated coal mining in Mozambique since 2011, producing a nominal capacity of 22 million metric tonnes per year. Fig. 1 plots Vale's production against the national industry total. Besides Vale, the other domestic mines that produce coal on a relatively smaller scale are Benga, Chirodzi and Minas Moatize Lda.

To date, the World Bank has estimated unit coal rents as the difference between the world export price of coal and the average unit costs of producing both thermal (soft) coal and metallurgical (hard) coal (Bolt et al., 2002; Hamilton et al., 1999). These two types of coal have the same geological roots as raw materials, but they differ in commercial value and industrial use. While thermal coal is consumed in the electricity-generation industry, metallurgical coal is used in the manufacture of iron and steel. Because the value of coal is defined by its quality, metallurgical coal is the more valuable, while thermal coal is cheaper due to its relatively low quality. Depending on the composition of each country's reserves, therefore, the average price of coal charged may differ across countries. In other words, countries whose coal deposits contain a higher percentage of metallurgical coal are expected to charge higher prices than those with a higher thermal coal content. However, since the World Bank uses one world price to calculate coal rents across the globe, this can lead to a positive bias of rent estimates for countries with a higher composition of thermal coal, while underestimating rents for countries whose reserves have a higher share of metallurgical coal.

The risk of under- or overestimating coal rents is illustrated by the data on coal production in African countries. According to these data, the deposits from Botswana, Congo-Kinshasa, Eswatini, Malawi, Niger, Nigeria, Tanzania, and Zambia are composed solely of thermal coal. In Mozambique, South Africa and Zimbabwe, however, the deposits contain both thermal and metallurgical coal, with metallurgical coal making up 51%, 1% and 13%, respectively, of the total in these three countries on average (U.S. Energy Information Administration, 2022). Since Mozambique has the best quality reserves on the African continent, it is the best case to study as regards establishing the extent to which discrepancies in coal prices due to discrepancies in deposit quality can lead to biases, particlarly when it comes to comparing World Bank and local-data-based estimates of coal rents.

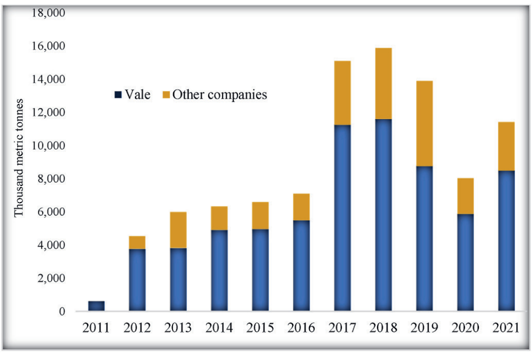

Fig. 1. Structure of coal production in Mozambique, 2011–2021.
Source: US-EIA (U.S. Energy Information Administration, 2022); Vale (2022b)

Another factor to consider is the cost of extraction. This varies with the location of the mine, the ease of mining, and the quality of the deposit (Hughes, 1975), making it difficult to capture accurately all the extraction costs incurred in a specific country's industry. For example, the cost of extraction is likely to be relatively high in Africa in comparison with more developed countries, due to the generally low level of development as well as the lack of facilities, especially in areas where mines are located. This poses the risk of the World Bank methodology underestimating extraction costs in developing countries – particularly where statistical institutions are less evolved, which in turn entails overestimating rents.

Meanwhile, the price effect presented above can lead to both over- and underestimating rents, depending on the reserve quality. Thus, the net effect which defines the direction of the estimation bias of coal rents between the World Bank and local-data-based estimates remains unknown. The current study attempts to narrow that knowledge gap.

5. Methodology and data

5.1. Methodology

This paper follows the residual value method recommended by SEEA-Energy (United Nations, 2019) for estimating resource rents, as represented by equations (5)–(7) in section 3. Here, the method is used to estimate coal rents using firm-level data collected from the coal industry in Mozambique. The aim is to compare these estimations with those of the World Bank for the same industry. Thus, using equation (5), coal rent (*CR*) is estimated as follows:

$$CR_t = GOS_t - Uc_t - Se_t + Te_t \tag{9}$$

Estimating the total user cost of produced asset for the extractive activity (*Uc*) based on equation (7) requires the depreciation value of fixed assets to be determined. This study calculated depreciation by measuring the discounted value of fixed capital used in production, adjusted for the investment needed to keep the relevant company's productive capacity. This measure does not, therefore, consider the changes in the relative asset prices (Organisation For Economic Co-operation and Development – OECD, 2009).

To determine the depreciation rates in this context, the direct age–price profile approach was adopted. This approach demands a geometric pattern of depreciation. The chosen pattern consists of a constant percentage decrease in asset values where, as recommended by SEEA-Energy, the depreciation rates are estimated according to equation (10) (Organisation For Economic Co-operation and Development – OECD, 2009), namely –

$$\delta^i = \frac{2}{\overline{T}^i} \tag{10}$$

where $\overline{T}$ is the average service life of the asset *i*.

The World Bank estimates of coal rents are released as percentages of GDP. To enable comparison with the results from the SEEA-Energy method, the World Bank figures are multiplied by Mozambique's GDP for each year. Furthermore, to compare the World Bank's and the SEEA-Energy-based estimates, the overall rents were first calculated for each year and then divided by the production volume to obtain the unit rents or net price.

5.2. Data

To estimate the rents based on equation (9), data were gathered not only on global nominal coal prices from the World Bank's so-called pink sheet database of annual commodity prices (World Bank, 2022a), but also on coal extraction figures in metric tonnes from the United States Energy Information Administration (U.S. Energy Information Administration, 2022). These two sets of data allowed the coal-mining output value to be determined. Data were then collected from Vale's production and sales reports in respect of the volume they extracted (Vale, 2022b); these data were also used to determine the production by other companies.

To compute operating costs, data were collected from Vale's financial statements as regards their pre-operating costs, the cost of goods sold, selling expenses, administrative expenses and other operating expenses, but not on their personnel costs (Vale, 2022e). Notably, these operating costs were aggregated by business line. This is because, when Vale started extraction in Mozambique in the third quarter (Q3) of 2011, it also operated three mines in Australia and one in Colombia. The Colombian mine was closed in Q2 of 2012, while the Australian mines were sequentially closed in Q3 of 2014, Q4 of 2014 and Q4 of 2016, respectively. Since 2017, Vale has only mined coal in Mozambique (Vale, 2022f). For years before 2017, the aggregate costs for all its coal-mining operations were disaggregated proportionally in the current study, based on the share of production and total sales in each year. Employee compensation cost data were taken from Vale's integrated and sustainability report (Vale, 2022d).

To estimate the total user cost of the produced asset based on equation (7), two things were done. Firstly, an average service life of 25 years was chosen for the assets. This choice was justified by the average term of mineral concession contracts. Applying $\overline{T} = 25$ in equation (10) yields a fixed economic depreciation rate of 8%. Data were also collected from Vale's financial statements with respect to the value of capital stock and of gross investments in fixed capital (Vale, 2022e).

Secondly, since estimating equation (7) required a real rate of return applicable to each year, an exogenous approach was followed. In this approach, the rate of return is assumed to be equal to an exogenous rate of return that takes into account investment risks. An economy-wide rate of return was therefore selected (United Nations et al., 2014). Further data were also gathered in respect of interest rates on Government bonds from the Bank of Mozambique (Banco de Moçambique, 2022b). These data were used as a proxy of normal rates of return on assets, as recommended by SEEA-Energy.

As regards specific taxes and subsidies in extraction data, it should be noted that taxes were paid net of subsidies. Moreover, all subsidies to Vale's benefit are described in Article 8 of their mining concession contract (Ministério dos et al., 2007). The only subsidy not mentioned in the contract is one established by recent legislation. This provision allows all mining companies that export at least 75% of their production to be exempt from value added tax on their domestic purchases. Vale's exportation of coal is covered by this provision (Vale, 2022c). Therefore, data on the net taxes on extraction paid by Vale were gleaned from its annual tax transparency report (Vale, 2022c).

Note that data on the other companies besides Vale are not available. Since the other companies mined coal in the same province as Vale did, it is reasonable to assume that the quality of their coal deposits may be identical or very similar. However, smaller companies are likely to have fewer economies of scale and, hence, higher costs and lower coal rents than Vale. Nonetheless, the difference does not affect the total estimates due these companies' lower share in total production.

To convert World Bank coal rents, data were gathered on coal rents measured as a percentage of GDP and nominal GDP from the World Bank's World Development Indicators database (World Bank, 2022b). Importantly, all the data mentioned in this section thus far were measured at current US$ values, unless otherwise specified, and encompass the 2011–2020 period after coal mining began in earnest in Mozambique.

After the rents were estimated as outlined in this section, coal rents at current prices were converted to real values. The energy price index – also known as the annual commodity price index – was used for this purpose. The index is expressed in US$ terms (constant for 2010), based on the weighted average provided in the World Bank's pink sheet for coal, crude oil and natural gas (World Bank, 2022a). The commodity price index was preferred over a consumer price index because the latter only removes general inflation, while the former removes both general inflation and the net effect of inflation on commodity markets after subtracting general inflation (Wårell, 2014).

5.3. Decomposition of the difference between World Bank and SEEA-energy estimates

Theoretically, the rent estimates made by the World Bank and those made based on the SEEA-Energy approach should be equivalent in value. However, with differences in the two methods as well as in the data used, two potential sources of discrepancy arise between the two respective estimates. To quantify the weight of each source in respect of the total discrepancy between the two rent estimates, the following analysis was performed. The analysis shows the respective estimates of coal rents as calculated by the World Bank and the SEEA-Energy approaches, namely –

$$RR_t = (p_t - c_t)q_t \tag{2}$$

$$RR_t^{'} = p_t^{'} * q_t - C_t^{'} \tag{11}$$

where $C_t^{'} = \sum X_t + Uc_t - NT_t$ and $NT_t = Te_t - Se_t$ represent taxes on extraction net of subsidies.

To obtain the unit coal rents (UCR), equations (2) and (11) were simply divided by the quantity extracted (q), which converts the two equations into equations (12) and (13), respectively:

$$UCR_t = p_t - c_t \tag{12}$$

$$UCR_t^{'} = p^{'} - \frac{C_t^{'}}{q} = p^{'} - c_t^{'} \tag{13}$$

Thus, the portion of the discrepancy between the World Bank estimates (UCR) and those based on the SEEA-Energy approach (UCR') that is due to the use of different data is given by the difference between equations (12) and (13), as follows:

$$UCR_t - UCR_t^{'} = (p_t - c_t) - (p_t^{'} - c_t^{'}) = \underbrace{(p_t - p_t^{'})}_{Price\ effect} - \underbrace{(c_t - c_t^{'})}_{Cost\ effect} \tag{14}$$

The *price effect* and *cost effect* are defined as the respective effects of the difference between the prices (p) and costs (c) used in unit coal rent estimates by the World Bank, on the one hand, and those (p' and c') used in such estimates based on SEEA-Energy's approach, on the other, on the total discrepancy between the estimates. Per equation (14), the price effect is expected to have a negative sign. In other words, if the World Bank uses low prices to calculate rents instead of the high prices that coal-mining companies in Mozambique actually receive, its rent estimates will be underestimated – all other things being constant. Moreover, the cost effect is also expected to have a negative sign if one assumes that the unit costs for mining Mozambican coal are higher than the costs used by the World Bank. Thus, the negative cost effect lead to this part of Mozambique's rent estimates being overestimated – all other things being constant.

6. Results

6.1. Results and discussion

The estimates of coal rents are recorded in Table 2. Unlike the quantity of coal extracted and the unit rent values, which are respectively given in thousand metric tonnes and US$ per metric tonne, all other results in Table 2 are given in US$-million terms. The reported GOS denotes the difference between the output value and the operating costs. The GOS is the surplus accruing from coal extraction before deducting any cost or any depreciation of fixed capital.

The user cost of produced assets is the sum of the values of the physical depreciation of fixed assets used in mining and processing coal and the return to produced assets. The last row in Table 2 shows the unit coal rent, which ranges between US$15 and US$29 per metric tonne.

Table 3 depicts the World Bank's estimate of Mozambican coal rents. The estimates in Row 1 report the coal rents measured as a share of GDP. Row 2 shows the coal rents in US$ millions, while the last row presents the unit coal rent, which ranges between US$34 and US$94 per metric tonne.

Note that the last rows of both Tables 2 and 3 are directly comparable because both are measured in real US$ per metric tonne terms. To compare and discuss the results recorded in these two Tables, the estimates of unit coal rents per tonne of extracted coal (see the last row of Tables 2 and 3, respectively) were taken and plotted as Fig. 2, as follows.

Fig. 2 reveals that the World Bank estimates are consistently at least twice as high as this study's estimates for the entire period covered by the research. Fig. 2 also illustrates that the World Bank estimate (solid line) is much more volatile than this study's (dotted line).

Based on Fig. 2, two findings can be highlighted. The first is that the World Bank overestimates coal rents for Mozambique. The second reveals that the volatility of the World Bank's estimated resource rent may actually be the source of the resource curse: since volatility makes rents unpredictable, it is difficult for the country to plan its investment in development projects.

Mozambique, as a member of the Bretton Woods Institutions, benefits from World Bank advice on what policies and strategies to adopt in order to maximise the country's earnings from exploiting its natural resources and to manage such resources sustainably. In this regard, the World Bank regularly issues a policy note that includes projections of future rents from a development project once it has been launched. The Mozambican Government uses these estimates to draw up a long-term development budget. Hence, if these projected rents are consistently overstated – as our results suggest, the Government's forecasts of future coal rents will be too optimistic and may lead it to incur excessive debt, i.e. which it may be unable to settle.

6.2. Discrepancy decomposition results

To account for the total discrepancy in the World Bank estimates and those based on the SEEA-Energy approach, the study attempted to determine the weight of each type of estimate on the total. The results are displayed in Table 4.

The price effect is negative, meaning that the average world export prices used by the World Bank to calculate coal rents for Mozambique are lower than the prices received by the mining companies in Mozambique. This result also implies an underestimation of coal rents. The cost effect, on the other hand, is also negative throughout the analysis period reported in Table 4, which means that the production costs used by the World Bank to calculate coal rents for Mozambique are lower than the costs reported by the mining companies in Mozambique. This results implies that the World Bank overestimates coal rents for Mozambique.

Thus, the price effect and the cost effect have opposite directions since the cost effect is larger than the price effect in absolute values. However, the cost effect offsets the price effect, meaning that their combined net effect is an overestimation of coal rents. Hence, the cost effect becomes the main driver of the total discrepancy between the World Bank and SEEA-Energy-based estimates.

The argument presented here is that the difference in prices results from the World Bank not capturing the high impact of the quality of Mozambican coal deposits in the export price it uses to estimate the country's rents. In other words, the share of hard coal in total coal production that the World Bank assumes to hold worldwide may be lower than Mozambique's share, thereby allowing Mozambique's mining companies to receive prices that are relatively higher than the world average. Similarly, the discrepancy in costs may arise because the regional average cost employed by the World Bank in its rent estimates is biased by developed or some regional countries. For example, compared with Mozambique, Botswana and South Africa enjoy a relatively high standard of mining facilities, which leads to lower production costs for their mining companies.

Apart from the different effects of price and cost on rent estimates, simply comparing resource rents calculated by using different methods would, per se, be a source of discrepancies in such estimates. The resultant method effect was captured by specific taxes and subsidies on extraction not explicitly accounted for in the World Bank estimates. Nonetheless, the effect of employing different methods to calculate rents was negligible (around 1%), whereas about 99% of the discrepancies could be explained by the effects of price and cost.

6.3. Limitations and further research

This research faced three principal limitations. The first was the lack of costs data from other small mining companies extracting coal in Mozambique during the study period. However, as noted in section 5.2, these companies are likely to face similar prices to those encountered by Vale. Nonetheless, they may face higher production costs due to lower economies of scale, so their resource rents are likely to be even lower than Vale's. This limitation could be overcome by having access to company-specific data for other firms, which may improve the results found in this paper. The second limitation entails that the study only covered coal rents. Concentrating on coal mining was ideal for answering the research problem of estimating resource rents in Mozambique because different types of coal in a deposit are associated with different qualities and prices, and coal is Mozambique's most

Table 2
Estimates of Mozambique's coal rent using the residual value method, 2011–2020.

Description	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Extraction[b]	617	4530	5992	6332	6600	7109	15 095	16 095	13 893	7250
Output[a]	90	777	909	700	496	659	2020	2264	1546	596
Gross operating surplus[a]	38	185	225	182	142	235	372	373	237	81
User cost[a]	25	69	87	71	70	138	122	81	78	42
Real coal rent[c]	13	119	140	119	130	197	436	414	264	106
Unit coal rent[d] (UCR_t')	22	26	23	19	20	28	29	26	19	15

Note: *a* is measured in nominal US$ millions; *b* is measured in 10^3 metric tonnes; *c* is measured in real 2010 US$ millions; and *d* is measured in real 2010 US$ per metric tonne.

Table 3
Estimates of Mozambique's coal rents by the World Bank, 2011–2020.

Description	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
Coal rent[a]	0.47	1.82	1.50	1.33	1.25	1.75	4.58	4.50	2.63	2.12
Coal rent[b]	58	258	220	215	300	357	865	782	529	568
Unit coal rent[c] (UCR_t)	94	57	37	34	46	50	57	49	38	78

Note: *a* is measured as a percentage of GDP; *b* is measured in real US$ millions; and *c* is measured in real 2010 US$ per metric tonne.
Source: World Bank and author estimates

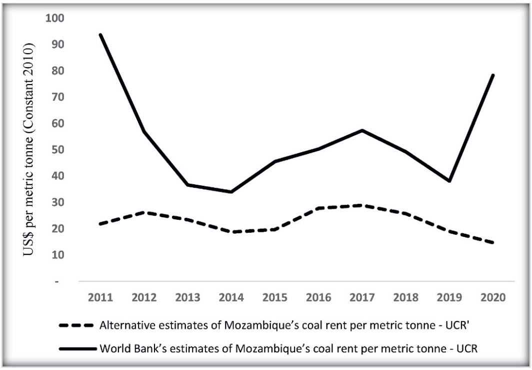

Fig. 2. Estimates of Mozambique's coal rent per metric tonne, 2011–2020.

important mineral commodity export. The study did not include other minerals exploited in Mozambique because firm-level data are lacking on them. The third limitation was the lack of detailed data on World Bank resource rent estimates, which may have led to unfair comparisons.

With respect to further research on the resource curse hypothesis, since the findings have an impact on empirical studies employing resource rent data, it is recommended that future work include a sensitivity analysis. Such an analysis would involve constructing scenarios that assumes rent figures could be adjusted depending on the composition of a deposit in the country concerned.

Moreover, since the SEEA-Energy methodology used may apply to mineral resources besides coal, future research should deepen the analysis by widening the study to include other resources and should use the most up-to-date data. This will highlight whether the findings of this research are country-specific or can be generalised worldwide.

7. Conclusion

Many studies in the literature use the World Bank's estimates of natural resource rents to test the resource curse hypothesis. These studies have shown empirically that natural resources are usually a curse rather than a blessing, especially in developing countries, where they contribute little if anything to economic growth. Furthermore, the World Bank advises governments around the world to adopt its policies on exploiting non-renewable mineral resources and to manage the income from such exploitation based on its resource rent estimates. However, since a single coal deposit, for example, may contain different qualities of coal and, hence, be sold at different prices, the use of one global price to estimate coal rents for all countries – as the World Bank does – may lead to such rents being misestimated for individual countries.

In order to track how the World Bank's calculations of resource rents differ from local-data-based estimates, the current study estimates used data gathered at company level from Mozambique's coal industry and compared these with the World Bank estimates for that industry. To this end, the residual value method recommended by SEEA-Energy was employed, which dictates that rents are measured as revenues net of all costs.

The results show that the average unit coal rent estimated by the residual value method is US$23 per metric tonne, while that estimated by the World Bank is US$54 per metric tonne. Furthermore, the rents estimated in this article are much more stable than the World Bank's.

The study also shows that the driver of this discrepancy is both the methodology and the data. The method effect, which is captured by specific taxes and subsidies on extraction not explicitly accounted for in the World Bank estimates, is statistically insignificant or negligible in this specific case. With respect to the data effect, this is decomposed into a price effect and a cost effect. The main driver of the discrepancy is the cost effect, since it is large enough to offset the price effect. These results mean that the World Bank overstates coal rents for Mozambique by underestimating the associated mining costs.

The policy implications of these results are twofold, i.e. there are implications for the literature as well as for economic policy design. From the literature perspective, the difference between the World Bank estimates of resource rents and those based on local data reveals that the regression coefficients estimated in empirical studies in the context of the resource curse hypothesis may be biased. From an economic policy perspective, the fact that the World Bank rent estimates are more volatile and higher than a country's own estimates may contribute to the resource curse not only by exaggerating future rents, but also by making them difficult for governments to forecast and use for planning. For instance, policy advice provided to Mozambique on how to manage its mining resources may be based on overstated rents. On the one hand, such advice may make Mozambican policymakers less sensitive to the subsidies granted to mining companies; on the other hand, if

Table 4
Results of discrepancy decomposition, 2011–2020.

Description	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
World Bank price (p)	105	83	73	64	89	113	127	125	102	116
World Bank cost (c)	11	26	36	30	44	63	69	77	64	38
Companies' price (p')	131	131	121	93	104	142	174	161	152	154
Companies' cost (c')	109	105	97	74	85	114	145	135	133	140
World Bank unit coal rent estimate (UCR)	94	57	37	34	46	50	57	49	38	78
Own unit coal rent estimate (UCR')	22	26	23	19	20	28	29	26	19	15
Total effect	72	31	13	15	26	23	28	23	19	64
Price effect only	−26	−48	−48	−29	−15	−29	−48	−36	−50	−38
Cost effect only	−98	−79	−61	−44	−41	−51	−76	−58	−69	−102

Note: Values in US$ per metric tonne.

policymakers expect to receive high rents from mining resources, they are incentivised to incur upfront public debt, i.e. even before mining starts. Once resource exploitation begins, therefore, the government would have to divert all received rents to repaying its debts instead of investing in development projects. This leads to a negative impact on growth – and, therefore, the so-called resource curse.

Statement of competing interests

None.

Declaration of competing interest

None.

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Paper III

Ganhane, J.J. (2025). Heterogeneity in preferences for water supply and forest use near a coal mine. *Manuscript*.

Heterogeneity in preferences for water supply and forest use near a coal mine

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Abstract

This study implements a choice experiment to examine the willingness to pay for improved water supply and forest use currently degraded due to mining activities, with a specific focus on how different household groups near coal mines value these services. The survey sample comprised 419 households in Moatize, Mozambique. Overall, the estimation results obtained via a latent class conditional logit model indicate that four classes of households exist, with different preferences across classes. The main drivers of class membership include gender, income, education and age. All classes express dissatisfaction with the status quo, and improvements in water supply is generally highly valued. However, the four groups in some cases express quite different valuations of the proposed improvements. Development interventions attempting to address the environmental impacts of mining should therefore consider the heterogeneous preferences of the intended beneficiaries, and how experiences from previous interventions are likely to affect attitudes toward new interventions.

Keywords: Moatize, coal mining, willingness to pay, choice experiment, latent class model

1. Introduction

This article estimates the willingness to pay (WTP) in respect of various households in the vicinity of coal mining in the Moatize District, Mozambique, for improved water supply and forest use where the resources concerned have been degraded or access to them denied due to the establishment of coal mines. While previous studies have provided an understanding that coal mining imposes negative effects on residents near such mines [1–4], there has been less research on how residents value these negative effects and whether residents' views differ in this regard. This lack of information hinders policymakers' understanding of how residents value different types of water supply and forest use. That gap also hampers the improved mitigation of the negative impacts of mining.

To address the gap in the literature, this study focusses on how mining affects the availability of water and forest resources. Coal deposits in Mozambique are located in rural areas, where mines are currently surrounded by forests. Processing coal also entails a high demand for water. Hence, coal exploitation can cause negative impacts on water and forest resources. For example, before the large-scale coal exploitation commenced in 2011, many households in Moatize lived close to the local river. They relied on this river not only as the main source of water for their own and their livestock's needs, but also for fishing, swimming, and as a source of wet clay collected from the riverbanks to make bricks. However, ongoing coal mining has polluted both the surface water and the groundwater, reducing the quantity and quality of fish stocks, damaging the riverbanks, and compromising the other stated livelihood-supporting activities [2, 4, 5].

Furthermore, for decades the indigenous population has relied on the forest to satisfy their energy needs in respect of providing fuelwood and charcoal as well as other aspects of their subsistence. The latter included sourcing food and other non-wood forest products; sourcing construction materials; utilising the available grazing; hunting forest animals for food and animal products; gathering traditional medicines; burying their relatives; and for recreational activities. However, with the development of coal mining, the forest was fenced off and its landscape is now covered by coal dust, choking the flora and fauna [2, 6, 7].

Yet, along with these negative impacts of coal mining, Moatize has also witnessed a rapid expansion of investment underpinned by inflows of both expatriate and national migrant labour [7, 8]. This suggests that there have been some positive impacts on employment and income. The positive impacts also include the generation of indirect employment linked to the rapid growth of activities that support mining, particularly in machinery services, construction, retail, hotels and catering [8, 9].

Given that coal mining has had both positive and negative impacts in Moatize, it is to be expected that different residents have been affected differently. Thus, it can also be expected that a heterogeneity of preferences will prevail between different groups of individuals resident there, depending not only on what costs they have suffered from mining activities, but also on whether they have experienced any benefits from them.

That different groups of Moatize's residents might feel differently about these mines is supported by the fact that Mozambique does not have the infrastructure or skills to mine its own coal. This deficiency makes the country dependent on outside investments brought in by large mining companies. The global capital inflow to Mozambique has been accompanied by large demographic dynamics of labour migration to the mining operation areas, both from abroad and from large cities within the country, with people looking for the employment and business opportunities that such mines bring [3, 7–10].

Therefore, communities in mining regions in general are made up of people of diverse cultural, social and economic characteristics – and, hence, different preferences. In this context, the findings of previous studies that highlight the environmental impacts of coal mining on the welfare of the local population (see e.g. [4, 6, 7, 11]), without considering the possible existence of differences in preferences between individuals according to their characteristics, may limit the definition of priorities in designing and implementing policies to mitigate the related environmental impacts.

This study therefore used a choice experiment method to elicit what households residing near mines preferred in respect of mitigating the impacts of mining. This stated-preference method is appropriate for valuing environmental goods and services [12–14]. In addition, the choice experiment is generally preferred over other stated-preference methods because it allows the relative importance of different attributes to be examined [12–14].

Mozambique is a relevant case study because it is the second largest exporter of coal in Africa [5, 15] and has the fifth largest untapped coal deposits in the world, currently estimated at about 37.6 billion metric tons [4, 8, 10]. These facts suggest that exploitation will continue, and that the environmental impacts of such mining will continue to matter. Moreover, since coal is exploited through open-pit mines in Mozambique [1, 3, 16], an approach that has been reported as driving biodiversity loss [17] and ecological environmental degradation [18], it is timely from a policy perspective to figure out how different residents value improvements to their compromised water supply and forest use as a result of mining. Furthermore, although the study sites are in Mozambique, the research approach and findings may have policy implications in other coal-exploiting developing countries as well.

The remainder of this paper proceeds as follows: Section 2 discusses the background and the environmental impact of coal mining in Mozambique. Section 3 presents the research material, which includes a description of the study area, the survey design, the data descriptive statistics, the econometric modelling and the analytical framework. Section 4 provides the results, while Section 5 discusses the study's conclusions.

2. Background

Mozambique's currently exploited coal deposits are located in the Moatize District of Tete Province in the west-central part of the country, which extends from the town of Tete to the country's border with Malawi [19]. Moatize is the only part of Mozambique that has ever hosted coal mining operations. Although coal mining in the country began over 50 years ago, before 2011 it was done at low levels and transported by truck. These restrictions were due to the civil war that destroyed the railway which was to transport coal to the port during the colonial era (1890s) [15]. When massive coal mining started in 2011, it could take advantage of investments made to restore damaged and establish new transport infrastructure networks. Therefore, the impacts of coal mining on the local water supply and forest use examined in this study also took place from 2011 onward. Since 2011, the country also experienced a massive influx of foreign investment in coal exploitation in Moatize [3, 8–10] (Figure 1).

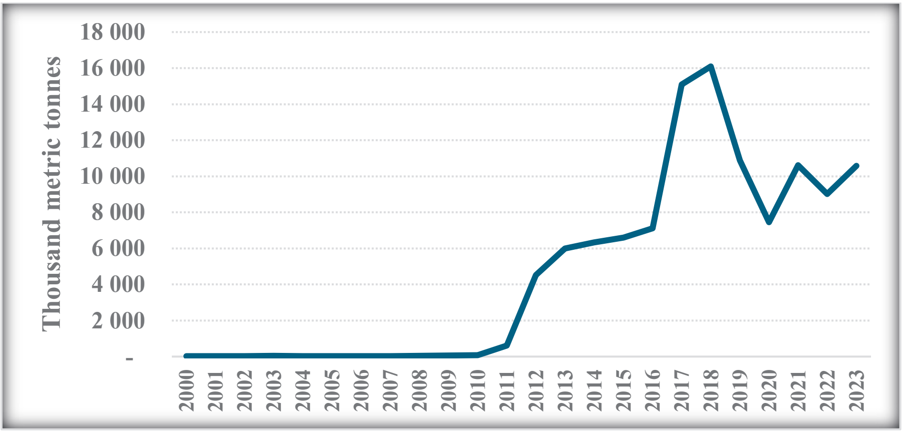

Figure 1. Coal production in Mozambique, 2000–2023
Source: United States Energy Information Administration [20]

Before this massive wave of coal mining in Moatize, an economic and social profile had been compiled of the indigenous households there [8]. This profile established the existence of three distinct groups. The first, which accounted for 54% of Moatize households, consisted of small-scale subsistence farmers dependent on the household's labour for production. This group's farmlands ranged between 2 and 3 ha. They also ran some informal businesses, selling firewood, charcoal, vegetables and fish. The second group, which represented 29% of the households, comprised those where at least one member had formal or informal wage employment. The third group, making up the remaining 17% of the study cohort, either had their own formal businesses or had at least 10 ha of farmland on which they employed wage labour [8].

Besides these three groups which were there before mining began, after coal mining started, Moatize witnessed a rapid expansion of investment underpinned by inflows of both skilled and unskilled expatriate and domestic migrant workers [7, 8], effectively constituting a fourth group. Thus, it is reasonable to assume that Moatize currently has different groups of households with different economic and social profiles. These groups may have different preferences regarding the use of water and forest resources and be differently affected by the environmental impacts of coal mining.

2.1. The environmental impacts of coal mining in Mozambique

Shortly before mining began in Moatize, the operation area was fenced off [7]. Before then, the forest where the mining area is located had been used by some indigenous people as communal land. They used the forest to satisfy their energy needs, which included harvesting firewood and creating charcoal. They also harvested wood, branches and thatch for homes, animal pens and other structures; game meat, wild fruits and honey for food; and herbs for medicine. In addition, the forest was used for grazing animals, for enjoying recreational activities and as a shortcut to other parts of the district [7, 8]. Besides this forest area being lost when mining began, preparations for coal mining involved using explosives that generated coal dust, which polluted the area [6, 7, 21, 22]. Notably, coal mining also generates mine rock, coal waste and coal dust containing hazardous elements that are dumped in the forest [1, 2, 4, 11].

When the mine rock, tailings and other toxic chemical elements generated by coal mining come into contact with the oxygen in air and water, it causes a hazardous phenomenon known as *acid mine drainage*

(AMD). In this process, salts, heavy metals and other elements harmful to human health and ecological systems create acids that flow into the surrounding environment. These orange-red compounds coat stream beds, thereby irrevocably compromising the aquatic habitat and much of the life that depends on it. A number of laboratory tests of water samples from areas adjacent to Moatize's coal mines found that the surface water, groundwater and rivers had been contaminated via AMD, and that the concentration of hazardous elements in pit water at the mines – which eventually leach into various freshwater sources – slightly exceeded the drinking water standards set by the World Health Organization [1, 4, 5, 11].

The water contaminated via AMD is deemed to affect humans' health and welfare through drinking water sources as well as through eating poisoned fish [5]. In addition to affecting human health, in Moatize the AMD pollution has worsened the quality of the river water considerably. This has led to a loss of livelihoods for the people who relied on fishing and rearing livestock, the artisans who collected humid clay from riverbeds for brickmaking, and those who used river water for irrigation [1, 2, 4–7, 11].

3. Research material

3.1. Study area and sampling strategy

The data used for analysis in this study were collected in Moatize, Tete Province, in west-central Mozambique (Figure 2). This is where all

Mozambican coal mines are currently located. The survey sample size comprised 419 households. Since the total number of households in Administrative Post of Moatize is 21,596 [23], the sample size accounts for 1.94% of all households there.

Since this study intended to examine the WTP among groups of households in the vicinity of coal mines in Mozambique, the main selection criterion for the sample was proximity to a coal mining plant. Thus, all households selected for the survey lived within 15 kilometres of such a mine.

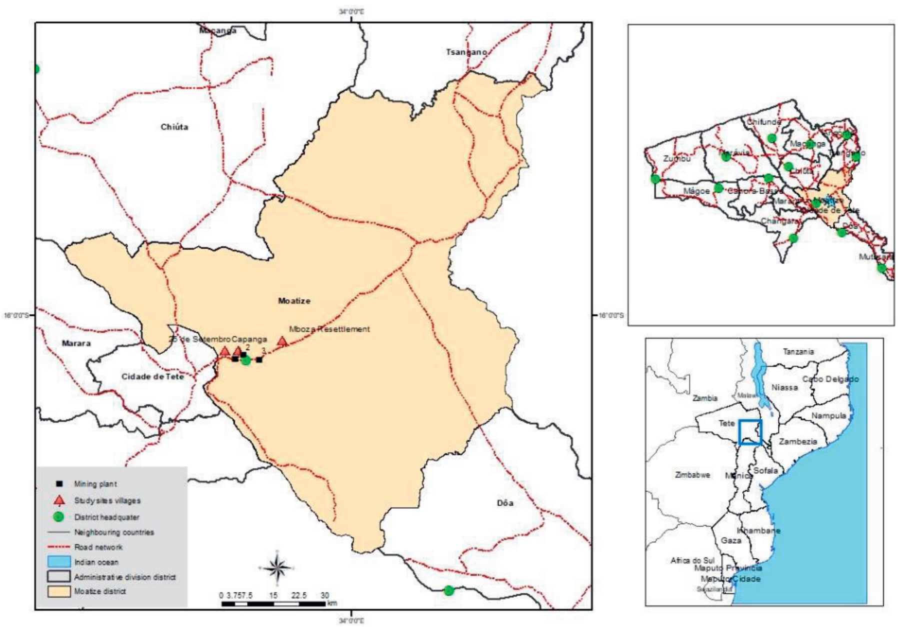

Figure 2. Location of study sites in the study area

3.2 Econometric modelling and analytical framework

This study employed a stated-preference choice experiment framework to elicit the WTP for improved water supply and forest use. The choice experiment method is the most appropriate for this study as it allows varying choice situations over a range of attributes to be analysed in the observed outcomes [12, 14].

The choice experiment is an analytical approach founded in Lancaster's consumer-utility theory of value [24] and Manski's random utility model [25]. Lancaster defines *goods* as "attributes" and the *characteristics* of the goods as "attribute levels", so that consumers choose a combination of a good's attribute levels that maximise the utility that the good has for them [24].

Manski shows that individuals select one alternative over others in a set only if the expected utility derived from the chosen alternative is not lower than the utility derived from the others [25]. Under the random utility model specification, the utility (U) that person n obtains by choosing alternative i is –

$$U_{ni} = \alpha' x_{ni} + \varepsilon_{ni} \tag{1}$$

where the vector of coefficients α' is the marginal utility, x_{njt} is a vector of observed variables, $\alpha' x_{ni}$ is the observed component of the utility, and ε_{ni} is an unobserved component of the utility that is assumed to be independently and identically distributed across individuals [14, 25, 29].

Given that the main objective of this study was to estimate the WTP among groups of respondents, the latent class model was adopted. This model groups respondents into a finite number of classes, and it treats them homogeneously within classes and heterogeneously between or among classes. This helps explain the unobserved heterogeneity of individuals' preferences by their membership in different classes [26–29].

Consider that there are *N* respondents. Each respondent n $(n \in N)$ makes a choice from *J* alternatives. Each alternative is described by a row vector of attributes Z_i that includes the monetary attribute. Furthermore, *n* is described by a set of respondent characteristics *X*. If there exist *C* different classes of preference structures, the conditional probability of respondent n choosing alternative *i* depends on the class *c* (c $\in C$) in which *n* belongs to and can be expressed by the choice probability model ($P_{in\backslash c}$) –

$$P_{in\backslash c} = \frac{exp(\beta_c Z_i)}{\sum_{K=1}^{J} \beta_c Z_n} \tag{2}$$

where $\beta_c = \beta_1, \ldots, \beta_C$ is a vector of class-specific utility parameters that vary by class, which are interpreted as the marginal utility of the corresponding attributes Z in class *c* [26, 27, 29, 30, 32, 45]. To determine which class respondent *n* belongs to, one needs to specify the unconditional probability of *n* being included in a particular class *c* as a function of *X*. This would then be the class membership probability model (P_{nc}), expressed as –

$$P_{nc} = \frac{exp(\delta_c X_i)}{\sum_{k=1}^{J} exp(\beta_c Z_n)} \quad (3)$$

where $\delta_c = (\delta_1, \dots, \delta_{c-1})$ is a vector of the parameter which indicate how the probability of being in a specific class is affected by *X*s [12, 26, 27, 29, 30, 32, 45]. Thus, the joint probability that respondent *n* belongs to class *c* and chooses alternative *i* is the sum over all classes of the product of $P_{in\backslash c}$ and P_{nc} is [27, 29, 32, 45] –

$$P_{in} = P_{in\backslash c} P_{nc} = \sum_{c=1}^{C} \frac{exp(\beta_c Z_i)}{\sum_{K=1}^{J} \beta_c Z_n} \frac{exp(\delta_c X_i)}{\sum_{k=1}^{J} exp(\beta_c Z_n)} \quad (4)$$

The interpretation of coefficients in the latent class model is not straightforward because the scale of the utilities in the model is unobservable. Therefore, the most convenient means of interpreting the results from these models is to compute the WTP for individual levels of attributes. This computation allows one to assess the degree to which households value the various attributes in the choice experiment. The WTP for an attribute is estimated as the ratio of the marginal utility of the attribute to the marginal utility of the money contribution. Hence, the WTP for any improvement in the level (k) of a single attribute (W) is calculated by dividing the coefficient of that attribute by the coefficient of the *Money contribution* variable in each class [26, 29, 31, 45], as follows:

$$WTP_K = -\frac{\frac{\partial U}{\partial W_K}}{\frac{\partial U}{\partial Money\ contribution}} = -\frac{\alpha_{W_k}}{\alpha_{money\ contribution}} \quad (5)$$

3.3. Survey design

A literature review on the environmental impacts of coal mining in Mozambique was carried out (see Section 2.1) to ensure that relevant attributes were included in the choice experiment survey design. *Water supply* and *Forest use* were used as attributes in the current study's choice experiment. Thus, respondents were asked about their WTP for an improvement in these attributes compared with their reference status. The levels of the status quo for each attribute and its alternative (improvement) were defined based on the existent statistics on water supply and forest use in Moatize.

The reported statistics showed that, in 2020 (the most recent year for which statistics are available), the main sources of drinking water in the Moatize District as a whole were from rivers and lakes (32%), hand-dug ground wells (36.6%), improved wells (13.9%), piped water (11.1%), a communal tap (5%), and bottled water (1.4%) [23]. Regarding forest use in Moatize, the statistics reported that 38% of households used charcoal as their main source of lighting energy [23]. One of the main economic activities reported was farming cattle and goats – for which forests were a potential source of grazing [23].

The different types of water supply used at the study sites included bottled water, backyard taps, communal taps, and unprotected wells on riverbanks. Despite its quality and reliability, bottled water was not accessible due to its high price. The piped and communal tap water at the study sites (installed by the mining companies as a compensatory measure for the worsened quality of the river water) was not reliably available. Moreover, the supplied water was contaminated and required further treatment before being potable. With the existing water supply options, respondents thus faced an unreliable supply, supply shortages, maintenance costs (especially for those who had water piped to their yards) and poor quality. In respect of forest use, because the forest had been fenced off by the mines, the local residents had to walk long distances to get around the exploitation area to graze their animals, collect firewood or hunt. (Details on the status quo of water supply and forest use appear in the supplementary materials to this paper.)

In the choice experiment, three different service levels were proposed specifically to supply potable water. All three such levels entailed water being supplied without the need for additional treatment and it being available 24 hours a day, every day. All three service levels would thus deliver a more reliable, affordable and higher-quality supply of water than any of the currently available options. Similarly, three different levels of improved use of forest resources were proposed.

The script describing the three attributes included in the choice experiment (Box 1) was intended to explain them to respondents in detail before they faced the choice tasks.

Box 1. Description of the attributes and hypothetical scenarios

Water supply

Before the coal mining era, the local population in Moatize relied on the Revúbué River to collect drinking water for themselves and their livestock, to bathe and to wash clothes. The land adjacent to the riverbanks was usually preferred for growing short-cycle crops, while artisans extracted the humid clay to produce bricks. Yet others fished, and everyone used the area to cool off during the heat (Moatize gets very hot). Now, due to coal mining, the surface water and groundwater are contaminated. To mitigate this problem, imagine measures are being taken under a community project where Level 1 would consist of opening improved wells near people's homes, and setting up filters and hand pumps to extract water. Level 2 would consist of supplying treated water via communal taps installed very close to people's homes, i.e. within a walking distance of less than five minutes. Level 3 would consist of pumping safe drinking water to a tap in each household's back yard. All options will supply safe water 24 hours a day, every day.

Forest use

The land conceded to coal mining is a forest where locals used to harvest game meat, honey, medicinal herbs and firewood; where they dried logs to produce charcoal and grazed their stock; and which they used as a shortcut. For safety and other reasons, the forest was fenced off. However, even the forest land outside the fence is now covered in coal dust, nullifying the forest's potential benefits. To mitigate this effect, suppose that a community project is proposed. Level 1 consist of placing guarded gates at important points that allow one to cross the forest. However, one would not be allowed to harvest anything from the forest while using it as a shortcut. In Level 2, in addition to Level 1, reforestation and restoration of species that have disappeared over time would be undertaken, together with the placement of beehives. The landscape would also be cleaned up to enhance it further. This would again allow the collection of firewood and dry logs for charcoal production, building materials, medicinal herbs and honey, while hunting would also be reintroduced. In Level 3, in addition to Level 2, space would be opened up intermittently for grazing.

Money contribution

However, to implement the mitigation project implies investment. These costs vary with each implementation phase presented above and would need to be paid by the beneficiaries. Their contribution would range from US$4 to US$15 monthly, depending on the project implementation phase concerned. Such contributions would last for ten years.

Note

If the project is implemented, only the water supply and forest use would improve at the levels indicated. Everything else would remain as it is.

Note: Translation of the Portuguese original.

The payment vehicle in the survey was described as households' contribution to the community project, as presented in Box 1. In the official figures released by Mozambique's National Institute of Statistics, the average monthly income per household in Tete was MZN10,953 or US$183 [23]. Taking this into account, the Moatize study therefore determined an initial monthly sum of US$4, US$10 and US$15 as a suitable level of contribution per household for each respective phase of project implementation. These payment amounts were also compared with previous choice experiment studies conducted in rural Mozambique involving households with similar income levels (see [33–38]). The attribute levels are displayed in Table 1.

Table 1. Attributes and attribute levels in choice tasks

Attributes	Levels	Variable names
Water supply	(0) Actual supply (1) Improved well (2) Communal tap (3) Piped to yard	n/a *Improved well* *Communal tap* *Piped to yard*
Forest use	(0) No use (1) Use of the forest as a shortcut (2) Easy collection of firewood, honey and medicinal herbs and permitted hunting and charcoal production, plus (1) (3) Easy grazing, plus (2)	n/a *Cross* *Forest collection* *Grazing*
Money contribution (per household per month)	(0) US$0 (1) US$4 (2) US$10 (3) US$15	n/a *Money contribution* *Money contribution* *Money contribution*

A full factorial design with all possible combinations of attribute levels (see Table 1) would yield 64 (= 4^3) profiles. However, addressing such a large number of choice tasks for the respondents would have been costly and time-consuming. For this reason, the study adopted the orthogonal design technique. This not only enabled the attribute levels to be combined into alternatives, but also that alternatives could be combined into choice sets in a such a way that no individual alternative became dominant or inferior to others [27, 39]. For this process, the experiment design algorithms of the *SurveyEngine* platform integrated with the Ngene™ design tool, and specifically its efficient orthogonal designs, were used to build a matrix of treatments for the current study [40, 41].

Thus, with attribute levels and choice sets defined, a survey questionnaire was developed in Portuguese to determine the WTP for improvements in water supply and forest use. The questionnaire was divided into five parts. Part 1 briefly described the intent of the survey and asked the respondents to confirm that they were willing to participate. They were also asked to provide certain of their socio-economic and socio-demographic characteristics. Part 2, the main component, presented the choice experiment setup. Part 3 contained questions about the respondent's household income and expenditure, and Part 4 asked attitudinal questions about coal mining. Part 5 asked respondents what parties they saw as being responsible for mitigating the negative effects of coal mining, and about their confidence in those parties fulfilling that obligation.

In research employing choice experiments, it is common to use pictures of the attribute levels to help respondents understand the choices more clearly (see e.g. [12, 13, 26, 28–30, 42]). The current study therefore also used pictures to show each attribute level, to ensure that respondents would make choices that reflected the type of outcome they wanted.

Box 2 offers an example of a choice set presented in Part 2 of the questionnaire. Respondents were given a total of ten different choice sets such as this. They were then asked to consider all three alternatives simultaneously and choose the one that would maximise utility in the attribute concerned – keeping in mind their own budget constraints. In each choice set, a status-quo alternative (Option C) was shown. Respondents were explicitly instructed to choose Option C if they found the other two alternatives (Options A and B) too expensive or unsuitable. The inclusion of such a status-quo option has been shown to mitigate bias between true and hypothetical WTP [43, 44].

Box 2. A typical choice set

Assuming that the following options A, B and C are the only choices you have, which one do you prefer the most?			
	Option A	**Option B**	**Option C**
Forest access	Use of the forest as a shortcut	Actual status	Actual status
Water supply	Communal tap	Communal tap	Current supply
Your contribution	US$10	US$4	US$0
Your choice	[......]	[......]	[......]

Note: Translation of the Portuguese original.

An early draft of the questionnaire was pre-tested through 60 face-to-face field interviews. This exercise aimed to assess not only whether respondents understood the choice sets, but also whether the proposed attribute levels were suitable. The results of the piloting exercise were used to clarify some of the questions and to determine the exact design of the payment vehicle.

The survey with the improved questionnaire took place during February and March 2024. The interviews were conducted in Portuguese, the national language, as well as oral translation of the Portuguese questions to Nyungwe, a local Mozambican language. The survey team included two experienced supervisors, thirteen enumerators and one driver. The enumerators were recruited from a local university and were all final-year undergraduate students. Before the pilot survey, one of the supervisors had trained these enumerators. The driver had the additional task of measuring the distance from the sampled households to the nearest coal mine.

After the survey had been conducted, the supervisors collected the completed questionnaires from the enumerators to check for incomplete or inconsistent responses, and for problems in the selection of eligible respondents. Questionnaires containing any of these issues were rejected, so that only the approved questionnaires qualified for data entry. This rejection process did not negatively affect the sample size: rejections were done daily during the survey and substitutions were made for them the following day. In this way, coherence and consistency in the data could be ensured.

3.4. Descriptive statistics

The definitions and descriptive statistics of the socio-economic and socio-demographic variables are presented in Table 2.

Table 2. Descriptive statistics of socio-economic and socio-demographic variables

Variable name	Definition	Mean	Std dev.	Min.	Max.
Income	Monthly household income (US Dollars)	197.93	103.82	31.75	666.67
Age	Respondent's age (years)	38.90	14.79	19	106
Distance	Distance from the respondent's home to the nearest coal mine (km)	5.90	3.07	2	13
Gender	1 if the respondent is female, and 0 otherwise	0.53	0.50	0	1
Indigenous	1 if the respondent is indigenous, and 0 otherwise	0.77	0.42	0	1
Livestock	1 if the household owns livestock, and 0 otherwise	0.61	0.49	0	1
Education	Respondent's education (years of schooling)	6.80	4.42	0	17
Employment	1 if at least one household member works at a mining-related company, and 0 otherwise	0.11	0.32	0	1

Variable name	Definition	Mean	Std dev.	Min.	Max.
Farmland	1 if the household owns farmland, and 0 otherwise	0.71	0.46	0	1
Household size	Family size (sum of members in the household)	5.71	2.30	1	18

However, in the model estimation, the continuous explanatory variables were turned into dummies (see Table 3) to ease the interpretation of the estimated parameters. The cut-off points for each dummy variable, namely *Income*, *Distance*, *Education* and *Household size*, were determined based on the average of the variable concerned.

Table 3. Descriptive statistics of class membership variables (dummy variables)

Variable name	Definition	Value	Proportion (n = 419)	%
High income	1 if the household's monthly income is US$200 or more, and 0 otherwise	1	73	17.42
		0	346	82.58
Older	1 if the respondent's age is 30 or more, and 0 otherwise	1	275	65.63
		0	144	34.37
Far distance	1 if the distance from the respondent's home to the nearest coal mine is 10 km or more, and 0 otherwise	1	62	14.80
		0	357	85.20
Female	1 if the respondent is female, and 0 otherwise	1	224	53.46
		0	195	46.54

Variable name	Definition	Value	Proportion (n = 419)	%
Indigenous	1 if the respondent is indigenous, and 0 otherwise	1	324	77.32
		0	95	22.68
Livestock	1 if the household owns livestock, and 0 otherwise	1	256	61.16
		0	163	38.84
High education	1 if the respondent has 12 or more years of schooling, and 0 otherwise	1	74	17.66
		0	345	82.34
Mining employment	1 if at least one household member works at a mining-related company, and 0 otherwise	1	47	11.32
		0	372	88.68
Farmland	1 if the household owns farmland, and 0 otherwise	1	296	70.53
		0	123	29.47
Large household	1 if the household has at least five members, and 0 otherwise	1	298	71.12
		0	121	28.88

The statistics show that 83% of respondents were in households that earned low incomes, 34% were young (under the age of 30), and 85% lived less than 10 km from the nearest coal mine. Just over half of the respondents were female (53%), while most respondents were indigenous (77%). The share of sampled respondents whose households owned livestock was 61%. Moreover, 18% possessed a high level of education, with at least 12 years of schooling.

Furthermore, only 11% of the respondents were part of a household that had at least one household member working at a coal-mining-related enterprise. Whilst 87% of this 11% had entered mining-related employment because it paid more than other jobs, the remaining 13% stated that they worked in mining-related jobs because they had no other option. The coal-mining-related enterprises provided accommodation or catering, car rental and security services, subcontracted by coal mining companies. Of the 89% of the respondents not directly or indirectly employed in mining, 68% stated that they would like to find employment in the sector, but that they lacked the minimum skills required by the mining companies. About 71% of all respondents included in the sample belonged to households that owned farmland, while 71% of all respondents were part of households with five or more members.

Although there are no official survey reports covering these indicators specifically for the Administrative Post of Moatize, these descriptive statistics can be compared with those in the most recent household budget survey for the Tete Province itself, carried out between 2019 and 2020 [23]. In that survey the average household size was 5 (vs 6 in the Moatize sample); the household's monthly average income was MZN10,953 (US$183, vs US$198 in the Moatize sample); the percentage of male-gendered household heads was 49 (47 in the Moatize sample); and the average percentage of people with higher education was 1% (3% in the Moatize sample). The Tete and Moatize samples are generally similar in key indicators, although there are some discrepancies that can be explained by differences between urban and rural districts and by the latter sample's relative proximity to mines.

Finally, when asked about how difficult they had found it to answer the choice tasks, 98% of the Moatize respondents said they had perceived it as easy or very easy to do, whilst 1% had considered it difficult or very difficult. The remaining 1% perceived the choice tasks as neither difficult nor easy.

4. Results and discussion

4.1. Results of the latent-class model estimations

In these estimations, the optimal number of latent classes needed to be determined. This was achieved by calculating a number of goodness-of-fit indices, namely the Bayesian information criterion (BIC), the Akaike information criterion (AIC) and the consistent AIC (CAIC), from 2 to 10 class models (see Table 4) without class membership variables.

Table 4. Goodness-of-fit of latent class models with up to ten latent classes

Indices	No. of classes								
	2	3	4	5	6	7	8	9	10
Log likelihood	-3,104.60	-2,969.38	-2,913.33	-2,893.75	-2,842.20	-2,836.98	-2,765.96	-2,647.16	-2,641.28
Bayesian information criterion	6,311.85	6,095.75	5,777.35	5,797.60	5,819.93	5,885.28	6,113.09	6,146.67	6,161.85
Akaike information criterion (AIC)	6,243.20	5,990.77	5,454.32	5,460.56	5,619.93	5,743.96	5,826.40	5,911.51	5,932.67
Consistent AIC	6,328.85	6,121.75	5,841.60	5,857.35	5,908.93	5,920.28	6,184.09	6,199.67	6,223.85

The estimation results consistently show that the best model fit is reached with four latent classes. Moreover, the four-class model minimises all the goodness-of-fit indices. The latent class model estimation results are presented in Table 5.

Table 5. Estimation results of latent class model with class membership variables

	Class 1		Class 2		Class 3		Class 4	
	Co-efficient	Std error	Co-efficient	Std error	Co-efficient	Std error	Co-efficient	Std error
Preference parameter								
Alternative specific constant	-1.411*	(0.766)	-1.173**	(0.578)	-1.750***	(0.461)	-0.208*	(0.118)
Improved well	0.286***	(0.056)	0.432***	(0.067)	-1.038**	(0.416)	0.842***	(0.062)
Common tap	1.296***	(0.177)	2.338***	(0.529)	2.831***	(0.676)	2.080***	(0.190)
Piped to yard	0.136***	(0.012)	0.941	(1.162)	2.018**	(1.015)	0.866	(1.184)
Cross forest	0.030	(0.183)	0.124***	(0.019)	-0.872	(1.020)	0.013	(0.010)
Forest collection	1.190***	(0.160)	2.835***	(0.233)	0.096***	(0.035)	1.061***	(0.130)
Grazing	0.174***	(0.013)	1.425***	(0.208)	-0.237	(1.044)	0.074***	(0.012)
Money contribution	-0.588***	(0.226)	-0.442**	(0.202)	-0.164***	(0.063)	-0.917***	(0.281)
Class assignment parameter								
High income	0.206	(0.209)	0.292	(0.200)	0.387***	(0.089)	–	–
Older	0.411**	(0.203)	0.360**	(0.162)	0.084	(0.118)	–	–
Far distance	0.217***	(0.084)	1.475***	(0.370)	-0.532***	(0.016)	–	–

	Class 1		Class 2		Class 3		Class 4	
	Co-efficient	**Std error**	**Co-efficient**	**Std error**	**Co-efficient**	**Std error**	**Co-efficient**	**Std error**
Female	0.835**	(0.352)	-0.789***	(0.232)	-0.068	(0.089)	–	–
Indigenous	1.033***	(0.092)	0.439**	(0.173)	1.770	(1.650)	–	–
Livestock	0.497	(0.732)	0.588***	(0.166)	0.646	(2.074)	–	–
High education	-0.776***	(0.194)	-0.259**	(0.121)	0.475**	(0.219)	–	–
Mining employment	-0.857	(0.750)	-1.505	(1.077)	0.541**	(0.232)	–	–
Farmland	0.742***	(0.182)	1.468***	(0.270)	0.375	(0.519)	–	–
Large household	0.307***	(0.086)	0.187**	(0.090)	-0.275**	(0.117)	–	–
Intercept	-0.917	(1.581)	- 1.104	(1.440)	-0.214	(1.714)	–	–
Model statistics								
Class share	36.1%		29.9%		7.4%		26.6%	
No. of choices	4,190	–		–		–		–
Log likelihood	-2,730	–		–		–		–
Bayesian information criterion	5,750	–		–		–		–
Akaike information criterion (AIC)	5,321	–		–		–		–
Consistent AIC	5,797	–		–		–		–

Note: Standard errors in parentheses. ***, ** and * imply statistical significance at the level of 1%, 5% and 10%, respectively.

The alternative specific constant (ASC) functions as a dummy variable intended to capture whether or not the respondent preferred a change from the status quo in a given choice task. The value of 1 represents choosing the status quo (e.g. Option C in Box 2), while 0 represents choosing one of the improvement alternatives (e.g. Options A or B in Box 2). The model estimation results in Table 5 show negative and significant coefficients for the ASC for all classes. This indicates that respondents in all groups preferred improvements over the current water supply and forest use status. Furthermore, all estimated coefficients of the money contribution are negative and statistically significant across the four classes, as expected.

The class-specific results show that, in Class 1 (36.1% of the sample), the coefficients for all levels of improved water supply are positive and significant. This suggests that members of Class 1 have strong preferences in respect of improved water supply, regardless of whether it is via an improved well, communal tap or piped to their yard. Members of Class 1 can therefore be classified as 'water improvement preferers' as they have positive marginal utility if the water supply is improved in any way. On the other hand, the estimated coefficient for using the forest as a shortcut (*Crossing the forest*) is not statistically significant.

In addition, the class membership model estimation results for Class 1 show that members of this class were more likely to be older, more likely to be women, more likely to be indigenous, and less likely to have high education compared with their counterparts in Class 4.

Furthermore, in comparison with Class 4 households, those in Class 1 were more likely to be located relatively far from the mining operations, more likely to own farmland, and more likely to be large. The results also show that income, livestock and employment in mining are not statistically significant explanatory factors of the probability that respondents are members of Class 1.

In the estimation results for Class 2 (29.9% of the sample), Table 5 shows that the coefficients for all attribute levels for forest use are positive and significant. Furthermore, members of this class were indifferent about having water piped to their back yards.

Moreover, the estimation results reveal that, when compared with their counterparts in Class 4, Class 2 respondents were more likely to be indigenous, more likely to be older and more likely to be men, whereas they were less likely to have high education. A further comparison between Class 2 and Class 4 households revealed that the former were more likely than the latter to be large, live relatively far from the coal mines, and own both livestock and farmland.

For Class 3 (7.4% of the sample), the smallest class, the estimation results indicate that a high standard of water supply was strongly preferred. This is illustrated by the coefficients for *Communal tap* and *Piped to yard* being positive and statistically significant. However, *Improved well* is negative and significant. While the estimated coefficients for *Crossing the forest* and *Grazing* are insignificant, the coefficient for *Forest collection* is significant.

Furthermore, the Class 3 membership estimation results indicate that these respondents were more likely to have higher education levels compared with those from Class 4. Moreover, compared with Class 4 households, households in Class 3 were more likely to live in small households, have at least one household member employed in coal mining or in a related company, and earn a higher income. Furthermore, the comparison between Class 3 and Class 4 respondents revealed that the former were more likely than the latter to live closer to the mining operations.

The model estimation results for Class 4 (26.6% of the sample) show that members of this class preferred improved well water and a communal water tap. Regarding forest use, members of this class preferred collecting resources from the forest and using it for grazing. Notably, members of Class 4 were indifferent about having water piped to their yard as well as using the forest as a shortcut (*Crossing the forest*).

4.1. Willingness to pay

The WTP was estimated by using, as the payment mode, the households' monthly contribution to the hypothetical project in the choice experiment. The WTP is therefore measured in US$/month.

The estimated WTP is based on the latent class model estimation coefficients. It represents the monetary values of changes in water supply and forest use. The estimation results (see Table 6) show positive and significant WTP for water supply, at all levels, in Class 1.

Furthermore, the WTP for forest use, in all levels, is positive and significant in Class 2.

Table 6. Willingness to pay (US$ per month)

Variable	Class 1		Class 2		Class 3		Class 4	
	Co-efficient	**Std error**	**Co-efficient**	**Std error**	**Co-efficient**	**Std error**	**Co-efficient**	**Std error**
ASC	-2.399*	(1.297)	-2.656**	(1.080)	-10.679***	(1.226)	-0.227*	(0.121)
Improved well	0.486***	(0.177)	0.978***	(0.244)	- 6.334***	(0.494)	0.919***	(0.217)
Communal tap	2.203***	(0.406)	5.294***	(0.754)	17.275***	(1.007)	2.269***	(0.320)
Piped to yard	0.231***	(0.035)	2.130	(1.578)	12.316***	(0.415)	0.945	(1.816)
Cross forest	0.051	(0.042)	0.044***	(0.015)	- 0.532	(0.502)	0.014	(0.009)
Forest collection	2.022***	(0.700)	6.420***	(0.977)	0.584***	(0.127)	1.158***	(0.203)
Grazing	0.296***	(0.087)	3.228***	(0.556)	-1.448*	(0.754)	0.080***	(0.013)

Note: ASC (Alternative specific constant – "Dummy variable")

The results illustrate that the highest WTP is expressed by members of Class 3, although they were only willing to pay for a relatively high standard of water supply, i.e. *Communal tap* and *Piped to yard*, and for *Forest collection*. Thus, a higher WTP is more likely to be found among highly educated individuals, with higher incomes, living near mining operations, working in mining-related companies, and being members of small households. Members of Class 4, on the other hand, have the smallest negative WTP for the status quo (Option C) compared with their counterparts in other classes, especially Class 3.

Overall, there is a positive WTP by households for improved water supply and forest use, and a strongly negative WTP for the status quo. This implies that there may be gains in welfare if water and forest products become more available. Policymakers could transpose the estimated average attribute-specific WTP to a village-wide WTP to explore how an additional social welfare might be created through improving villagers' water supply and forest use.

4.2. Study limitations and further research

The *Livestock* variable in this study's survey questionnaire aimed to differentiate between respondents who farmed animals from those who do not. The definition of this variable included animals such as rabbits, ducks, chickens, turkeys, pigs and others that were raised in enclosed spaces without the need for grazing, in addition to animals such as cows or goats that could benefit from grazing. Unfortunately, this entailed that information from the *Livestock* variable could not be used to study how ownership of grazing livestock affected preferences for grazing space.

Hence, a recommendation to future studies aiming to deepen the topic of this paper would be to include a question on whether respondents owned livestock that benefited from grazing.

5. Conclusion

As shown in this research, several studies have found that the population in Mozambique's coal mining region is being negatively affected by the environmental impacts such mining continues to impose. However, less well known is what impacts are considered most important, and whether and, if so, by how much this varies across different groups in the population. Information about how different households value these negative impacts is therefore needed to help implement mitigation policies. To partially fill this gap, this study used a choice experiment to elicit preferences regarding improvements in water supply and forest use negatively affected by coal mining.

To allow for heterogeneity in preferences between different groups, a latent class model was applied. The model estimations indicate that the respondents could be divided by preferences into four latent classes. While all four groups expressed varying (but usually quite strong) dissatisfaction with the status quo, the groups in some cases expressed quite different preferences and WTP for the offered improvements. This suggests that preference heterogeneity is indeed important for how projects aimed at mitigating mining impacts are likely to be perceived.

For example, while all respondents expressed preferences for an improved water supply, a small group of respondents – who were more likely to earn higher incomes and have a relatively high education – were only willing to pay for the higher standards of water supply (communal taps and piped water to their yards), i.e. they expressed a negative WTP for improved wells. Notably, WTP was consistently lower, across all four classes, for the highest proposed standard of water supply. This probably reflects the poor experiences that households in the area have had with this type of water provision in the past. In other words, even if the type of supply described in the choice experiment was purportedly more reliable, respondents may not have trusted that it would be.

Similarly, while all respondents expressed a WTP for improved access to forest products, other activities that required forest access were valued quite differently – even negatively, in some cases. For example, improving forest access enough to permit livestock grazing was intended to be the highest improvement of forest use, but not all respondent classes expressed a WTP for this. Possibly, the response could imply that continued degradation of the environment has meant many households no longer have livestock that would benefit from grazing opportunities.

Water supply and forest use clearly have strong impacts on local welfare, and this study reveals considerable support for their improvement. Both the government and the mining companies need to be aware that people in the area value projects to improve water supply and forest use because such projects are very likely to improve their welfare. Thus, public policies and mining companies' corporate social responsibility programmes are strongly encouraged to implement projects to improve water supply and forest use.

Nonetheless, heterogeneities in preferences need to be considered in designing and implementing such projects for Moatize (or elsewhere). Any projects – whether financed by the Mozambican Government or by the relevant mining companies – which aim to mitigate the negative impacts of mining in the region concerned should therefore include improvements to the affected communities' water supply and forest use. Consideration should also be given to this study's finding that, although respondent households expressed strong preferences for such improvements, the poor implementation of similar projects in the past may have contributed to the low WTP for some of the suggested mitigation measures. If new projects are equally poorly implemented, they are unlikely to contribute to improving their intended beneficiaries' welfare.

Even in a situation where almost nobody preferred the status quo of compromised natural resources due to coal mining, there is a need to think carefully about what is offered to improve the situation as well as consider how people feel about such improvements. Heterogeneity in the affected groups overall, and how those groups may have changed over time, are other vital considerations.

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Paper IV

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Willingness to pay for post-mining landscape restoration

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Abstract

This paper uses the contingent valuation method to estimate displaced and resettled Mozambican households' willingness to pay (measured in labour) to restore the landscape where they used to live before mining began there. The study results indicate that, on average, households were willing to contribute about nine working days per month. The results further indicate that resettled respondents had been adaptive and had used the monetary compensation they were given for resettlement to buy productive land to offset that lost due to resettlement. However, they still saw themselves as worse off than before their relocation. One explanation for this is that they are now far from marketplaces and the river, making it difficult to develop new sources of income and have access to water. Mitigation interventions and future resettlements should therefore think more carefully about selecting resettlement sites.

Keywords: mining-induced resettlement, double-bounded contingent valuation, Moatize, coal

1. Introduction

This paper studies some of the long-run impacts of resettlement on rural Mozambican households who were relocated to make way for coal mining. Previous research on the impact of similar involuntary relocation found that resettlement had worsened the welfare of the communities affected as the relevant compensation offered smaller and less fertile farm plots than those they had had in their areas of origin. Other negative resettlement impacts on these studies' respondents were the disruption of sources of income derived in their areas of origin, reduced access to water, and dwellings of lower quality [1–12].

However, these previous studies were conducted shortly after the resettlements concerned had taken place, and they primarily examined whether the compensation package provided at the time of resettlement indeed made up for the losses caused by displacement. Thus, the studies did not consider whether those who had been resettled could adapt to improve their welfare over time, and did not consider the potential role of the resettlement package in creating the conditions for such adaptation to happen.

To fill this gap, this paper uses two distinct steps to examine some of the long-term impacts of resettlement. The first compares the current living conditions with those prior to resettlement for the people concerned, while the second estimates their willingness to pay (WTP) to restore the landscape in their places of origin before coal mining began and to potentially move back there. The study expected that those who had adapted comparatively well to their new surroundings and who had created better sources of income that had elevated their welfare, relatively speaking, would either have a very low or no WTP for such restoration. On the other hand, those who had failed to adapt to their new location were expected to have a relatively high WTP.

The WTP for the restoration programme was estimated using contingent valuation (CV), a technique widely employed in the field of environmental economics to examine how people value non-market goods and services. In addition, a double-bounded dichotomous choice setup was adopted, which is generally preferred to its single-bounded counterpart because the second bid can help correct for initial bids that are too low or too high [13–17]. Notably, the research approach and findings here may have similar policy implications for other mineral-exploiting developing countries with mining-induced involuntary displacement and resettlement.

The study site selected was Moatize in Mozambique. Mozambique hosts the fifth largest untapped coal deposit in the world [18–20]. This suggests that displacing and resettling people to make way for mining is likely to continue, as is landscape deterioration. Therefore, the findings of this paper may help improve the compensation packages aimed at assisting resettled persons with adapting to their new environments over time.

The remainder of this paper proceeds as follows: Section 2 describes the background to coal-mining-induced displacement and resettlement in Moatize. Section 3 describes the research strategy including study site selection, the research method and the survey design, while Section 4 presents the results. Section 5 analyses the results and concludes the discussion.

2. Background

Involuntary mining-induced resettlement is a process by means of which the people occupying proclaimed mining areas are displaced from such areas and located elsewhere, subject to compensation. To this end, the World Bank and global mining stakeholders have formulated international best practices, guidelines and directives to determine how such involuntary resettlements should be carried out [9, 10, 21–25]. These formulations guide the planning and execution of involuntary resettlements to ensure that mining companies mitigate adverse resettlement effects by compensating fully and fairly for the affected parties' losses and by providing them with development benefits [26, 27]. In the World Bank's formulations, such benefits refer to displaced people being assisted with restoring their standards of living to at least pre-resettlement levels [28].

For example, the international best practices defined by the World Bank mandate that, before resettlement is effected, the mining companies concerned need to take a census of all items eligible for compensation and describe them in a resettlement action plan. The action plan should also describe the intended compensation package. Besides compensating for lost assets, such packages should make up for lost production and income from the former economic activities of those displaced. Furthermore, the best practices propose that the resettlement site selection should ensure that the productive potential and locational advantages of the new site are at least comparable to those of the old one. Thus, issues such as water supply, housing, land tenure, fishing, grazing, use of forest areas, and any other common property or natural resources which matter for local livelihoods need to be considered [26, 27, 29].

Most international mining companies have aligned with these international best practices as a global reference point to manage implementation of mining-induced resettlement [10, 23]. However, in many mineral-resource-exploiting African countries such as Ghana [2], Sierra Leone [21] and Zimbabwe [11] as well as those in non-African countries, including Afghanistan [10], China [9], Indonesia [12] and Pakistan [1], mining companies have been criticised for not adhering to these best practices.

Adverse post-resettlement impacts are thus relatively common. For example, the involuntary resettlement in Sierra Leone induced by rutile mining led to the social and economic impoverishment of resettled communities who had lost their land-based resources and experienced joblessness, marginalisation and other adverse impacts on their livelihoods [21]. Similarly, a study in Ethiopia found that resettlement had negatively affected resettled households' livelihoods, and had led to the loss of natural resources and social disintegration [25]. Zimbabwe is another case in point. There, mining companies not only compensated resettled people insufficiently, unjustly and unfairly, but also did so too late – all of which led to a loss of livelihoods, jobs, houses and land for the community concerned [11].

In Mozambique's case, the latest substantial wave of communities affected by coal mining and being displaced and resettled involuntarily by mining companies was around 2010. At the time, the multinationals Vale SA and Rio Tinto displaced and relocated 1,190 households about 60 km further away from their home village in the concession area, i.e. in the Moatize District, Tete Province, in west-central Mozambique [5, 19, 30, 31].

2.1. *The adverse effects of coal-mining-induced resettlement on resettled communities*

At the time of the resettlement processes, Mozambique had no specific national legislation or regulatory framework on resettlement. Hence, resettlement packages were designed and implemented by the multinational mining companies concerned themselves and were, in theory, based on the World Bank's guidelines and Mozambican land law [4, 28, 32]. As a result of complaints about how this was done, in 2012 the Government issued Decree No. 31/2012 of 8 August 2012 to regulate resettlement induced by economic activities. Two years later, it revised its mining legislation (Act No. 20/2014 of 18 August 2014). The new law included resettlement-related provisions mandating not only fair compensation, but also negotiation between mining entities and the resettled individuals to ensure the latter enjoyed at least an equal quality of life in their new environments as well as social equity [4, 28, 33].

However, unlike what is envisaged in the World Bank's international standard for involuntary resettlement [26, 27, 29], coal-mining-induced resettlement in Mozambique is seen as having harmed the resettled community – economically, socially and culturally [3–6]. A few years after such resettlements in Cateme and Mualadzi, researchers found that the relocated individuals had experienced a reduced amount and quality of farmland, reduced water access, lower-quality dwellings and disrupted sources of income, compared with their pre-resettlement situation [5–7]. For example, contrary to the planned provision of 2 ha of farmland for each resettled household, only 1 ha was actually provided [5] in each respective resettlement location. Given that farmland was the resettled households' main source of food and income, the resulting shortage of land worsened their living conditions.

Besides plot size, the farmland in the resettlement villages was of inferior quality: it was arid, infertile and difficult to cultivate. This caused some members of the resettled community to leave the area in search of better land in other parts of the Tete Province [4–7, 19, 28, 34–36].

A lack of water has also been cited as a problem in the resettlement areas. Before their relocation, the affected communities had relied on water from a nearby river. The river near the resettlement villages, on the other hand, was seasonal. Moreover, the electric pumps used to supply water constantly broke down, disrupting the water supply because they could not afford the high maintenance costs, and leading to water shortages for the resettled households and their livestock [4, 7, 20, 30, 35–38]. The seasonality of the river also meant fishing and growing vegetables had been lost as income-generating activities [30, 36].

Regarding the dwelling conditions in the resettlement, several studies have reported that the houses given to resettled individuals lacked solid foundations or had foundations that had cracked. In several cases, the roofs leaked. The poor quality of these new houses was worsened by the lack of green spaces or trees nearby [19, 28, 30, 34, 38].

Additional resettlement problems included the loss of other sources of income. As a case in point, one of the resettled households' key income-generating activities before resettlement was to make red-clay artisanal bricks using suitable humid soil from the nearby river. Such bricks were the main material for constructing houses. In the resettlement area, however, the only available soil was too dry to make bricks [5, 34]. Other sources of income before resettlement included petty trade in charcoal, firewood, sand, vegetables and stones in the local market and on the main road. The challenge after resettlement was that the villages were now all far away from the main road and Moatize's town market [4, 5, 7, 30, 34, 36, 38].

Shortly after these studies, the Government drafted a law on social corporate responsibility for the mining industry (Resolution 21/2014 of 16 May 2014). This resolution determines measures to be implemented by the mining entities concerned to improve the welfare of the people affected by a mine throughout its lifespan [32].

Subsequently, in accordance with the new law, mining companies implemented several interventions to correct the negative impacts of resettlement that had been highlighted. These included providing additional monetary payments for uncompensated loss of farmland during the resettlement, constructing a water tower connected to a network of common water taps, renovating most houses, training the resettled community in poultry farming and crop management for income generation, and providing fruit trees to diversify the community's diet [32, 39].

While one can suspect that some of the short-term negative impacts of resettlement found by previous studies may be driven by high expectations that the resettled people may have had regarding compensation, when their expectations were not met, frustration soon followed. There may also have been expectations of additional, ongoing compensation from mining companies throughout the life-of-mine. These hopes were dashed when, for example, Rio Tinto sold the mines located where these resettled people were settled to International Coal Ventures Limited in 2014, while Vale sold its operations to Vulcan in 2022 [3, 28, 34, 35, 38, 40]. Thus, since the companies originally involved in the resettlement no longer operate in Mozambique, one can assume communities' expectations about ongoing compensation also no longer exist.

Nonetheless, as useful as the findings of these previous studies are, they reflect only the short-run impacts of resettlement since most were conducted within a few years after the affected parties had been resettled. By now, 15 years after that process, the affected households might have adapted to the new conditions – irrespective of how individuals were compensated for what they had lost in being relocated, or for the limitations of their new environments. The current situation should, therefore, be examined to see whether the resettled households are still worse off than they were before being relocated and after adapting to the resettlement area.

3. Research strategy

3.1. Study site and survey design

This paper surveyed two resettlement villages, Cateme and Mualadzi, which lie near each other in the Moatize District, Tete Province, in west-central Mozambique (see Figure 1). A total of 1,190 households had been involuntarily resettled there by coal mining companies. Of these, 712 now lived in Cateme and 478 in Mualadzi.

Based on statistical power considerations, 308 households were randomly sampled for the current study, which is about 26% of the total population in the two villages. The main sample selection criterion in this study was resettlement, so only resettled households still living in the resettlement area were included in the sample.

A questionnaire was designed to elicit the willingness to contribute labour to restore the landscape from which the respondents had been relocated. To this end, the questionnaire contained five sections. The first presented the scope of the study and asked the respondents' consent. It also collected the demographic characteristics of the respondents, including their gender, level of education, age, and household size. The second section contained the contingent valuation questions, discussed in more detail below (see Section 3.2).

The third section of the questionnaire asked about farm and non-farm income. Section four asked about socioeconomic characteristics, including current and pre-resettlement farmland size, farmland quality, water access, dwelling conditions and income sources. The last section of the questionnaire collected information on the level of confidence in, and perceived responsibility of, third parties about the mitigation of resettlement-driven impacts.

The surveys were carried out during February and March 2024. The process began with an enumerator training programme in line with the guidelines in [41], in which 13 undergraduate students were instructed in conducting the interviews. Enumerators were trained to ensure not only that they understood the questionnaire, but also that they could answer any questions that respondents might raise. Moreover, the training ensured that the enumerators would give similar responses to such questions, based only on the information in the questionnaire. To test and potentially improve the questionnaire, a pilot series of interviews were conducted before the main survey. The pilot results were used to amend the questionnaire where necessary.

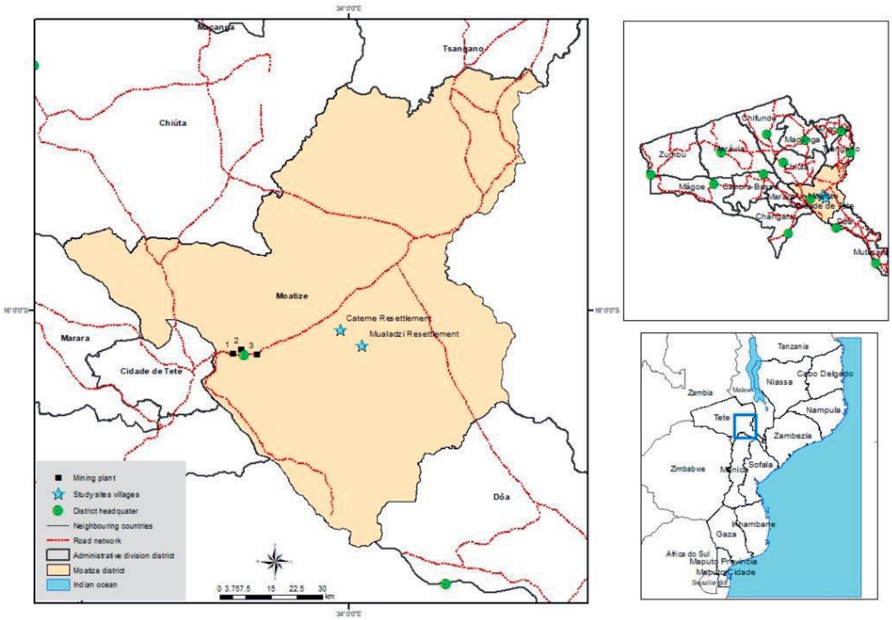

Figure 1. Location of study site villages

3.1.1. Description of the CV scenario

In Moatize – the District where Mozambican coal mining is located – the landscape is covered by coal dust. A CV scenario was therefore designed for Moatize where the mine would close and households would be required to provide unpaid labour to a 10-year landscape restoration programme. This scenario was designed to assess respondents' preferences for landscape restoration that would give them the possibility to go back to live in the restored area.

Since households had been compensated for their loss of the landscape on their sites of origin, the recommended valuation measure would seem to be the level of compensation that would have made them as well off as they had been before resettlement. In other words, this valuation measure would be the minimum level of compensation that would have made them willing to accept the resettlement [42-46]. However, one of the drawbacks of trying to estimate willingness to accept (WTA) in empirical work is that this variable is unbounded, and respondents have few incentives to answer with their true minimum acceptable value, especially when they face an open-ended question [46]. This lack of an upper bound permits respondents to ask for extremely large amounts of compensation as a form of protest answer. Moreover, respondents often struggle to understand and answer questions about WTA compensation, which also tends to lead to extreme values [47]. Moreover, the possible overevaluation of the landscape damage would risk calling into question the validity of the research findings. Another disadvantage of employing WTA is that an offer of compensation to respondents can be perceived as bribery [44].

Hence, the CV scenario was framed to value the WTP for a landscape restoration programme. The sample included only the resettled households who lived in the landscape destroyed by mining. This sample selection criterion avoided the need for designing a long CV scenario to describe the state of the landscape concerned before mining.

3.2. *Method*

In this study the CV – an environmental valuation approach where a hypothetical scenario is presented to respondents who are asked to state their WTP for that scenario – was adopted. In CV studies, single- and double-bounded dichotomous formats have both been used to elicit the WTP. A *single-bounded* format is a single take-it-or-leave-it scenario where only one bid is presented to the respondent; in a *double-bounded* format, a second bid is presented as a follow-up. The double-bounded format is generally preferred to its single-bounded counterpart because the second bid can help correct for initial bids that are too low or too high. The double-bounded format also helps to improve the efficiency of the model-estimated coefficients and to tighten the confidence intervals of the mean WTP [14, 17, 24, 48–52].

The CV's theoretical model is founded in Lancaster's [53] approach to consumer theory, while its empirical model is grounded in Manski's [54] random utility modelling [42, 55]. In this method, respondents given a hypothetical programme and bids can decide whether to accept. Respondents are expected to form their decision by comparing their reference status with the potential utility level to be attained with the hypothetical programme's implementation, given the proposed bid. Hence, by a rationality assumption, respondents will accept a bid if they feel that the potential utility will not be less than that attained in the reference status. Thus, under random utility modelling, the WTP of respondent i (i = 1, …, N), can be written as –

$$WTP_{it} = \beta_0 + X_i'\alpha_i + B_t\beta_t + \mu_{it} \quad (1)$$

where t (t = 1, 2) is bid timing in the survey, β_0 is the constant term, X represents a vector of explanatory variables, α is a vector of parameters of X, B is the set of bid values, β is the coefficient of the bid value variable, and μ is non-observable random component [13–17, 48, 50, 51].

For reasons discussed in Section 3.3, a labour – rather than a monetary – payment vehicle was used. Respondents were therefore asked how much of their household's time they would be willing to provide in the form of labour. Thus, the second section of the questionnaire, the core part of the study, started with a sample selection question where respondents were asked whether they would agree to contribute household time to a community-managed programme of landscape restoration if the mines closed. The given bids ranged from 2 to 12.5 working days per month. In CV surveys, a common problem is that respondents might answer "yes" just to ensure implementation of the proposed programme (compliance bias) or simply to please the enumerator (enumerator bias) [56, 57]. To reduce the risk of such biased answers, six different reasons for answering "no" were included in the questionnaire to emphasise that this was also an acceptable response.

Those who said "yes" to the selection question were then chosen to complete the double-bounded dichotomous choice part of the questionnaire. The individual respondents were first asked if they would be willing to contribute an initial time-slot bid (IB) each month. Those who responded "yes" were subsequently asked if they would also be willing to contribute a higher time-slot bid (HB) for the same purpose. Conversely, those who responded "no" were subsequently asked if they would be willing to contribute a lower time-slot bid (LB). Hence, each respondent provided two responses to the WTP question [13–17, 48, 50, 51].

The method assumes that respondents are maximising utility. In other words, they would answer "yes" to a given bid if and only if the expected utility level of restoring the landscape destroyed by mining, and contributing the given bid for this, was higher than or equal to (a) the utility of continued displacement and (b) having the time in that bid available to do something else rather than contributing. Thus, a given bid would be accepted if it was lower than or equal to their maximum WTP (max WTP) [48]. Therefore, asking respondent i to answer on two bids, where each had two possible answers, yielded four possible outcomes. These were (i) "yes" to both bids (yy) if $HB_i \leq$ max WTP_i; (ii) "yes" followed by "no" (yn) if $IB_i \leq$ max $WTP_i < HB_i$; (iii) "no" followed by "yes" (ny) if $LB_i \leq$ max $WTP_i < IB_i$; and (iv) "no" to both bids (nn) if max $WTP_i < LB_i$. The probabilities of these outcomes are expressed as Pr_i^{yy}, Pr_i^{yn}, Pr_i^{ny}, and Pr_i^{nn}, respectively.as

Consider $G(B, \theta)$, a statistical cumulative density function of the respondent's true max WTP, which depends on a parameter θ and on the set of the given bids (B). Since the max WTP is a random variable; IB, LB and HB are constants; and the sum of all probabilities for the random variable must equal 1, the following are yielded if one replaces the outcomes (i), (ii), (iii) and (iv), respectively, to the discrete probabilities' rules:

$$Pr_i^{yy} = Pr(\mathrm{HB}_i \leq \max \mathrm{WTP}_i) = 1 - G(\mathrm{HB}_i, \theta) \quad (2)$$

$$Pr_i^{yn} = Pr(\mathrm{IB}_i \leq \max \mathrm{WTP}_i < \mathrm{HB}_i) = G(\mathrm{HB}_i, \theta) - G(\mathrm{IB}_i, \theta) \quad (3)$$

$$Pr_i^{ny} = Pr(\mathrm{LB}_i \leq \max \mathrm{WTP}_i < \mathrm{IB}_i) = G(\mathrm{IB}_i, \theta) - G(\mathrm{LB}_i, \theta) \quad (4)$$

$$Pr_i^{nn} = Pr(\max \mathrm{WTP}_i < \mathrm{LB}_i) = G(\mathrm{LB}_i, \theta) \quad (5)$$

Thus, the log-likelihood function for this set of probabilities for N respondents is –

$$lnL(\theta) = \sum_{i=1}^{i=N} \left[d^{yy} lnPr_i^{yy} + d^{yn} lnPr_i^{yn} + d^{ny} lnPr_i^{ny} + d^{nn} lnPr_i^{nn} \right], \quad (6)$$

where d^{**} is a binary value taking the value of 1 if ** occurs and 0 otherwise [13–16, 48, 50, 58, 59]. Then the maximum likelihood estimator, $\hat{\theta}$, is the one that maximises equation (6). Assuming a logistic cumulative density function, the probability that respondent *i* will answer "yes" can be derived from the demand function in equation (1). Then, integrating this probability, taking the maximum bid as the upper limit, yields the mean WTP as –

$$WTP_{mean} = \int_0^{B_{max}} \frac{1}{1+EXP(-\beta_0 - \alpha\bar{X} - \beta B)}\, db \quad (7)$$

where B_{max} is the maximum bid, and $\bar{X}$ is the mean value of X [16, 50, 59].

Moreover, the mean WTP value can be converted into monetary value using a corresponding reasonable economic value of work time, as follows:

$$monetary\ WTP_{mean} = \sum_{i=1}^{N} \left(WTP_{mean_i} * Value\ of\ time_i \right) / N \quad (8)$$

where the value of time is the opportunity cost of the work time [60]. Table 1 presents the alternative bids used in the final survey.

Table 1. Alternative bids and number of respondents assigned different initial bids

Initial bids (IB)	**Assigned IB (N = 308)**	**Percentage**	**Lower bids**	**Higher bids**
2	62	20.13%	1.5	5.0
5	63	20.45%	2.0	7.5
7.5	62	20.13%	5.0	10.0
10	61	19.81%	7.5	12.5
12.5	60	19.48%	10.0	14.0

Note: Bids were presented as labour contribution in number of days per month.

3.3. *Labour as payment mode*

To encourage truthful responses in CV studies, a payment vehicle should be perceived as familiar, realistic and credible. Moreover, it should be perceived as binding for the entire target population to ensure incentive compatibility and prevent free-riding [42].

In stated preference studies in rural areas in developing countries, money has been considered an inappropriate payment vehicle because many there are not engaged in wage labour and have only limited interaction with the monetary economy. Their production is predominantly subsistence agriculture, and it is common for goods and services to be paid for by bartering other goods or by providing labour in return [57, 61–67].

Thus, using a monetary payment vehicle in stated preference studies in rural areas in developing countries risks underestimating the value of the improvement being studied. Respondents may value the good or service under study positively, yet may have little money to contribute, thereby leading to a low estimated WTP. However, given that economic transactions may occur in rural communities without the use of money, proposing that respondents commit their own time to a restoration programme would make it accessible to them. Hence, a labour payment vehicle might offer a better estimate of what economic value a landscape restoration programme would hold for the rural respondents concerned [60, 63, 64, 66, 67].

During the pilot survey both payment modes were tested, i.e. respondents could choose between monetary and labour contributions. Since most respondents chose labour contributions, only these contributions were used in the main survey.

4. Results

4.1. *Descriptive statistics*

Table 2 reports descriptive statistics of the variables. The statistics show that the majority of respondents were female (56.49%). This is line with the national and local demographic statistics at the District level. Also, about 16% of the respondents were illiterate, and none of the respondents had a high level of education.

There was a considerable share of respondents of working age, as 83% of respondents were under 50 years old. This density of young people in the sample was consistent with the population structure at the national level at the time of the study. The monthly monetary income in the study site was low overall, since 81% of respondents earned incomes lower than US$200 per month. This is normal for a poor rural region and lends further support to the decision to use labour rather than money as the payment vehicle. Most surveyed households (82%) had more than five members.

To ask the respondents to compare their current and pre-settlement situations, a five-point grading scale was used in the questionnaire to categorise their answers, ranging from "much worse" to "much better" (see Figure 2).

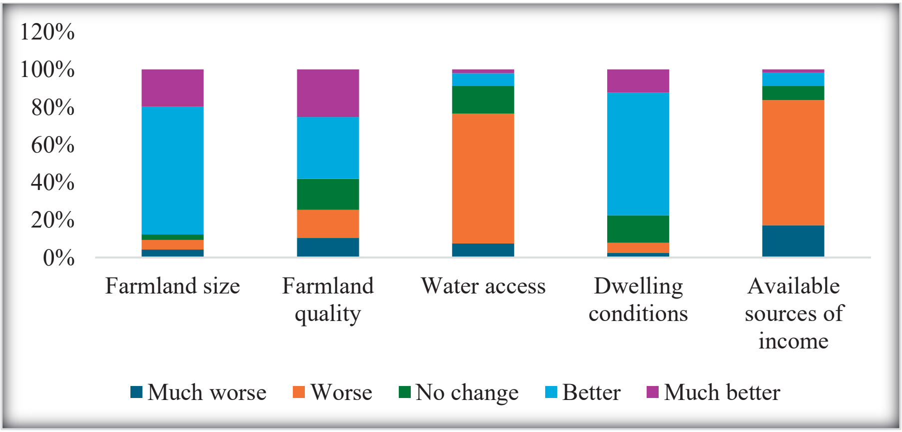

Figure 2. Current vs pre-resettlement satisfaction

The variables presented in Figure 2 serve as dummy variables, where "better" and "much better" were defined as 1, and "much worse", "worse" and "no change" as 0 (see Table 2). Of all respondents, 88% stated that they currently owned bigger areas of farmland compared with their pre-resettlement situation. Furthermore, 58% ranked the quality of their farmland as better than before resettlement. On the other hand, 77% of respondents stated that their current access to water was worse than before resettlement.

A total of 78% of respondents stated that their dwellings were currently better than before resettlement. On the other hand, about 84% of respondents felt their available sources of income had declined in comparison with their pre-settlement position.

Table 2. Definition and descriptive statistics of the variables

Name of variable	Definition	Min.	%	Mean	Std dev.	Max.	%
Gender	Respondent's gender (1 = Female, 0 = Male)	0	43.51	0.56	0.50	1	56.49
Education	Respondent's years of schooling	0	15.58	7.69	1.79	12	27.03
Age	Respondent's age (years)	19	0.70	38.00	12.84	85	0.32
Income	Monthly household income (US Dollars)	3	0.30	128.00	92.76	534	0.32
Household size	Sum of household's members	3	20.00	5.50	2.11	16	0.32
Increased farmland size	1 = Bigger farmland size now compared to that in area of origin, 0 = Otherwise	0	12.01	0.88	0.33	1	87.99

Name of variable	Definition	Min.	%	Mean	Std dev.	Max.	%
Improved farmland quality	1 = Better farmland quality now compared to that in area of origin, 0 = Otherwise	0	41.88	0.58	0.49	1	58.12
Improved water access	1 = Better water access now compared to that in area of origin, 0 = Otherwise	0	89.94	0.11	0.42	1	10.06
Improved dwelling	1 = Better dwelling conditions now compared to that in area of origin, 0 = Otherwise	0	12.34	0.90	0.30	1	87.66
Improved availability of sources of income	1 = More sources of income available now compared to that in area of origin, 0 = Otherwise	0	88.64	0.09	0.28	1	11.36

To ensure consistency, improve accuracy and avoid biases of misperception in the five main variables in this study, the survey included questions that were used to cross-check each of these variables. As a first step, besides asking respondents to compare the sizes of their current and pre-settlement farmlands, respondents were also asked how many plots of farmland they had had before resettlement compared with their current situation, and what the plots' respective sizes were, in hectares.

In a second step, respondents' assessment of the comparative quality of their farmlands before resettlement and at the time of the survey was examined. In addition to the direct question asked in this regard, they were also asked how much (in kilograms) they had harvested of their main crop per hectare during each harvest.

Thirdly, in addition to being asked to compare the relative difficulties they had experienced in accessing water via various means, respondents were asked how long (in minutes) it took them to walk from home to the nearest water source, how many times a day they made such trips, and how much water they fetched on each trip. Table 3 details the respondents' perceived changes in regard to farmland and access to water.

Table 3. Perceived changes in regard to farmland and access to water

	Before resettlement		**Current situation**	
Variables	**N = 308**	**Proportion**	**N = 308**	**Proportion**
Number of farmland plots				
Up to 2	142	46%	24	8%
3–5	117	38%	98	32%
6 or above	49	16%	186	60%
Farmland size (hectares)				
Up to 2	71	23%	9	3%
3–5	172	56%	96	31%
6 or above	65	21%	203	66%
Number of 50-kg bags of the main crop per hectare in each harvest				
Up to 5	111	36%	52	17%
6–10	108	35%	65	21%
11 or above	89	29%	191	62%

Variables	Before resettlement		Current situation	
	N = 308	Proportion	N = 308	Proportion
Main water source				
Piped water	6	2%	0	0%
Community tap	41	13%	274	89%
Pumpless well	86	28%	34	11%
River	175	57%	0	0%
Walking time to the main water source (minutes)				
Up to 10	182	59%	59	19%
11–20	95	31%	108	35%
21–30	28	9%	132	43%
31 or above	3	1%	9	3%
Daily round trips to the main water source				
Up to 2	201	65%	19	6%
3–5	64	21%	182	59%
6 or above	43	14%	107	35%
Average number of 20-litre containers fetched in each round trip				
Up to 2	108	35%	39	13%
3–5	96	31%	143	46%
6 or above	104	34%	126	41%

In a fourth step, besides being asked to compare the comfort and quality of their housing conditions before and after relocation, the respondents were asked specifics about whether they had faced lower standards in respect of their dwellings' roofs, walls and flooring as a result of resettlement. There was no need for the respondents to elaborate on the condition of their current dwellings because not only were the houses homogeneous, but the interviews were also conducted in them. Thus, the enumerators could easily verify the conditions of these dwellings.

Finally, as a fifth step, respondents were asked to compare the availability of sources of income for them currently and before they were resettled. The same question was posed about their sources of non-farm income for the two points of comparison. Table 4 depicts the perceived changes in both dwelling conditions and availability of sources of non-farm income.

Table 4. Changes in quality of dwellings and perceived change in availability of sources of income

Variables	Before resettlement		Current situation	
	N = 308	Proportion	N = 308	Proportion
Material used as roofing for the main house				
Concrete slab	2	1%	0	0%
Tile	34	11%	0	0%
Fiber cement sheet	6	2%	0	0%
Zinc	58	19%	308	100%

Variables	Before resettlement		Current situation	
	N = 308	Proportion	N = 308	Proportion
Grass	208	68%	0	0%
Material used for the walls of the main house				
Wood and zinc	77	25%	0	0%
Adobe	71	23%	0	0%
Sticks and stones	65	21%	0	0%
Cement block	12	4%	308	100%
Burnt brick	22	7%	0	0%
Unburnt brick	55	18%	0	0%
Cans	6	2%	0	0%
Material used as flooring for the main house				
Cement	44	14%	308	100%
Tile	6	2%	0	0%
Adobe	258	84%	0	0%
Main source of non-farm income				
House rental	3	1%	0	0%
Farmland rental	28	9%	22	7%
Sale of agricultural products	55	18%	34	11%
Sale of livestock products	31	10%	49	16%
Sale of fish	40	13%	0	0%

Variables	Before resettlement		Current situation	
	N = 308	Proportion	N = 308	Proportion
Sale of clothing	6	2%	6	2%
Sale of firewood and charcoal	62	20%	71	23%
Sale of handicraft products	3	1%	0	0%
Sale of construction materials	37	12%	0	0%
Sale of honey and hunting products	43	14%	59	19%
None	0	0%	67	22%

In the last part of the questionnaire, respondents were asked whether they thought the hypothetical programme of landscape restoration was feasible. Most respondents (99%) believed implementing the proposed restoration programme in Moatize was feasible.

4.2. *Model estimation results*

Of the two estimated logistic models (see Table 5), the full model containing explanatory variables (Model 2) had a lower Akaike information criterion value than the bids-only model (Model 1), meaning that the added explanatory variables significantly improved the fit of the willingness-to-contribute-labour (i.e. WTP) model.

Table 5. Logit model estimation results of the willingness to contribute labour

Variables	**Model 1**		**Model 2**	
	Coefficient	**Standard error**	**Coefficient**	**Standard error**
Bid	-0.207***	0.012	-0.127***	0.025
Intercept			2.944	1.963
Gender (Male = 0, Female = 1)			0.143***	0.044
Education			0.812	1.309
Age			0.597***	0.220
Income			-0.023**	0.010
Household size			0.526***	0.179
Increased farmland size			-0.946	1.075
Improved farmland quality			-0.532	0.385
Improved water access			-0.296***	0.100
Improved dwelling			-0.357	0.991
Improved availability of sources of income			0.480***	0.126
Number of observations	308		308	
Log-likelihood	-509.981		-477.628	
Akaike information criterion	1023.962		1006.241	

Note: ***, ** and * imply statistical significance at the level of 1%, 5% and 10%, respectively.

In respect of the factors explaining the respondents' WTP, the estimated coefficient of the bid was negative and statistically significant (see Model 1, Table 5). This indicates that the size of the IB affected the respondents' willingness to contribute labour. Furthermore, the coefficient's negative sign means that, as the IB amount rose, the less likely respondents were to agree about their willingness to contribute labour. Hence, respondents were sensitive to the opportunity cost of their households' work time.

As regards Model 2, the regression coefficient of *Gender* suggests that, compared with the males, the female respondents seem to have a higher WTP. The regression coefficient of the variable *Education* was statistically insignificant, however, indicating that differences in levels of education among respondents did not affect WTP significantly. Conversely, the estimated coefficient of the *Age* variable shows that older respondents were more willing to contribute their households' work time to support the landscape restoration than their younger counterparts were.

The estimated regression coefficient of *Income* indicates that respondents with high income were less likely to contribute to landscape restoration compared with those with lower incomes. In addition, the estimated coefficient on household size means that larger households were more likely to be willing to contribute household labour to the proposed restoration project than smaller households were.

The estimated coefficients of *Increased farmland size*, *Improved farmland quality* and *Improved dwelling* dummies indicate that none of these affected WTP. On the other hand, the model estimation results show that the *Improved water access* and *Improved availability of sources of income* dummies indeed affected WTP.

The mean WTP (see Table 6) decreased slightly with the inclusion of explanatory variables in comparison with its counterpart in the bid-only logistic model estimation.

Table 6. Mean willingness to pay (WTP) in days per month

Models	Mean WTP (days per month)	Standard error
Excluding explanatory variables	9.507***	0.321
Including explanatory variables	9.455***	0.736

The mean WTP presented in Table 6 is more than nine days per month. If one considers that the average household size is 5.5 members, that the use of child labour is common, and that there are five working days per week, nine days a month corresponds to 9% of the average household's labour endowment. This includes child labour.

4.3. *Monetising the willingness to contribute time*

There is no consensus in the literature on which value to use as a monetary value equivalent to time contributed as labour. Various researchers have used the sectoral wage rate [60, 61, 63, 64, 66, 68, 69], the stated household income in the survey [60, 62], and/or the country's minimum wage [65]. In the current study, therefore, three candidate values of time were tried as tools for converting WTP into monetary value. These were the stated opportunity cost of labour, the minimum wage for the agriculture sector, and the stated households' income.

In order to estimate the opportunity cost of household labour, respondents were asked how much they would charge if they had to do their daily activities for another person or how much they would be willing to pay for the same activities if they had to hire labour to perform them. Responses were largely similar across households and led to an estimated opportunity cost of time of approximately US$4 per day, yielding a monetised monthly mean WTP of US$37.52 per household. Using the government-mandated minimum wage for agricultural labour instead gives a mean WTP of US$31.83 per household. If households' monthly income (including the value of production for own consumption) is used, monthly mean WTP is US$40.36 per household. Thus, the three methods give roughly comparable results. These three estimates correspond to US$44,649, US$37,878, and US$48,028 per month for the entire population of 1,190 resettled households.

4.4. *Analysis of those not being willing to contribute labour*

Of the total sample, 22 (7%) respondents stated that they were not willing to contribute their time to work on the hypothetical landscape restoration programme. Figure 3 displays the main reasons they gave for their unwillingness. Thus, about 9% of respondents chose this position because they believed that the lifestyle in resettled places was good enough. Some 18% of respondents were worried that the household's time was too limited to afford an additional activity. Around 36% believed that, the government or the mining companies (23%) were responsible for – and should therefore pay to resolve – the problems respondents faced in resettlement villages. Approximately 9% of respondents felt they had paid enough taxes, and therefore did not want to pay more. Finally, one respondent stated that he had recently found employment in another province, was about to move, and was not planning to return.

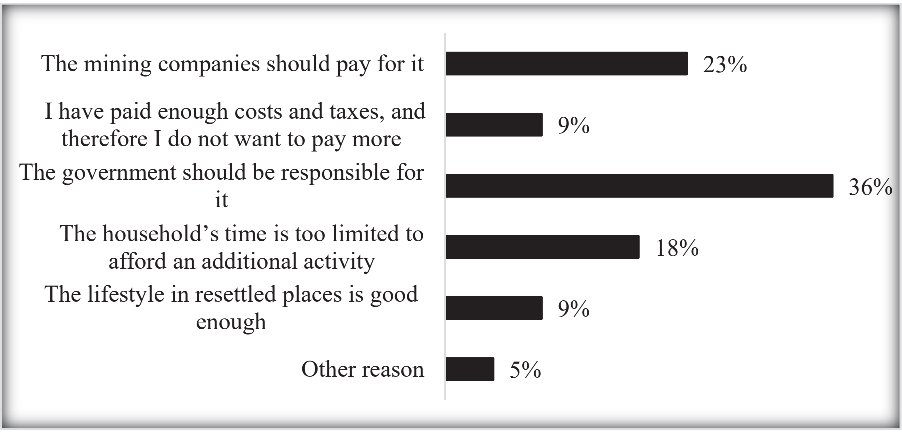

Figure 3. Reasons for not accepting to contribute to the restoration programme (n = 22)

Overall, the share of the responses presented in Figure 3 indicate that most respondents who had been unwilling to contribute labour to the restoration programme would nevertheless like the programme to take place. Of all respondents, 9% were happy with their current lifestyle, while 5% were unwilling to contribute their labour for some other reason. These last two respondent groups correspond to about 1% of the entire sample of this study. Thus, 99% of the sample would prefer the programme to take place.

5. Discussion and conclusion

This study looked at the WTP for landscape restoration among people who had been resettled as part of a mining project in Moatize, Mozambique. Some 15 years after their resettlement, many of those affected had better houses as well as larger and more productive farms than before. Notably, despite this, many of them expressed a clear preference and a considerable WTP for restoring the landscape of the area they had been forced to leave, rather than continuing to live where they currently were.

Older respondents displayed a higher WTP compared with younger respondents. This may be because older people have better memories than younger members of the resettled community of the lifestyle they had had before resettlement. Conversely, higher-income households showed a lower WTP compared with their lower-income counterparts. This outcome may reflect the higher opportunity cost of time for those earning higher incomes. Another possible explanation could be because the largest share of the earnings in question was farm income, and households who earned more were those that had better farmland in the resettlement area and, hence, were more sensitive to leaving their current village. However, larger households had a higher WTP in comparison with smaller ones, presumably because the opportunity cost of their time was lower.

The model estimation results in this study show that the improvements in farmland size and quality did not affect WTP for the restoration package. Findings in previous studies, carried out shortly after resettlement, showed that the resettled had farms of smaller sizes and poorer quality than before [4,8]. Conversely, most respondents in the current study revealed that they had more, and more productive, farmland than before their resettlement. Thus, the findings from the previous studies seem to have been based on resettlement packages compensating insufficiently for lost farmland with new land.

Most of the current study's respondents stated that the resettlement package had planned to provide two farm plots for each household; in the end, however, only one such plot materialised per household. Nonetheless, a cash compensation of US$1,889 (119,000 Meticais) was given in lieu of the missing plot. Part of this cash was used to buy additional farm plots in the resettlement villages. This is probably why the average farmland size per resettled household is larger than in their areas of origin. Moreover, the additional plots purchased were more productive than those awarded to resettled individuals as compensation for land lost. Furthermore, those who left the resettlement area at some point after their relocation [6] may have sold their land, making more land available – and at a lower cost – for those who remained.

The survey data also show that most respondents (57%) had local river as their main source of water before resettlement (see Table 3). Being resettled in a place without access to a river therefore seems to be the greatest loss the respondents experienced: the river had previously provided unlimited access to water that, in addition to personal use, was employed for irrigation and for watering livestock.

Nonetheless, the distance from the home to the main water source, the number of round trips to the water source, and the amount of water brought in on each round trip do not appear to have changed substantially for the two periods compared in this study. This can be explained by the fact that before the resettlement the distance from home to the river was fixed, while after the resettlement it was no longer fixed because whenever there is a breakdown of the nearest tap, they have to get the water from another one. Moreover, some water-consumption activities such as washing clothes, bathing, and watering livestock used to be done directly in the river; they are now done at home, using water brought from a public tap. For this reason, the results of the model estimation show that access to water is a key determinant of WTP and that those with better access to water have significantly lower WTP.

Moreover, some previous studies found that dwelling conditions had worsened in the resettlement compared to the area of origin due to the poor quality of the resettlement houses, and that some already had cracks in the walls shortly after their delivery to the beneficiaries [19, 28, 30, 34]. Conversely, the data from this study show that, on average, households declared that they enjoyed better housing conditions than before. For example, many households in the areas of origin had houses with grass roofs and walls made of sticks and adobe. In the resettled areas, all the houses had walls made of cement or brick blocks and had zinc sheets as roofing. These materials were relatively better than those used in the areas of origin, regardless of the quality of the houses pre- or post-resettlement.

Another revelation by the survey data was that, prior to resettlement, many sources of income were linked to the river, market and road. Resettling people away from these three points of customer access disrupted their available sources of income. As the model estimation results show, the current availability of these sources of income was an important determinant of WTP.

It is also worth noting that the way resettled individuals have adapted to their new villages over time may plausibly explain the discrepancy between some of the findings by previous studies and this one. As a case in point, the resettled households adapted to their situation over time by purchasing additional and more productive land from the host community. This initiative gradually resolved their shortage of farmland. Somewhat surprisingly, however, even those who had adapted successfully remained willing to contribute considerable amounts of their working time to restore the landscape of their areas of origin instead.

Overall, this study found that, among the potential determinants of WTP for landscape restoration that were studied, namely changes in farmland size, farmland quality, dwelling quality, access to water and availability of sources of income, only the last two variables were strong determinants of WTP.

Thus, as regards the policy implications of these results, interventions that aim to improve the welfare of resettled households should target their access to water and sources of income. This recommendation is based on the finding that, even 15 years after their resettlement, the households concerned preferred to return to their villages of origin – most probably because they had been resettled far from a river, the main road and the city, which meant they had lost previously unlimited access to water and available sources of income.

Future mining-induced resettlement initiatives are therefore advised to be very careful in selecting resettlement sites, particularly when it comes to the loss of access to water and sources of income: these are difficult to recover – even in the long term.

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Appendix I: Questionnaire collecting data for paper III, in English

Coal mining impacts in rural Mozambique

Note 1: Reminder to the interviewer
We are interested in interviewing the head of the household or their spouse. If one of the household members is more highly educated than the head of the household, they can respond jointly. Respondents other than these will not be accepted for the survey.
Note 2: To be read by the interviewer to the respondents
Good ... ! Thank you for receiving us. My name is ... . I am here with ... . With this questionnaire I intend to collect information from you which will help us to find out if there is any effect induced by coal mining. We are here on behalf of the Eduardo Mondlane University in collaboration with the Luleå University of Technology in Sweden. We do not represent a mining company, the government, or any political party. We are interested in your sincere views, opinions and experience in answering the questions we are going to ask. Your answers will be used for academic purposes only. However, the results may be used by policymakers to design strategic policies to reduce any possible negative impacts of coal mining, if we find there are some. You have been randomly selected to participate in the study. We also assure that your responses are anonymous and will be treated with strict confidentiality. Your responses will be added to those of other respondents and included in the general findings of our study, so there will be no way of identifying you according to your responses after the analysis is done. Only if you don't mind, please share your telephone number with us so that we can contact you if there is some information in the questionnaire that is unclear. Would you like to participate in the interview? ___. If any question we ask you seems unclear, please let us know before you answer it. We will be happy to clarify it for you. The questionnaire is estimated to take about two hours. We are therefore offering you a small monetary gift to thank you for your time.

Start of interview: Date (mm/dd/yy): _______________ Time: __________

Name of interviewer: ____

District	
Ward	
Enumerator area	
Household identity code	
Name of household head/contact (optional) 1 = Male, 2 = Female	

Section 1: Background data

Questions		Response codes	Response
1.1	Relationship of the respondent to the head of the household	1 = Head of household 2 = Spouse (Male) 3 = Spouse (Female)	
1.2	Gender of the respondent	1 = Female, 2 = Male	
1.3	Marital status	1 = Single, 2 = Married/with partner	
1.4	Have you ever been to school?	1 = Yes, 2 = No	
1.4.1	(If the answer to 1.4 is 1) State your level of schooling.	1 = Preschool; 2 = Literacy; 3 = Grade 1 Primary; 4 = Grade 2 Primary; 5 = Basic Secondary; 6 = Middle Secondary; 7 = Senior Secondary	
1.5	Have you been resettled?	1 = Yes, 2 = No	
1.6	Have you ever received any monetary or non-monetary compensation from a coal mining company?	1 = Yes, 2 = No	
1.7	How do you rank the compensations received from coal mining?	1 = Very little, 2 = Little, 3 = Neutral, 4 = Adequate, 5 = Very adequate; 6 = I don't know	
1.8	How many times have you or someone in the household ever faced any respiratory disease this year?	1 = None, 2 = Once, 3 = Twice, 4 = More than twice	
1.9	The house where you live today is …	1 = Owned, 2 = Rented, 3 = Supplied free by employer, 4 = Supplied free or rent paid by relative or another person, 5 = Other (please specify)	

Questions		Response codes	Response
1.10	How do you rank your dependence on the forest?	1 = Not dependent, 2 = Somewhat dependent, 3 = Neutral, 4 = Dependent, 5 = Very dependent, 6 = I don't know	
1.11	How do you think that coal mining has impacted the forest?	1 = Very negatively, 2 = Negatively, 3 = Neutral, 4 = Positively, 5 = Very positively	
1.12	How do you rank your dependence on the river?	1 = Not dependent, 2 = Somewhat dependent, 3 = Neutral, 4 = Dependent, 5 = Very dependent; 6 = I don't know	
1.13	How do you perceive the water quality?	1 = Very bad, 2 = Bad, 3 = Neutral, 4 = Good, 5 = Very good, 6 = I don't know	
1.14	Do you think that coal mining has affected the water quality?	1 = Yes, 2 = No	
1.15	How do you perceive the water scarcity?	1 = Very scarce, 2 = Scarce, 3 = Neutral, 4 = Abundant, 5 = Very abundant; 6 = I don't know	
1.16	Do you think that coal mining has affected the availability of water?	1 = Very negatively, 2 = Negatively, 3 = Neutral, 4 = Positively, 5 = Very positively, 6 = I don't know	
1.17	How much is your household impacted by the fencing off of the mining area?	1 = Not impacted, 2 = Somewhat impacted, 3 = Neutral, 4 = Impacted, 5 = Highly impacted, 6 = I don't know	

1.18 Distance from your residence to the nearest coal mine. (Tip. Get the distance from the car) _______km

1.19 How old are you? _______ years

1.20 Do you have children? 1. Yes ☐ 2. No ☐
If yes, how many children do you have? ________

1.21 How many members currently live in your household? __________

1.22 Do you have any arable farmland? 1. Yes ☐ 2. No ☐

1.23 What is the size of your household's arable land in the village? __________ hectares

1.24 How much land did you lose to pave the way for coal exploration? _________hectares.

1.25 Were you compensated for this? 1. Yes ☐ 2. No ☐
1.25.1 How much compensation did you receive? ___________ Mzn

You can provide an interval if you are unwilling to provide the exact amount, i.e.
?between? ______________ ?and? __________________________
Mzn

1.25.2 Were you satisfied with this compensation? 1. Yes ☐ 2. No ☐

1.26 Are you a native in this region? 1. Yes ☐ 2. No ☐

1.26.1 (If the answer to 1.26 is 1)
How many years have you been living in this region?
________years

1.27 Do you have livestock? 1. Yes ☐ 2. No ☐

Section 2: Choice experiment

Note 3: Reminder to the interviewer

In this section we need the respondents to answer questions about their willingness to contribute money ?to a proposed project? as well as to make a choice from a set of options presented to them. Make sure to read out the description of the attributes and their levels first. Then give the respondent the opportunity to ask about anything that is unclear to them before you present the choice sets.

BOX 1

Description of the attributes and attribute levels framed in a mitigation project

Now we are going to describe the impacts of coal mining in Moatize. After that we will present a proposed mitigation project whose implementation costs can be financed by the people who will benefit from it. These beneficiaries can contribute either by way of money or labour.

Water supply

Before the coal mining era, the local population in Moatize relied on the Revúbué River to collect drinking water for themselves and their livestock, to bathe and to wash clothes. The land adjacent to the riverbanks was usually preferred for growing short-cycle crops, while artisans extracted the humid clay to produce bricks. Yet others fished, and everyone used the area to cool off during the heat (Moatize gets very hot). Now, due to coal mining, the surface water and groundwater are contaminated. To mitigate this problem, imagine measures are being taken under a community project where Phase 1 will consist of opening improved wells near people's homes, and setting up filters and hand pumps to extract water. Phase 2 will consist of supplying treated water via communal taps installed very close to people's homes, i.e. within a walking distance of less than five minutes. Phase 3 will consist of pumping safe drinking water to a tap in each household's back yard. All options will supply safe water 24 hours a day, every day.

Forest use

The land conceded to coal mining is a forest where locals used to harvest game meat, honey, medicinal herbs and firewood; where they dried logs to produce charcoal and grazed their stock; and which they used as a shortcut. For safety and other reasons, the forest was fenced off. However, even the forest land outside the fence is now covered in coal dust, nullifying the forest's potential benefits. To mitigate this effect, suppose that a community project is proposed. Phase 1 consists of placing guarded gates at important points that allow one to cross the forest. However, one would not be allowed to harvest anything from the forest while using it as a shortcut. In Phase 2, in addition to Phase 1, reforestation and restoration of species that have disappeared over time will be undertaken, together with the placement of beehives. The landscape would also be cleaned up to enhance it further. This would again allow the collection of firewood and dry logs for charcoal production, building materials, medicinal herbs and honey, while hunting would also be reintroduced. In Phase 3, in addition to Phase 2, space would be opened up intermittently for grazing.

Money contribution

However, to implement the mitigation project implies investment. These costs vary with each implementation phase presented above and would need to be paid by the beneficiaries. Their contribution would range from US$4 to US$15 monthly, depending on the project implementation phase concerned. Such contributions would last for ten years.

Note

If the project is implemented, only the water supply and forest use would improve at the levels indicated. Everything else would remain as it is.

The pictures below illustrate the levels of the forest use and water supply planned in the project.
[Photos omitted here]

2.1 Given the mitigation project presented, would you wish to participate in the project?

Yes ☐ No ☐

We are interested in your view on coal mining impacts. Therefore, you will be given ten sets of three options each. We would like you to choose one option in each set.

The options will differ from each other in terms of the impact of mitigation levels and the contribution required from you to finance the measures. Note that there is no 'right' or 'wrong' option. Your task is simply to weigh the attributes of each option against the others and then choose the option you prefer the most. Always keep your budget in mind when you make your choice.

Note 4: Reminder to the interviewer
The choice sets in treatments 1 to 10 will be shown to the respondents separately.

Treatment 1

Project factors	Option A	Option B	Option C
Forest access	Shortcut + collection	Shortcut + collection + grazing	Current status
Water supply	Improved well	Piped to yard	Current supply
Your contribution	US$4	US$10	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 2

Project factors	Option A	Option B	Option C
Forest access	Shortcut + collection	Current status	Current status
Water supply	Piped to yard	Improved well	Current supply
Your contribution	US$15	US$10	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 3

Project factors	Option A	Option B	Option C
Forest access	Current status	Shortcut + collection + grazing	Current status
Water supply	Piped to yard	Improved well	Current supply
Your contribution	US$15	US$10	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 4

Project factors	Option A	Option B	Option C
Forest access	Shortcut + collection	Shortcut + collection + grazing	Current status
Water supply	Communal tap	Communal tap	Current supply
Your contribution	US$4	US$10	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 5

Project factors	Option A	Option B	Option C
Forest access	Shortcut + collection + grazing	Current status	Current status
Water supply	Current supply	Piped to yard	Current supply
Your contribution	US$10	US$4	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 6

Project factors	Option A	Option B	Option C
Forest access	Current status	Shortcut	Current status
Water supply	Communal tap	Current supply	Current supply
Your contribution	US$15	US$ 15	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 7

Project factors	Option A	Option B	Option C
Forest access	Shortcut + collection + grazing	Shortcut + collection	Current status
Water supply	Current supply	Improved well	Current supply
Your contribution	US$4	US$15	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 8

Project factors	Option A	Option B	Option C
Forest access	Shortcut	Shortcut + collection	Current status
Water supply	Piped to yard	Current supply	Current supply
Your contribution	US$4	US$15	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 9

Project factors	Option A	Option B	Option C
Forest access	Current status	Shortcut + collection	Current status
Water supply	Piped to yard	Communal tap	Current supply
Your contribution	US$10	US$15	US$0
Your choice	[ ]	[ ]	[ ]

Treatment 10

Project factors	Option A	Option B	Option C
Forest access	Shortcut	Current status	Current status
Water supply	Communal tap	Communal tap	Current supply
Your contribution	US$10	US$4	US$0
Your choice	[ ]	[ ]	[ ]

2.2 How difficult they had found it to answer the choice tasks? 1. Very easy, 2. Easy, 3. Very difficult, 4. Difficult, 5. Neither difficult nor easy. __

Section 3: Income and expenditure

3.1 Please fill in values of income below in Mzn:
3.1.1 Your annual total household income
3.2.2 Average monthly total household income
3.2 Please fill in values of the expenses below in Mzn:
3.2.1 Your total household expenditure
3.2.2 Average monthly expenditure
3.3 What food do you consume that you have produced yourself? ______________________ 3.3.1 How much would you be able to sell this for if you sold it instead? (Amount in Mzn) ______________________ 3.3.2 How much would you have to pay if you bought it? (Amount in Mzn) ______________________

Section 4: Attitudes towards coal mining

4.1 Do you or does someone at your household participate in any kind of coal exploration activities?
1. Directly ___ 2. Indirectly (e.g. as a vendor selling food to mine employees) ____ 3. Not at all ___
(If not at all, skip to 4.1.5)

4.1.1 Why do you participate?
1. It pays more than other activities ___ 2. I had no other alternative activity ___

4.1.2 In which activities are you mainly involved?__________________

4.1.3 (If not at all in 4.1) Do you wish to take part one day?
1. Yes ___ 2. No ___ 3. Don't know ___

4.1.4 (If answer above was yes) Why?____________________________

4.1.5 How have coal mining activities affected you?
1. Economically: (a) Positively ___ (b) Negatively ___ (c) No effect ___
2. Socially (e.g. improved provision of social services):
(a) Positively ___ (b) Negatively ___ (c) No effect ___
3. Culturally: Please specify ______________________________

4. Health: Please specify ________________________________
5. Other: Please specify __________________________________

4.1.6 (For those who answered no in question 1.26)
What factors attracted you to this area?______________________
1. Economic opportunities ___ 2. Social amenities ___ 3. Marriage ___ 4. Social relations (e.g. connection with relatives/friends/workmates) ___ 5. Other (specify) ______________________

4.2 How do you rank the employment opportunities before and after coal mining?
1. More available after ___ 2. More available before ___ 3. Less available after ___ 4. Less available before ___ 5. No change ___

4.2.1 What type of employment opportunities have been brought by coal mining? ____

4.3 How was your quality of life before and after coal mining?
1. Better before ___ 2. Worse before ___ 3. Better after ___ 4. Worse after ___ 5. Constant ___

4.4 What is your general perception about coal mining in your area (regarding the quality of life/welfare)?
1. Very good ___ 2. Good ___ 3. Average ___ 4. Poor ___ 5. Very poor ___
Can you explain your choice? ___________________________________

4.5 What types of crops do you grow now?
1. Food crops (please list): ______________________________________
2. Cash crops (please list): ______________________________________
3. None ___

4.5.1 What types of crops did you grow before and after coal mining activities?
1. Before:
____
2. After:
____

4.6 How do you rank the physical and social service infrastructure before and after coal mining? See the choices in the following table:

Services	Before coal explorations					After coal explorations				
	Very good	Good	Average	Poor	Very poor	Very good	Good	Average	Poor	Very poor
Healthcare, e.g. hospitals										
Schools										
Transport (roads)										
Telephone network										
Financial services (banks)										

Section 5: Responsibility and confidence assessment

5.1 How much responsibility do you believe the following actors in Mozambique have for preventing negative effects of coal mining?

Agents who can prevent negative effects of coal mining	No responsi bility	Little responsibility	Don't know	Large responsibi lity	Very large responsi bility
The state					
The municipality					
Mining companies					
Private companies (other than mining)					
Private individuals					

5.2 How much confidence do you have that the abovementioned actors in Mozambique will live up to their responsibility of preventing negative impacts of coal mining, such as water quality deterioration, lack of access to water, and lack of access to forest products?

Agents who will live up to their responsibility to prevent negative effects of coal mining	No confidence	Some confidence	Don't know	Above-average confidence	Great confidence
The state					
The municipality					
Mining companies					
Private companies (other than mining)					
Private individuals					

Appendix II: Questionnaire collecting data for paper III, in Portuguese

Impactos da Mineração de Carvão na zona rural de Moçambique

Nota 1: Lembrete ao entrevistador – Estamos interessados em entrevistar o chefe do agregado familiar ou cônjuge. No caso de um dos membros do agregado possuir um nível de instrução superior ao do chefe do agregado familiar, podem responder em conjunto. Não serão aceites quaisquer outros inquiridos que não estes.

Nota 2: Para ser lido pelo entrevistador aos entrevistados – Bom ....!! Obrigado por nos receber. Meu nome é ....!! Estou aqui com...!! Com este questionário pretendo recolher informações que nos ajudem a perceber se existe algum efeito induzido pela extração de carvão. Estamos aqui em nome da Universidade Eduardo Mondlane em colaboração com a Universidade de Tecnologia de Luleå, Suécia, para que eu não represente nem a empresa de mineração, nem o governo ou qualquer partido político. Estamos interessados na sua opinião sincera, opiniões e experiência sobre as perguntas que vamos fazer e será usado para fins académicos, no entanto, os resultados podem ser emprestados pelos decisores políticos para conceber políticas estratégicas para reduzir qualquer possível impacto negativo, caso exista. Foi selecionado aleatoriamente para participar no estudo e garantimos que as suas respostas são anónimas e serão tratadas com estrita confidencialidade e adicionadas às de outros inquiridos e incluídas nas conclusões gerais do estudo, pelo que não haverá forma de identificar as suas respostas após a análise ser feita. No entanto, se não se importar, pode partilhar o seu número de telefone para que possamos contactá-lo caso alguma informação no questionário não seja clara. Gostaria de participar na entrevista? ___. Se alguma questão lhe parecer pouco clara, por favor informe-nos antes de responder para que tenhamos todo o gosto em esclarecer. Estima-se que o questionário demore cerca de 2 horas, portanto, estamos oferecendo um presente monetário para recompensar seu tempo.

Início da entrevista. Data (mm/dd/ano):________________Time:______ Nome do entrevistador:_________________________

Distrito	
Ala	
Área do recenseador	
Identificação do agregado familiar	
Nome do chefe do agregado familiar/contacto (opcional)1. Masculino 2. Feminino	

Secção 1: Dados de base

Perguntas	Códigos de resposta	Resposta
1.1 Relação do entrevistado com o chefe do agregado familiar.	1= Chefe de família; 2= Marido; 3= Cônjuge	
1.2 Sexo do entrevistado.	1=Feminino; 2=Masculino	
1.3 Estado civil.	1=Solteiro; 2= Casado/ com companheiro	
1.4. Frequentou a escola?	1= sim; 2= não	
1.4.1. (Se a resposta a 1.4 for 1) Indique o seu nível de escolaridade.	1= pré-escola; 2= Alfabetização; 3= primeiro ano do ensino primário; 4= ensino primário de segundo grau; 5= ensino secundário básico; 6= ensino médio médio; 7= ensino superior	
1.5 Foi reassentado?	1= sim; 2= não	
1.6 Alguma vez recebeu alguma compensação monetária ou não monetária de uma empresa mineira de carvão?	1= sim; 2= não	
1.7-Como classificam as compensações recebidas da extração de carvão?	1= Muito pouco, 2= Pouco, 3= nenhum; 4= Suficiente; 5= Muito suficiente; 6= Não sei	
1.8 Quantas vezes você ou alguém da família já enfrentou alguma doença respiratória este ano?	1= nenhuma; 2= uma vez; 3= duas vezes; 4= mais de duas vezes.	
1.9 A casa onde você mora hoje é ...	1= Própria; 2= Arrendada; 3= Fornecida gratuitamente pelo empregador; 4= Fornecida gratuitamente ou aluguel pago por parente ou outra pessoa; 5= Outros (especificar)	
1.10 Como classifica a sua dependência em relação à floresta?	1 = não dependente, 2= pouco dependente, 3= nem, 4= dependente, 5= muito dependente; 6= Não sei	
1.11 Como você acha que a mineração de carvão impactou a floresta?	1= muito negativamente; 2= negativamente; 3= sem impacto; 4= positivamente; 5= muito positivo	
1.12 Como classifica a sua dependência em relação ao rio?	1 = não dependente, 2= pouco dependente, 3= nem, 4= dependente, 5= muito dependente; 6= Não sei	
1.13 Como vê a qualidade da água?	1 = muito ruim, 2= ruim, 3= nenhum, 4= bom, 5= muito bom; 6= Não sei	
1.14 Considera que a extração de carvão afetou a qualidade da água?	1= sim; 2= não	

Perguntas	Códigos de resposta	Resposta
1.15 Como vê a escassez de água?	1 = muito escasso, 2= escasso, 3= nenhum, 4= abundante, 5= muito abundante; 6= Não sei	
1.16 Considera que a extração de carvão afetou a disponibilidade de água?	1= muito negativamente; 2= negativamente; 3= sem impacto; 4= positivamente; 5= muito positivamente; 6= Não sei	
1.17 Quanto a sua família é impactada pela vedação da área de mineração?	1= não impactado, 2= pouco impactado, 3= nem, 4= impactado, 5= muito impactado; 6= Não sei	

1.18 Distância da sua residência até à mina de carvão mais próxima. (Dica. Obter a distância do carro) ________km.
1.19 Que idade tem? ________ anos.
1.20 Tem filhos? (1= sim; 2= não) __. Em caso afirmativo, quantos filhos tem? _____.
1.21 Quantos membros vivem atualmente no seu agregado familiar? ___________.
1.22 Existem terras aráveis? (1= sim; 2= não) ________.
1.23 Qual é a área das terras aráveis do seu agregado familiar na aldeia? ______ hectares.
1.24 Quanta terra perdeu para abrir caminho à exploração de carvão?__________hectares.
1.25 Foi compensado por isso? 1. Yes_ 2. Não__.
1.25.1 Qual o montante da sua compensação? ____________ Mzn, pode fornecer a escala se não estiver disposto a fornecer a amount_______________________ exata Mzn.
1.25.2 Ficou satisfeito com a compensação? 1. Yes_____ 2. Não______.
1.26. É natural desta região? (1= sim; 2= não) ________.
1.26.1 (Se a resposta a 1.26 for 1) Há quantos anos vive nesta região? _______ anos.
1.27. Tem gado? 1.Yes_____ 2. Não______.

Secção 2: Experiência de escolha

Nota 3 - lembrete ao entrevistador: Nesta seção, queremos que o entrevistado responda a perguntas sobre a vontade de contribuir com dinheiro, bem como faça uma escolha em cada um dos conjuntos de escolha apresentados. Certifique-se de preparar a descrição dos atributos e seus níveis e dê a ele/ela a oportunidade de fazer qualquer pergunta sempre que algo soar obscuro antes que o conjunto de escolhas seja apresentado.

Caixa 1 – Descrição dos atributos e níveis de atributos enquadrados num projeto de mitigação.

Agora estamos descrevendo os impactos da mineração de carvão em Moatize. Depois disso, propõe-se um projeto de mitigação onde os custos de implementação podem ser financiados pela contribuição monetária dos beneficiários.

Abastecimento de água

Antes da era da mineração de carvão, a população local em Moatize dependia do rio Revúbué para coletar água potável para si e seu gado, tomar banho e lavar roupas. A terra adjacente às margens do rio era geralmente preferida para o cultivo de culturas de ciclo curto, enquanto os artesãos extraíam a argila úmida para produzir tijolos. Outros ainda pescaram, e todos usaram a área para se refrescar durante o calor (Moatize fica muito quente). Agora, devido à mineração de carvão, as águas superficiais e subterrâneas estão contaminadas. Para mitigar este problema, imagine que estão a ser tomadas medidas no âmbito de um projeto comunitário onde a Fase 1 consistirá na abertura de poços melhorados perto das casas das pessoas e na instalação de filtros e bombas manuais para extrair água. A fase 2 consistirá no fornecimento de água tratada através de torneiras comunitárias instaladas muito perto das casas das pessoas, ou seja, a uma distância a pé inferior a cinco minutos. A fase 3 consistirá em bombear água potável para uma torneira no quintal de cada residência. Todas as opções fornecerão água potável 24 horas por dia, todos os dias.

Utilização das florestas

A terra cedida à mineração de carvão é uma floresta onde os moradores costumavam colher carne de caça, mel, ervas medicinais e lenha, onde secavam troncos para produzir carvão vegetal e pastavam seu estoque, e que usavam como atalho. Por razões de segurança e outras, a floresta foi vedada. No entanto, mesmo as terras florestais fora da cerca estão agora cobertas de pó de carvão, anulando os potenciais benefícios da floresta. Para mitigar esse efeito, suponha que um projeto comunitário seja proposto. A fase 1 consiste na colocação de portões vigiados em pontos importantes que permitem atravessar a floresta. No entanto, não seria permitido colher nada da floresta enquanto a usava como atalho. Na Fase 2, além da Fase 1, será realizado o reflorestamento e restauração de espécies que desapareceram ao longo do tempo, juntamente com a colocação de colmeias. A paisagem também seria limpa para melhorá-la ainda mais. Isto permitiria novamente a recolha de lenha e toras secas para a produção de carvão vegetal, materiais de construção, ervas medicinais e mel, enquanto a caça também seria reintroduzida. Na Fase 3, além da Fase 2, o espaço seria aberto intermitentemente para o pastoreio.

Contribuição em dinheiro

No entanto, implementar o projeto de mitigação implica investimento. Estes custos variam em função de cada fase de execução acima apresentada e teriam de ser pagos pelos beneficiários. A sua contribuição variaria entre 4 e 15 dólares mensais, dependendo da fase de implementação do projeto em causa. Essas contribuições durariam dez anos.

Observação

Se o projeto for implementado, apenas o abastecimento de água e a utilização florestal melhorarão nos níveis indicados. Tudo o resto permaneceria como está.

As imagens abaixo ilustram os níveis de uso da floresta e abastecimento de água planejados no projeto.

- **Fotos omitidos devido a direitos autoriais**

2.1 Tendo em conta o projeto de mitigação apresentado, gostaria de participar no projeto? Sim___ Não___

Estamos interessados na sua opinião sobre os impactos da mineração de carvão; Portanto, você receberá 10 conjuntos de três opções, das quais gostaríamos que você escolhesse uma opção em cada conjunto. As opções serão diferentes em termos dos níveis de atenuação do impacto e da contribuição necessária para financiar as medidas. Observe que não há uma opção correta, sua tarefa é pesar as propriedades de diferentes opções umas contra as outras e, em seguida, escolher a opção que você prefere mais sempre tendo em mente sua restrição de orçamento.

Nota 4 - lembrete ao entrevistador: Os conjuntos de escolha nos tratamentos 1 – 10 serão mostrados aos entrevistados separadamente.

Tratamento 1

	Opção A	**Opção B**	**Opção C**
Acesso à floresta	Cruzar + Coleção	Cruzar + recolha + pastoreio	Estado atual
Abastecimento de água	Melhorou bem	Canalizado para quintal	Fornecimento atual
A sua contribuição	EUA $ 4	EUA $ 10	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 2

	Opção A	**Opção B**	**Opção C**
Acesso à floresta	Cruzar + Coleção	Estado atual	Estado atual
Abastecimento de água	Canalizado para o quintal	Poço melhorado	Fornecimento atual
A sua contribuição	EUA $ 15	EUA $ 10	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 3

	Opção A	**Opção B**	**Opção C**
Acesso à floresta	Estado atual	Cruzar + recolha + pastoreio	Estado atual
Abastecimento de água	Canalizado para quintal	Poço melhorado	Fornecimento atual
A sua contribuição	EUA $ 15	EUA $ 10	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 4

	Opção A	**Opção B**	**Opção C**
Acesso à floresta	Cruzar + Coleção	Cruz + recolha + pastoreio	Estado atual
Abastecimento de água	Fontenária comunitária	Fontenária comunitária	Fornecimento atual
A sua contribuição	EUA $ 4	EUA $ 10	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 5

	Opção A	Opção B	Opção C
Acesso à floresta	Cruzar + recolha + pastoreio	Estado atual	Estado atual
Abastecimento de água	Fornecimento atual	Canalizado para quintal	Fornecimento atual
A sua contribuição	EUA $ 10	EUA $ 4	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 6

	Opção A	Opção B	Opção C
Acesso à floresta	Estado real	Cruzamento	Estado atual
Abastecimento de água	Fontenária comunitária	Fornecimento atual	Fornecimento atual
A sua contribuição	EUA $ 15	EUA $ 15	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 7

	Opção A	Opção B	Opção C
Acesso à floresta	Cruzar + recolha + pastoreio	Cruzar + Coleção	Estado atual
Abastecimento de água	Fornecimento atual	Poço melhorado	Fornecimento atual
A sua contribuição	EUA $ 4	EUA $ 15	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 8

	Opção A	Opção B	Opção C
Acesso à floresta	Cruzamento	Cruzar + Coleção	Estado atual
Abastecimento de água	Canalizado para quintal	Fornecimento atual	Fornecimento atual
A sua contribuição	EUA $ 4	EUA $ 15	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 9

	Opção A	Opção B	Opção C
Acesso à floresta	Estado atual	Cruzar + Coleção	Estado atual
Abastecimento de água	Canalizado para quintal	Fontenária comunitária	Fornecimento atual
A sua contribuição	EUA $ 10	EUA $ 15	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

Tratamento 10

	Opção A	Opção B	Opção C
Acesso à floresta	Cruzar	Estado real	Estado atual
Abastecimento de água	Fontenária comunitária	Fontenária comunitária	Fornecimento atual
A sua contribuição	EUA $ 10	EUA $ 4	EUA $ 0
A sua escolha	[ ]	[ ]	[ ]

2.2-Quão difícil tinham encontrado para responder às tarefas escolhidas? 1. Muito fácil, 2. Fácil, 3. Muito difícil, 4. Difícil, 5. Nem difícil nem fácil. ___

Secção 3: Receitas e despesas

3.1 Por favor, preencha os valores de renda em Mzn	
3.1.1 Rendimento total anual do agregado familiar	
3.2.2 Rendimento médio mensal total do agregado familiar	

3.2 Por favor, preencha os valores das despesas em Mzn	
3.2.1 Total das despesas do agregado familiar	
3.2.2 Despesas médias mensais	

3.3-Que alimentos consome e que você mesmo produziu? ___________________
3.3.1 Por quanto poderia vendê-lo se o vendesse? ____________________(MZN)
3.3.2 Quanto teria de pagar se o comprasse? _________________________(MZN)

Seção 4: Questões atitudinais em relação à mineração de carvão

4.1 Você ou alguém do seu agregado familiar participa em algum tipo de atividades de exploração de carvão? 1. Diretamente _ 2. Indiretamente (por exemplo, como vendedor de venda de alimentos aos empregados)___ 3. De modo algum__. Caso contrário, avance para 4.1.5
4.1.1 Porquê participar? 1. Mais pagando do que outras atividades ___. 2. Não tive outra atividade alternativa __.
4.1.2 Em que atividades está mais envolvido?________________________________
4.1.3 Se não estiver em 4.1 Deseja participar um dia?1. Yes_ 2. No_ 3. Não sei__
4.1.4 Porquê? Em caso de resposta SIM em 4-1-3 _________________________
4.1.5 As atividades de mineração de carvão afetaram-no? 1. Economicamente a) positively__ b) negativamente __c) no__; 2. Socialmente (por exemplo, melhor prestação de serviços sociais) a) positivamente _ b) negatively_ c) no_; 3. Culturally__ queira especificar ____; 4. Health__; 5. Outros (especificar)____

4.1.6 (Para aqueles que responderam não na pergunta 1.26) que fatores de atração o atraíram para esta área?___. 1. Oportunidades económicas; 2. Sócio-amenities; 3.

Casamento; 4. Relações sociais (por exemplo, conexão com parentes/amigos/colegas de trabalho)_____; 5. Outros (especificar)______

4.2.0 Como classifica as oportunidades de emprego antes e depois da extração de carvão?
1. Mais disponível depois; 2. Mais disponível antes; 3. Menos disponível depois; 4. Menos disponível antes; 5. Sem alteração; ____

4.2.1-Que tipo de oportunidades de emprego surgiram com a extração de carvão? ____.
4.3-Como era a sua qualidade de vida antes e depois da mineração de carvão?
1. Melhor before__ 2. Pior antes de __ 3. Melhor depois de ___ 4. Pior depois de __ 5. Constant__
4.4-Qual é a sua perceção geral sobre a mineração de carvão na sua área (no que diz respeito à qualidade de vida/bem-estar)?
1. Muito bom _ 2. Good_ 3. Average__ 4. Pobre ___ 5. Muito poor___. Pode explicar a sua escolha? ________________
4.5 Que tipos de culturas cultiva atualmente? 1. Culturas alimentares; Por favor, list_____________; 2. Culturas comercializáveis; Por favor, liste____; 3. None___.
4.5.1 Que tipos de culturas cultivava antes e depois das atividades de extração de carvão? 1.Antes_________________; 2.Depoi____________________

4.6 Como você classifica a Infraestrutura de Serviço Físico e Social antes e depois da mineração de carvão de acordo com a tabela a seguir:

Serviços	Antes das explorações de carvão					Após as explorações de carvão				
	Muito bom	Bom	Média	Pobre	Muito pobre	Muito bom	Bom	Média	Pobre	Muito pobre
Cuidados de saúde, por exemplo. Hospitais										
Escolas										
Transportes (Estradas)										
Rede telefónica										
Serviços financeiros (bancos)										

Secção 5: <u>Avaliação da responsabilidade e da confiança</u>

5.1 Quanta responsabilidade considera que os seguintes atores em Moçambique têm na prevenção dos efeitos negativos da extração de carvão?

	Sem responsabilidade	Pouca responsabilidade	Não sei	Grande responsabilidade	Responsabilidade muito grande
O Estado					
O município					
As empresas mineiras					
As empresas privadas (exceto a exploração mineira)					
Os particulares					

5.2 Quanta confiança tem nos atores acima mencionados em Moçambique, no que diz respeito a estarem à altura da responsabilidade de prevenir os impactos negativos da extração de carvão, como a qualidade e disponibilidade da água; e o acesso aos produtos florestais?

	Sem confiança	pouca confiança	Não sei	Grande confiança	Confiança muito grande
O Estado					
O município					
As empresas mineiras					
As empresas privadas (exceto a exploração mineira)					
Os particulares					

Appendix III: Supplementary Material for Paper III

Current situation of water supply and forest use during the survey

A. *Water supply*

During the survey, it was noted that most households had piped water infrastructure in their back yards. The water delivered was piped from the water treatment centre which lay about 20 km away. These water supply systems were metered. Regardless of consumption, a fixed charge for rent of the infrastructure assets (pipe, tap and meter) was included in the monthly bill. According to the respondents, this fixed fee varied from US$5 to US$10 (300 to 600 meticais), depending on the household's profile. This fixed charge and any monthly water consumption were payable by a certain deadline; unpaid accounts led to fines. However, the water service was considered expensive by the respondents. They also mentioned that the water pressure in the infrastructure was insufficient to reach their backyard taps in. This meant households dug holes to try to access water directly from the main distribution pipe that ran along the roads. Once they found the main pipe, they made holes in the pipe and collected water by catching it in bowls and used these to fill water containers that they brought home. Furthermore, most households are very concerned about water contamination by coal. Some therefore treat their water before drinking it, while others reported mainly using the water for household purposes and not human consumption. Water was also treated for drinking. The two main methods used were either to boil it, or to add a very popular type of chlorine at the point of use. Nonetheless, the respondents reported that boiling water had been constrained by the cost of charcoal and firewood. Moreover, the chlorine used was expensive, and treated water had to be used the same day. Another of the respondents' concerns was the reliability of the water supply because it was neither permanent nor regular. Sometimes it was supplied on one day but interrupted the next; or it might be supplied for two days, only to be followed by interruptions of two days or longer. Furthermore, even when there was water, the supply only lasted for three to five hours. To cater for interrupted supplies, some households had resorted to holding water reserves in tanks in their houses and then reselling the water to their neighbours. The price charged in these cases varied according to water availability, the relationship between the supplier and the customer, and the quantity supplied. In some cases, instead of charging for the amount supplied, families very close to each other shared the cost of the monthly bill. Due to the long interruptions in supply, insufficient water pressure in the pipes and power outages at the treatment plant, most backyard taps fell into disuse and were clogged and rusty.

A second source of water was from communal taps with hand pumps. These also faced regular breakdowns. Respondents indicated that the main reason for such breakdowns was coal from mining operations contaminating the water. This led the water to carry waste to the pipes, clogging them, and causing the pumps to malfunction. This happened especially when the water table was very low. The water that came out of these taps was contaminated and not safe to drink without being treated first. This source of water was paid for by way of contributing to the repair of breakdowns.

A third source of water was a communal tap powered by an electric pump. Here, the water was pumped into overhead tanks from where it would flow freely with gravity. During the survey, almost all these pumps were broken – for the same reasons that led to breakdowns in the hand-operated water pumps. In an attempt to redress the situation, Vulcan Minerals, a subsidiary of India's Jindal Group and the largest coal miner in the region, began transporting water in trucks to fill the tanks. This supply was irregular, however, and the quantities limited.

A fourth source of water was from unprotected water pits that were dug into the banks of the river. The water taken from these wells was contaminated by coal as well. This source was used mainly for cattle consumption and for washing clothes on site; it was rarely brought home. In some exceptional cases where the water had been brought home, it was applied only for domestic uses and rarely used for drinking. Access to this water was low-cost. Only when the wells dried up did users need to contribute to maintaining them or to opening others.

A fifth source of drinking water was bottled water, locally called *mineral water*. Of all the sources, this water had the highest standard but also the highest cost. At the time of the survey in 2024, a 1.5-litre bottle cost approximately US$1.

Statistically, an attempt to rank and indicate the share of households using each different type of water source is complex and risks misleading the reader. The complexity arises because households combine these sources, depending on the distance between their residences and the nearest source; the availability of water at the respective source; the cost; and the share of the water cost in the household's monthly income. These variables are dynamic in the region, so households constantly have to adjust how they combine the various sources to fit water costs into their available income. Supplement Table 1 below provides a summary of the water supply situation described above.

Supplement Table 1. Water supply situation during the survey period, 2024

Water supply infrastructure	Water use	Origin of the water	Water quality
Backyard tap	○ Treated for drinking ○ Domestic use	Catchment and treatment in centre about 20 km away	Acceptable – can be treated to drink
Hand-pumped communal tap	○ Treated for drinking ○ Domestic use	Local	Acceptable – can be treated to drink
○ Electronic pump ○ Water brought in by truck ○ Communal tap	○ Potable ○ Domestic use	Catchment and treatment in centre about 20 km away	Acceptable – can be drunk without needing treatment
Unprotected water pit	○ Watering livestock ○ Some domestic uses	Local	Very contaminated – can hardly be treated for drinking
Bottled water	Safe drinking for personal use	Extracted, treated and bottled in other regions of the country and in neighboring countries	Excellent and potable

B. Forest use

Crossing: Respondents in the study navigated their way around the mining area via public transport, on foot, by motorcycle or by bicycle, depending on the household's financial capacity. Walking was usually difficult on most days during the study period, owing to high temperatures in the region. The main destination that motivated travelling in the mining areas was the round trip to the farmlands.

Collection: The respondent households bought firewood, charcoal, honey and medicinal herbs at the local markets. Few households mentioned buying or consuming game meat. The interviewers suspected that residents declined to report their presumed consumption because they did not trust that the study team would not provide such information to the local anti-poaching office.

Grazing: Most of the respondent households that had livestock raised goats. Their animals were left to graze freely along the side of the road or in some pastures relatively close to their dwellings. Cattle breeders, on the other hand, walked relatively long distances with their animals as they grazed. Usually, the cattle were taken out to graze in the morning and returned by the end of the day. It took the herders at least an hour to walk from their homes to the pasture.

Appendix IV: Questionnaire collecting data for paper IV, in English

Coal mining impacts in rural Mozambique

Note 1: Reminder to the interviewer
We are interested in interviewing the head of the household or their spouse. If one of the household members is more highly educated than the head of the household, they can respond jointly. Respondents other than these will not be accepted for the survey.
Note 2: To be read by the interviewer to the respondents
Good ... ! Thank you for accepting the interview. My name is ... . I am here with ... . With this questionnaire I intend to collect information from you which will help us to find out if there is any effect induced by coal mining. We are here on behalf of the Eduardo Mondlane University in collaboration with the Luleå University of Technology in Sweden. We do not represent a mining company, the government, or any political party. We are interested in your sincere views, opinions and experience in answering the questions we are going to ask. Your answers will be used for academic purposes only. However, the results may be used by policymakers to design strategic policies to reduce any possible negative impacts of coal mining, if we find there are some. You have been randomly selected to participate in the study. We also assure that your responses are anonymous and will be treated with strict confidentiality. Your responses will be added to those of other respondents and included in the general findings of our study, so there will be no way of identifying you according to your responses after the analysis is done. Only if you don't mind, please share your telephone number with us so that we can contact you if there is some information in the questionnaire that is unclear. Would you like to participate in the interview? ___. If any question we ask you seems unclear, please let us know before you answer it. We will be happy to clarify it for you. The questionnaire is estimated to take about two hours. We are therefore offering you a small monetary gift to thank you for your time.

Start of interview: Date (mm/dd/yy): _______________ Time: _________

Name of interviewer: ____

District	
Ward	
Enumerator area	
Household identity code	
Name of household head/contact (optional) 1 = Male, 2 = Female	

Section 1: Background data

Questions		Response codes	Response
1.1	Relationship of the respondent to the head of the household	1 = Head of household 2 = Spouse (Male) 3 = Spouse (Female)	
1.2	Gender of the respondent	1 = Female, 2 = Male	
1.3	Marital status	1 = Single, 2 = Married/with partner	
1.4	Have you ever been to school?	1 = Yes, 2 = No	
1.5	(If the answer to 1.4 is 1) State your level of schooling.	1 = Preschool; 2 = Literacy; 3 = Grade 1 Primary; 4 = Grade 2 Primary; 5 = Basic Secondary; 6 = Middle Secondary; 7 = Senior Secondary	
1.6	Have you ever received any monetary or non-monetary compensation from a coal mining company?	1 = Yes, 2 = No	
1.7	(If the answer to 1.6 is 1) How do you rank the compensations received from coal mining?	1 = Very little, 2 = Little, 3 = Neutral, 4 = Adequate, 5 = Very adequate; 6 = I don't know	
1.8	How many times have you or someone in the household ever faced any respiratory disease this year?	1 = None, 2 = Once, 3 = Twice, 4 = More than twice	
1.9	The house where you live today is …	1 = Owned, 2 = Rented, 3 = Supplied free by employer, 4 = Supplied free or rent paid by relative or another person, 5 = Other (please specify)	
1.10	How do you rank your dependence on the forest?	1 = Not dependent, 2 = Somewhat dependent, 3 = Neutral, 4 =	

Questions	Response codes	Response
	Dependent, 5 = Very dependent, 6 = I don't know	
1.11 How do you think that coal mining has impacted the forest?	1 = Very negatively, 2 = Negatively, 3 = Neutral, 4 = Positively, 5 = Very positively	
1.12 How do you rank your dependence on the river?	1 = Not dependent, 2 = Somewhat dependent, 3 = Neutral, 4 = Dependent, 5 = Very dependent; 6 = I don't know	
1.13 How do you perceive the water quality?	1 = Very bad, 2 = Bad, 3 = Neutral, 4 = Good, 5 = Very good, 6 = I don't know	
1.14 Do you think that coal mining has affected the water quality?	1 = Yes, 2 = No	
1.15 How do you perceive the water scarcity?	1 = Very scarce, 2 = Scarce, 3 = Neutral, 4 = Abundant, 5 = Very abundant; 6 = I don't know	
1.16 Do you think that coal mining has affected the availability of water?	1 = Very negatively, 2 = Negatively, 3 = Neutral, 4 = Positively, 5 = Very positively, 6 = I don't know	

1.17 How old are you? _______ years

1.18 Do you have children? 1. Yes ☐ 2. No ☐
If yes, how many children do you have? ________

1.19 How many members currently live in your household? __________

1.20 Do you have any arable farmland? 1. Yes ☐ 2. No ☐

1.21 What is the size of your household's arable land in the village? ___ hectares

1.22 How much land did you lose to pave the way for coal exploration?_hectares.

1.23 Were you compensated for this? 1. Yes ☐ 2. No ☐

1.23.1 How much compensation did you receive? ___________ Mzn
You can provide an interval if you are unwilling to provide the exact amount, i.e. between ______and _________________ Mzn

1.23.2 Were you satisfied with this compensation? 1. Yes ☐ 2. No ☐

1.24 Are you a native in this region? 1. Yes ☐ 2. No ☐

1.24.1 (If the answer to 1.26 is 1)
How many years have you been living in this region? _______years

1.25 Do you have livestock? 1. Yes ☐ 2. No ☐

Section 2: Contingent valuation

Note 3: Reminder to the interviewer
In this section we need the respondents to answer questions about their willingness to contribute their time to a proposed project. Make sure to read out the description first. Then give the respondent the opportunity to ask about anything that is unclear to them before they respond. Throw the dice to randomly select bids in 2.2 [see second column in table below]. For a yes answer to 2.2, select the bid immediately above it, i.e. 2.3. For a now answer to 2.2, select bid 2.4.

Categories	Questions	Response code	Answer
Sample selection questions	2.1 Assume that the mine closes down. Are you or someone at your household prepared to contribute unpaid labour to a programme to restore the landscape where you used to live before you were resettled?	1 = Yes 2 = No	
Elicitation questions	2.2 (If the response to 2.1 is yes) Suppose that the programme requires from your household a contribution of [2/5/7.5/10/12.5] working days per month for ten years. Would you choose to contribute time? ___	1 = Yes 2 = No	
Follow-up questions	2.3 (If the response to both 2.1 and 2.2 is yes) Would you contribute [5/7.5/10/12.5/14] working days per month as well? ___	1 = Yes 2 = No	

Categories	Questions	Response code	Answer
Follow-up questions	2.4 (If the response to 2.1 is yes, but the response to 2.2 is no) Would you contribute [1.5/2/5/7.5/10] working days per month as well? ___	1 = Yes 2 = No	
Motives questions (distinguishing protest responses from genuine zero ones)	2.5 (If the response to 2.1 is no, the interviewer will continue to ask for reasons why the respondent is not willing to pay for the project.)	1 = The lifestyle in resettled places is good enough. 2 = The household's working time is too limited to afford any additional activity. 3 = The government should be responsible for it. 4 = I have paid enough costs and taxes, and therefore I do not want to pay more. 5 = Mining companies should pay for it.	

2.6 How difficult they had found it to answer the previous questions? 1. Very easy, 2. Easy, 3. Very difficult, 4. Difficult, 5. Neither difficult nor easy.

Section 3: Income and expenditure

3.1 Please fill in values of income below in Mzn:	Farm-related	Non-farm-related
3.1.1 Your annual total household income		
3.2.2 Average monthly total household income		
3.2 Please fill in values of the expenses below in Mzn:		
3.2.1 Your total household expenditure		

3.2.2 Average monthly expenditure		

3.3 What food do you consume that you have produced yourself?
____
____

3.3.1 How much would you be able to sell this for if you sold it instead? (Amount in Mzn) ______________________________

3.3.2 How much would you have to pay if you bought it? (Amount in Mzn) ______________________________

Section 4: Attitudes towards coal mining

4.1 Do you or does someone at your household participate in any kind of coal exploration activities?
1. Directly ___ 2. Indirectly (e.g. as a vendor selling food to mine employees) ____ 3. Not at all ___
(If not at all, skip to 4.1.5

4.1.1 Why do you participate?
1. It pays more than other activities ___ 2. I had no other alternative activity ___

4.1.2 In which activities are you mainly involved?________________________________

4.1.3 (If not at all in 4.1) Do you wish to take part one day?
1. Yes ___ 2. No ___ 3. Don't know ___

4.1.4 (If answer above was yes) Why?
____

4.1.5 How have coal mining activities affected you?
1. Economically: (a) Positively ___ (b) Negatively ___ (c) No effect ___
2. Socially (e.g. improved provision of social services):
(a) Positively ___ (b) Negatively ___ (c) No effect ___
3. Culturally: Please specify
____
4. Health: Please specify
____
5. Other: Please specify
____

4.1.6 (For these who answered no in question 2.1 in section 2 above) What factors attracted you to this area? (Please choose all that apply)
1. Economic opportunities ___ 2. Social amenities ___ 3. Marriage ___ 4. Social relations (e.g. connection with relatives/friends/workmates) ___ 5. Other (specify)
____

4.2 How do you rank the employment opportunities before and after coal mining?
1. More available after ___ 2. More available before ___ 3. Less available after ___ 4. Less available before ___ 5. No change ___
4.2.1 What type of employment opportunities have been brought by coal mining?
____

4.3 How was your quality of life before and after coal mining?
1. Better before ___ 2. Worse before ___ 3. Better after ___ 4. Worse after ___ 5. Constant ___

4.4 What is your general perception about coal mining in your area (regarding the quality of life/welfare)?
1. Very good ___ 2. Good ___ 3. Average ___ 4. Poor ___ 5. Very poor ___
Can you explain your choice? -
____

4.5 What types of crops do you grow now?
1. Food crops (please list):
____
2. Cash crops (please list):
____
3. None ___
4.5.1 What types of crops did you grow before and after coal mining activities?
1. Before:
____
2. After:
____

4.6 How do you compare the current and pre-resettlement situations regarding the items in the table below? (Tick all that apply)

Services	Before resettlement					Currently				
	Much worse	Worse	No change	Better	Much better	Much worse	Worse	No change	Better	Much better
Farmland size										
Farmland quality										
Water access										
Dwelling conditions										
Available sources of income										

4.6.1 Regarding changes in your household's farmland size, please fill in the table below.

Change element	Before resettlement	Currently
Number of farmland plots		
Up to 2		
3 to 5		
6 or more		
Farmland size (hectares)		
Up to 2		
3 to 5		
6 or more		

4.6.2 What was your main crop before resettlement?

____

What is your current main crop?

____

4.6.2.1 What is the average quantity of your main crop harvested per hectare for each harvesting session? (You can use 50-kg bags as units if necessary)

Average quantity of main crop harvested per harvesting session	Before resettlement	After resettlement
Up to 5 50-kg bags		
6 to 10 50-kg bags		
11 or more 50-kg bags		

4.6.3 Now we are asking questions about your access to water, comparing the situation before resettlement and currently.

Access to water	Before resettlement	Currently
Main water source		
Piped water		
Community tap		
Pumpless well		
River		
Walking time to the main water source (minutes)		
Up to 10		
11 to 20		
21 to 30		
31 or more		
Daily round trips to the main water source		
Up to 2		
3 to 5		

Access to water	Before resettlement	Currently
6 or more		
Average number of 20-litre fetched per round trip		
Up to 2		
3 to 5		
6 or more		

4.6.4 Now we are asking questions about your housing conditions, again comparing both the pre-resettlement and current situations.

Housing conditions	Before resettlement	Currently
Material used for the roof of the main house		
Concrete slab		
Tile		
Lusalite		
Zinc		
Grass		
Material used on the wall of the main house		
Wood and zinc		
Adobe		
Sticks and stones		
Cement block		
Burnt brick		
Unburnt brick		

Housing conditions	Before resettlement	Currently
Cans		
Material used on the floor of the main house		
Cement		
Tile		
Adobe		

4.6.5 Now we are giving you a list of sources of non-farm income. Please select only your main source of income in both cases presented.

Source of non-farm of income	Before resettlement	Currently
House rental		
Farmland rental		
Sale of agricultural products		
Sale of livestock products		
Sale of fish		
Sale of clothing		
Sale of firewood and charcoal		
Sale of handicraft products		
Sale of construction materials		
Sale of honey and hunting products		
None		

4.7 How do you rank the physical and social service infrastructure before and after coal mining? See the choices in the following table:

Services	Before coal explorations					After coal explorations				
	Very good	Good	Average	Poor	Very poor	Very good	Good	Average	Poor	Very poor
Healthcare, e.g. hospitals										
Schools										
Transport (roads)										
Telephone network										
Financial services (banks)										

Section 5: Responsibility and confidence assessment

5.1 How much responsibility do you believe the following actors in Mozambique have for preventing negative effects of resettlement?

Agents who can prevent negative effects of resettlement	No responsibility	Little responsibility	Don’t know	Large responsibility	Very large responsibility
The state					
The municipality					
Mining companies					
Private companies (other than mining)					
Private individuals					

5.2 How much confidence do you have that the abovementioned actors in Mozambique will live up to their responsibility of preventing negative impacts of coal mining, such as water quality deterioration, lack of access to water, and lack of access to forest products?

Agents who will live up to their responsibility to prevent negative effects of coal mining	No confidence	Some confidence	Don't know	Above-average confidence	Great confidence
The state					
The municipality					
Mining companies					
Private companies (other than mining)					
Private individuals					

Appendix V: Questionnaire collecting data for paper IV in Portuguese

Impactos da Mineração de Carvão na zona rural de Moçambique

Nota 1: Lembrete ao entrevistador – Estamos interessados em entrevistar o chefe do agregado familiar ou cônjuge. No caso de um dos membros do agregado possuir um nível de instrução superior ao do chefe do agregado familiar, podem responder em conjunto. Não serão aceites quaisquer outros inquiridos que não estes.

Nota 2: Para ser lido pelo entrevistador aos entrevistados – Bom ....!! Obrigado por aceitar a entrevista. Meu nome é ....!! Estou aqui com...!! Com este questionário pretendo recolher informações que nos ajudem a perceber se existe algum efeito induzido pela extração de carvão. Estamos aqui em nome da Universidade Eduardo Mondlane em colaboração com a Universidade de Tecnologia de Luleå, Suécia, para que eu não represente nem a empresa de mineração, nem o governo ou qualquer partido político. Estamos interessados na sua opinião sincera, opiniões e experiência sobre as perguntas que vamos fazer e será usado para fins académicos, no entanto, os resultados podem ser emprestados pelos decisores políticos para conceber políticas estratégicas para reduzir qualquer possível impacto negativo, caso exista. Foi selecionado aleatoriamente para participar no estudo e garantimos que as suas respostas são anónimas e serão tratadas com estrita confidencialidade e adicionadas às de outros inquiridos e incluídas nas conclusões gerais do estudo, pelo que não haverá forma de identificar as suas respostas após a análise ser feita. No entanto, se não se importar, pode partilhar o seu número de telefone para que possamos contactá-lo caso alguma informação no questionário não seja clara. Gostaria de participar na entrevista? ___. Se alguma questão lhe parecer pouco clara, por favor informe-nos antes de responder para que tenhamos todo o gosto em esclarecer. Estima-se que o questionário demore cerca de 2 horas, portanto, estamos oferecendo um presente monetário para recompensar seu tempo.

Início da entrevista. Data (mm/dd/ano):________________Time:______ Nome do entrevistador:___________________________

Distrito	
Ala	
Área do recenseador	
Identificação do agregado familiar	
Nome do chefe do agregado familiar/contacto (opcional)1. Masculino 2. Feminino	

Secção 1: Dados de base

Perguntas	Códigos de resposta	Resposta
1.1 Relação do entrevistado com o chefe do agregado familiar.	1= Chefe de família; 2= Marido; 3= Cônjuge	
1.2 Sexo do entrevistado.	1=Feminino; 2=Masculino	
1.3 Estado civil.	1=Solteiro; 2= Casado/ com companheiro	
1.4. Frequentou a escola?	1= sim; 2= não	
1.5. (Se a resposta a 1.4 for 1) Indique o seu nível de escolaridade.	1= pré-escola; 2= Alfabetização; 3= primeiro ano do ensino primário; 4= ensino primário de segundo grau; 5= ensino secundário básico; 6= ensino médio; 7= ensino superior	
1.6 Alguma vez recebeu alguma compensação monetária ou não monetária de uma empresa mineira de carvão?	1= sim; 2= não	
1.7 (Se a resposta a 1.6 for 1)Como classifica as compensações recebidas da extração de carvão?	1= Muito pouco, 2= Pouco, 3= nenhum; 4= Suficiente; 5= Muito suficiente; 6= Não sei	
1.8 Quantas vezes você ou alguém da família já enfrentou alguma doença respiratória este ano?	1= nenhuma; 2= uma vez; 3= duas vezes; 4= mais de duas vezes.	
1.9 A casa onde você mora hoje é ...	1= Próprio; 2= Arrendado; 3= Fornecido gratuitamente pelo empregador; 4= Fornecido gratuitamente ou aluguel pago por parente ou outra pessoa; 5= Outros (especificar)	
1.10 Como classifica a sua dependência em relação à floresta?	1 = não dependente, 2= pouco dependente, 3= nem, 4= dependente, 5= muito dependente; 6= Não sei	
1.11 Como você acha que a mineração de carvão impactou a floresta?	1= muito negativamente; 2= negativamente; 3= sem impacto; 4= positivamente; 5= muito positivo	
1.12 Como classifica a sua dependência em relação ao rio?	1 = não dependente, 2= pouco dependente, 3= nem, 4= dependente, 5= muito dependente; 6= Não sei	
1.13 Como vê a qualidade da água?	1 = muito ruim, 2= ruim, 3= nenhum, 4= bom, 5= muito bom; 6= Não sei	
1.14 Considera que a extração de carvão afetou a qualidade da água?	1= sim; 2= não	

Perguntas	Códigos de resposta	Resposta
1.15 Como vê a escassez de água?	1 = muito escasso, 2= escasso, 3= nenhum, 4= abundante, 5= muito abundante; 6= Não sei	
1.16 Considera que a extração de carvão afetou a disponibilidade de água?	1= muito negativamente; 2= negativamente; 3= sem impacto; 4= positivamente; 5= muito positivamente; 6= Não sei	

1.17 Que idade tem? _______ anos.

1.18 Tem filhos? (1= sim; 2= não) _______. Em caso afirmativo, quantos filhos tem? ________.

1.19 Quantos membros vivem atualmente no seu agregado familiar? __________.

1.20 Existem terras aráveis? (1= sim; 2= não) _______.

1.21 Qual é a área das terras aráveis do seu agregado familiar na aldeia? __________ hectares.

1.22 Quanta terra perdeu para abrir caminho à exploração de carvão?_________hectares.

1.23 Foi compensado por isso? 1. Yes_ 2. Não__.

1.23.1 Qual o montante da sua compensação? ___________ Mzn, pode fornecer a escala se não estiver disposto a fornecer a amount_______________________ exata Mzn.

1.23.2 Ficou satisfeito com a compensação? 1. Yes____ 2. Não_____.

1.24. É natural desta região? (1= sim; 2= não) _______.

1.24.1 (Se a resposta a 1.26 for 1) Há quantos anos vive nesta região? ______ anos.

1.25. Tem gado? 1.Yes____ 2. Não_____.

Secção 2: Avaliação Contingente

Nota 3 - lembrete ao entrevistador: Nesta seção, queremos que o entrevistado responda a perguntas sobre a vontade de contribuir com tempo. Certifique-se de preparar a descrição e dar-lhe a oportunidade de fazer qualquer pergunta sempre que algo soar obscuro antes da resposta. Lance um dado para selecionar lances aleatoriamente em 2.2. Selecione o lance imediatamente acima para 2.3 e o lance imediatamente abaixo para 2.4 para respostas sim e não para 2.2, respectivamente.

Categorias	Perguntas	Código de resposta	Resposta
Exemplos de perguntas de seleção	2.1 Suponha que a mineração encerra, você ou alguém da sua família contribui com trabalho não remunerado para um programa de restauração da paisagem onde vivia antes do reassentamento?	1= Sim 2= Não	
Perguntas de elicitação	2.2 (Se a resposta a 2.1 for 1) Suponha que o programa exige do seu agregado familiar uma contribuição de [2/5/7.5/10/12.5] dias úteis por mês durante 10 anos _____ optaria por contribuir?	1= Sim 2= Não	

Categorias	Perguntas	Código de resposta	Resposta
Perguntas complementares	2.3 (Se a resposta a 2.1 e 2.2 for 1). Você contribuiria com [5/7.5/10/12.5/14] dias úteis por month______ também?	1= Sim 2= Não	
Perguntas complementares	2.4 (Se a resposta a 2.1 for 1 mas a resposta a 2.2 for 2). Você contribuiria com [1,5/2/5/7,5/10] dias úteis por month__ também?	1= Sim 2= Não	
Perguntas sobre os motivos (distinguindo as respostas de protesto das verdadeiras respostas zero)	2.5 (Se a resposta a 2.1 for 2), o entrevistador continuará a perguntar a razão pela qual não está disposto a pagar pelo projeto.	1= O estilo de vida em lugares reassentados é bom o suficiente. 2= O tempo de trabalho do agregado familiar é demasiado limitado para permitir qualquer atividade adicional. 3= O governo deve ser responsável por isso. 4= Paguei custos e impostos suficientes e, portanto, não quero pagar mais. 5= As empresas de mineração devem pagar por isso.	

2.6-Que dificuldade tiveram em responder às perguntas anteriores? 1. Muito fácil, 2. Fácil, 3. Muito difícil, 4. Difícil, 5. Nem difícil nem fácil. ___

Secção 3: Receitas e despesas

3.1 Por favor, preencha os valores de renda em Mzn	Agrícola	Não agrícola
3.1.1 Rendimento total anual do agregado familiar		
3.2.2 Rendimento médio mensal total do agregado familiar		

3.2 Por favor, preencha os valores das despesas em Mzn	
3.2.1 Total das despesas do agregado familiar	
3.2.2 Despesas médias mensais	

3.3-Que alimentos consome e que você mesmo produziu? ____________________
3.3.1 Por quanto poderia vendê-lo se o vendesse? _____________(montante em MZN)
3.3.2 Quanto teria de pagar se o comprasse? _________________ (montante em MZN)

Seção 4: Questões atitudinais em relação à mineração de carvão

4.1 Você ou alguém do seu agregado familiar participa em algum tipo de atividades de exploração de carvão? 1. Diretamente _ 2. Indiretamente (por exemplo, como vendedor de venda de alimentos aos funcionários)___ 3. De modo algum__. Se não todos, pule para 4.1.4.1.2

4.1.1 Porquê participar? 1. Mais pagando do que outras atividades ___. 2. Não tive outra alternativa activity__.

4.1.2 Em que atividades está mais envolvido?______________________________

4.1.3 Se não estiver em 4.1 Deseja participar um dia?1. Yes_ 2. No_ 3. Não sei__

4.1.4 Porquê? Em caso de resposta SIM above____

4.1.5 As atividades de mineração de carvão afetaram-no?

1. Economicamente a) positively__ b)negativamente __c) no__; 2. Socialmente (por exemplo, melhor prestação de serviços sociais) a) positivamente _ b) negatively_ c) no_; 3. Culturally__ especificar __; 4. Health__; 5. Outros (especificar)____

4.1.6 Para aqueles que responderam não na pergunta 1.24, que fatores de atração o atraíram para esta área? (Assinale todos os requisitos)

1. opportunities__ económica; 2. Sócio-amenities___; 3. Marriage___; 4. Relações sociais (por exemplo, ligação com familiares/amigos/colegas de trabalho) __; 5. Outros (especificar)____

4.2.0 Como classifica as oportunidades de emprego antes e depois da extração de carvão? _____

1. Mais disponível depois; 2. Mais disponível antes; 3. Menos disponível depois; 4. Menos disponível antes; 5. Sem alteração

4.2.1-Que tipo de oportunidades de emprego surgiram com a extração de carvão? __________________________.

4.3-Como era a sua qualidade de vida antes e depois da mineração de carvão?

1. Melhor before__ 2. Pior antes de __ 3. Melhor depois de ___ 4. Pior depois de __ 5. Constant__

4.4-Qual é a sua perceção geral sobre a mineração de carvão na sua área (no que diz respeito à qualidade de vida/bem-estar)?

1. Muito bom _ 2. Good_ 3. Average__ 4. Pobre ___ 5. Muito poor___. Pode explicar a sua escolha? _______

4.5 Que tipos de culturas cultiva atualmente?

1. Culturas alimentares; Por favor, list______________________________
2. Culturas comercializáveis; Por favor, liste __________________________
3. None______

4.5.1 Que tipos de culturas cultivava antes e depois das atividades de extração de carvão?

1.Before_____________________________________
2. After______________________________________

4.6 Como se comparam as situações atuais e pré-reinstalação no que diz respeito aos elementos incluídos no quadro abaixo? (Assinale todos os requisitos)

Serviços	Antes da reinstalação					Atualmente				
	Muito pior	Pior	Sem alteração	Melhor	Muito melhor	Muito pior	Pior	Sem alteração	Melhor	Muito melhor
Dimensão das terras agrícolas										
Qualidade das terras agrícolas										
Acesso à água										
Condições de habitação										
Fontes de rendimento disponíveis										

4.6.1 Em relação às alterações na dimensão dos terrenos agrícolas do seu agregado familiar, por favor preencha o quadro abaixo.

	Antes do reassentamento	Atualmente
Número de parcelas de terras agrícolas		
Até 2		
3-5		
6 ou superior		
Dimensão das terras agrícolas (hectares)		
Até 2		
3-5		
6 ou superior		

4.6.2 Qual era a sua principal cultura antes da reinstalação? ___ Qual é a sua principal cultura atual? _____.
4.6.2.1 Qual é a quantidade média da sua cultura principal colhida por hectare em cada colheita (pode utilizar sacos de 50 kg como unidade sempre que possível)?

	Antes do reassentamento	Atualmente
Até 5		
6-10		
11 ou superior		

4.6.3 Colocamos agora questões sobre o acesso à água, comparando tanto antes da reinstalação como atualmente.

	Antes do reassentamento	Atualmente
Principal fonte de água		
Água canalizada		
Toque na comunidade		
Poço sem bomba		
Rio		
Tempo de caminhada até a fonte de água principal (minutos)		
Até 10		
11-20		
21-30		
31 anos ou mais		
Viagens diárias de ida e volta à principal fonte de água		
Até 2		
3-5		
6 ou superior		
Número médio de galões de 20 litros buscados por cada viagem de ida e volta		
Até 2		
3-5		
6 ou superior		

4.6.4 Agora colocamos questões sobre as vossas condições de habitação, mais uma vez tanto para o pré-reassentamento como para a situação atual.

	Antes do reassentamento	Atualmente
Material utilizado no telhado da casa principal		
Laje de betão		
Telha		
Lusalite		
Zinco		
Relva		
Material utilizado na parede da casa principal		
Madeira e zinco		
Adobe.		

	Antes do reassentamento	Atualmente
Vara e pedra		
Bloco de cimento		
Tijolo queimado		
Tijolo não queimado		
Latas		
Material utilizado no chão da casa principal		
Cimento		
Telha		
Adobe.		

4.6.5 Agora estamos a fornecer-lhe uma lista de rendimentos não agrícolas, por favor selecione apenas a sua fonte principal em ambos os casos apresentados.

	Antes do reassentamento	Atualmente
Aluguer de casa		
Aluguer de terrenos agrícolas		
Venda de produtos agrícolas		
Venda de produtos animais		
Venda de peixe		
Venda de vestuário		
Venda de lenha e carvão vegetal		
Venda de produtos artesanais		
Venda de materiais de construção		
Venda de mel e de produtos da caça		
Nenhum		

4.7 Como você classifica a Infraestrutura de Serviço Físico e Social antes e depois da mineração de carvão de acordo com a tabela a seguir:

Serviços	Antes das explorações de carvão					Após as explorações de carvão				
	Muito bom	Bom	Média	Pobre	Muito pobre	Muito bom	Bom	Média	Pobre	Muito pobre
Cuidados de saúde, por exemplo. Hospitais										
Escolas										
Transportes (Estradas)										

Serviços	Antes das explorações de carvão					Após as explorações de carvão				
	Muito bom	Bom	Média	Pobre	Muito pobre	Muito bom	Bom	Média	Pobre	Muito pobre
Rede telefónica										
Serviços financeiros (bancos)										

Secção 5: <u>**Avaliação da responsabilidade e da confiança**</u>

5.1 Que responsabilidade considera que os seguintes atores em Moçambique têm na prevenção dos efeitos negativos da reinstalação?

	Sem responsabilidade	Pouca responsabilidade	Não sei	Grande responsabilidade	Responsabilidade muito grande
O Estado					
O município					
As empresas mineiras					
As empresas privadas (exceto a exploração mineira)					
Os particulares					

5.2 Quanta confiança tem nos atores acima mencionados em Moçambique, no que diz respeito a estarem à altura da responsabilidade de prevenir os impactos negativos da extração de carvão, como a qualidade e disponibilidade da água; e o acesso aos produtos florestais?

	Sem confiança	Pouca confiança	Não sei	Grande confiança	Confiança muito grande
O Estado					
O município					
As empresas mineiras					
As empresas privadas (exceto a exploração mineira)					
Os particulares					

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