Gold and climate change: Current and future impacts

About the World Gold Council

The World Gold Council is the market development organisation for the gold industry. Our purpose is to stimulate and sustain demand for gold, provide industry leadership, and be the global authority on the gold market.

We develop gold-backed solutions, services and products, based on authoritative market insight, and we work with a range of partners to put our ideas into action. As a result, we create structural shifts in demand for gold across key market sectors. We provide insights into the international gold markets, helping people to understand the wealth preservation qualities of gold and its role in meeting the social and environmental needs of society.

Based in the UK, with operations in India, the Far East and the US, the World Gold Council is an association whose members comprise the world's leading gold mining companies.

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Cover photo: Essakana mine, courtesy of Wärtsilä, IAMGOLD Corporation.

Executive summary

This research builds on our initial work in 2018 on gold's greenhouse gas (GHGs) emissions profile and climate change impacts. We have now deepened and extended our analysis, with a focus on the potential decarbonisation of the gold supply chain and climate-related investment impacts. This report, produced with technical support from independent sustainability consultancy, Anthesis, documents our findings on the following:

Gold's carbon footprint

Refining and broadening our understanding of gold's overall emissions profile, we have produced more detailed estimates of the GHG emissions associated with gold mining and refining and confirmed that gold's downstream emissions are relatively small.

Potential net zero transition pathways for the gold supply chain

Our analysis suggests there are substantial opportunities for the gold supply chain, and particularly gold mining, to adapt to a net zero carbon future. We outline a range of possible steps and pathways to decarbonisation that we calculate to be both practical and, over time, cost-effective for the industry.

Climate-related impacts on gold as an asset in comparison to other economic sectors and mainstream asset classes

We conclude that gold's risk-return profile and performance as a portfolio asset is expected to be relatively robust in the context of a range of climate scenarios. The contrasting vulnerability of many other sectors and asset classes to climate-related physical and transition risks suggests a strong case for gold as a strategic diversification and insurance asset in the face of climate change.

Key findings

- This analysis, using more granular data covering the whole supply chain, has produced more accurate estimates of gold's greenhouse gas (GHG) intensity and carbon footprint, while broadly validating our 2018 work.
- Gold's downstream uses – gold in bullion, jewellery, and electronic products – have little material impact on either gold's overall carbon footprint or GHG emissions.
- The current primary source of GHG emissions in the gold supply chain – energy and fuel use in gold mine production – can transition towards a net zero pathway in a practical and cost-effective manner.
- Gold's risk-return profile is likely to be relatively robust in the context of climate-related physical and transition risks, particularly in comparison to the vulnerability of many other mainstream assets.
- Heightened market volatility and uncertainty from climate-related risks are likely to be supportive of further investment demand for gold, as gold's roles as a risk hedge, portfolio diversifier and market insurance asset are well established.
- Taken together, these findings suggest gold may have an additional role to play as a climate risk mitigation asset in long-term investment strategies.

Foreword by Dr Ben Caldecott

Dr Ben Caldecott

Investors, from the very largest institutional investors to the smallest millennial retail savers, increasingly want their holdings across different asset classes to have smaller environmental footprints and for these to become aligned with environmental thresholds over time. The primary focus has been on climate change, but this growing societal demand extends to other environmental challenges including habitat destruction, biodiversity loss, air quality and water stress, among others.

In the case of climate change, globally we need to have a negative carbon footprint ('net zero') by mid-century if we are to meet the 'well-below two degrees' objective of the Paris Agreement on Climate Change. Net zero will allow us to stabilise the stock of carbon in the atmosphere, but that means reducing carbon emissions to zero in every sector we can, while also extracting and sequestering carbon from the atmosphere using biological, chemical, and industrial processes at incredibly large scales.

This massive challenge (and opportunity) will reshape the value of assets and companies across sectors of the global economy, as well as portfolios and loan books exposed to them. But in addition to these climate-related transition risks, we have locked in large and growing future physical climate impacts from greenhouse gas emissions that have already been emitted.

According to the Global Warming Index produced by the University of Oxford the planet is already 1.12°C warmer today the period from 1850-1900,[1] with warming unevenly distributed across the planet. Climate impacts are already being felt, including from increased storms and floods, rising sea levels, diminishing Arctic sea ice, and more regular and intensive heatwaves. For example, Europe's 2019 record-breaking heatwave was made up to '100 times more likely' by climate change.[2]

In every future state, therefore, there will be an increased combination of both climate-related transition and physical risks that will need to be managed by society, and by extension by financial institutions. As a result, climate-related risks are increasingly being recognised as financially material, even by those traditionally most sceptic.

Growing concern for the environment, combined with environment-related risks becoming both increasingly felt and anticipated, has resulted in massive and ongoing interest in aligning finance with sustainability. According to the Global Sustainable Investment Alliance assets managed under sustainable investment strategies reached US$30.7 trillion (trn) globally in 2018, a 34% increase from 2016.[3]

1. See: www.globalwarmingindex.org
2. www.worldweatherattribution.org/human-contribution-to-the-record-breaking-july-2019-heat-wave-in-western-europe/
3. www.gsi-alliance.org/wp-content/uploads/2019/03/GSIR_Review2018.3.28.pdf

While we shouldn't take these staggeringly large numbers at face value as finance is nowhere near to realising the genuine integration of the environment into financial decision-making, they nonetheless demonstrate the rapid growth and increasing interest in sustainable finance.

This is the context into which this report and its underlying analysis arrives. The authors seek to answer important questions: what role, if any, can gold as an asset class play in reducing i) the negative climate impact that investment portfolios have and ii) the climate-related risks that portfolios face? How can the gold value chain align with net zero by mid-century? And what role does gold have in supporting other sectors to achieve net zero?

Gold has a role to play in answering all these questions. But as with anything, and particularly with climate change, the devil is in the detail. For example, while in general newly mined gold has greater environmental impact than recycled gold, can we differentiate between the two as investors and should they be priced differently? Can gold mining play a role in increasing the resilience of communities and local economies to climate change? What environmental impacts beyond climate does gold have and how do we factor that into the analysis? To what extent is decarbonisation of other sectors dependent on gold vs other metals and minerals? What are the most effective pathways for gold companies to achieve net zero? And which companies have credible targets and pathways, and how can these be monitored and improved?

This report does much to systematically map out the questions the industry should now answer, and I commend its proactive contribution. Gold can be a part of the solution, but there is much more to do. The report is an initial roadmap for turning the shared ambition of net zero into a reality across a global industry. Much will depend on the industry itself, as well as investors in gold as an asset class. Both need to work together so that net zero alignment can be achieved. Time is of the essence.

Dr Ben Caldecott is founding Director of the Oxford Sustainable Finance Programme and an Associate Professor at the University of Oxford, as well as Co-Chair of the Global Research Alliance for Sustainable Finance and Investment and a Senior Advisor to the Chair and CEO of the Green Finance Institute.

Bald Mountain, Nevada USA. Image courtesy of Kinross Gold Corporation.

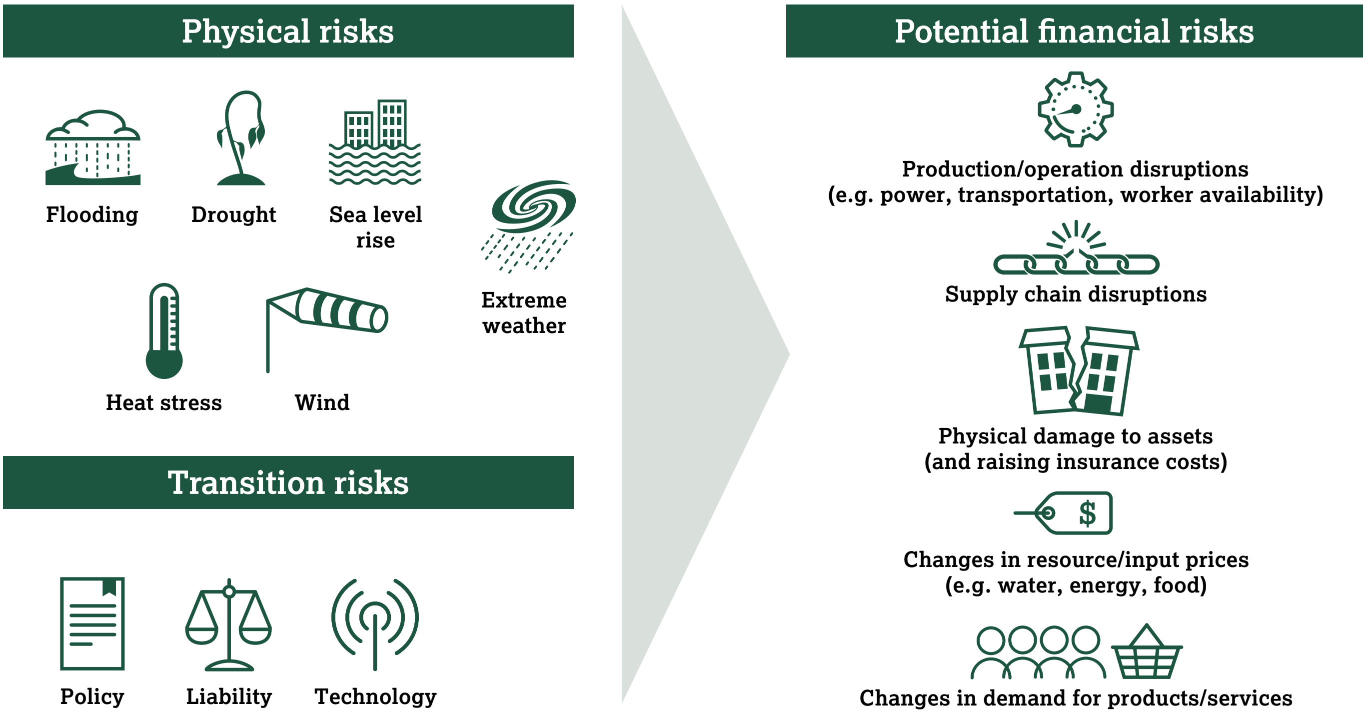
Introduction

Climate change now

Human activity has caused the release of greenhouse gases (GHGs), such as carbon dioxide (CO_2), into the atmosphere causing climate change. The concentration of atmospheric CO_2e[4] has increased by more than 40% since pre-industrial times. This has led to a global average temperature rise of 1°C above pre-industrial levels, with some regions, such as the Arctic, experiencing far greater warming.

The potential consequences and impacts of climate change are significant and wide-reaching. Scientists can now say with virtual certainty that extreme weather events caused by global warming, such as heatwaves and very heavy rainfall, will continue to increase in scale, intensity and frequency.[5] Changes in temperatures and weather patterns alter plant and animal behaviour and have significant implications for natural environments and human society across the world.

Social and political understanding of climate science, and the urgency behind calls to action to limit global warming, have rapidly been gaining momentum since the Paris Agreement on Climate Change was successfully negotiated by 196 countries in December 2015. The Paris Agreement, entered into force on 4 November 2016, sets a goal of limiting global warming to "well below 2°C" compared to pre-industrial levels.



4 See the Glossary for a fuller description of CO_2e.

5 *Confronting the Reality of Climate Change* (2018), IGEL (The Initiative for Global Environmental Leadership) and Knowledge@Wharton Special Report.

Recent extreme weather events have reinforced the significance of the Intergovernmental Panel on Climate Change (IPCC) special report,[6] published late last year, which stressed that immediate and concerted action is needed to limit the rise in global temperatures to below 1.5°C this century. This will require a 45% reduction in CO_2e emissions by 2030 and net zero carbon emissions globally by mid-century. Current plans are falling far short of what is necessary to achieve these objectives.

Consequences for national economies and local communities are far reaching, with the world's poorest nations being particularly vulnerable to physical climate-related risks. The recent United Nations update on the progress of the Sustainable Development Goals stated that climate change probably represents the most substantial obstacle to achieving the goals.[7]

Furthermore, rapid and substantial changes to move towards a global net zero carbon economy will increase climate-related transition risks that could strand assets, prematurely curtailing their economic value and ability to generate returns.[8]

Every future scenario presents combinations of climate-related physical and transition risks. Even though significant action on climate change may reduce physical risks, it is likely to heighten transition risks.[9]

Risks *and* opportunities

While there are many challenges, energy transition and climate risk mitigation will also create substantial opportunities for clean, low-carbon technologies and more robust, sustainable infrastructure.

In 2016, the World Bank's International Finance Corporation (IFC) assessed the national climate change commitments and policies in 21 developing countries and found that the period 2016 to 2030 offered an initial investment opportunity of US$23trn in key sectors. Commenting in 2017 on climate-related opportunities for investment, and noting the vast pool of low- and negative-yield bearing assets that has become a feature of the current financial landscape, World Bank President Jim Yong Kim stated, *"Quite apart from what you think about climate change, there are opportunities for investments that will give you higher yield than any of those investments in which over US$40trn is sitting right now."*[10]

Seeking to identify specific investment opportunities in the context of future climate scenarios, the investor-led Global Adaptation & Resilience Investment Working Group (GARI) published a white paper in 2017, in which it surveyed its 150 members. Survey responses highlighted the development of climate-resilient infrastructure and companies offering specific climate risk solutions as being of particular interest as prospective investments.

More recently, the World Bank, launching its *Climate-Smart Mining*[11] initiative, has again drawn attention to the strategic role metals and minerals will play in the manufacture of cleaner energy technologies. This is likely to significantly raise levels of demand, requiring both more mining and more minerals recycling. In a key paper on this subject, published in the leading science publication, Nature, researchers noted, *"Successful delivery of the United Nations sustainable development goals and implementation of the Paris Agreement requires technologies that utilise a wide range of minerals in vast quantities. Metal recycling and technological change will contribute to sustain supply, but mining must continue and grow for the foreseeable future to ensure that such minerals remain available to industry."*[12]

6 *Special Report on Global Warming of 1.5°C* (2018), IPCC; www.ipcc.ch/sr15/

7 www.un.org/sustainabledevelopment/blog/2019/07/sdg-progress-report-2019/

8 See *Stranded Assets in Agriculture: Protecting Value from Environment-Related Risks* (2013), Caldecott, Howarth, and McSharry; *Stranded Assets and Subcritical Coal: The Risk to Companies and Investors* (2015), Caldecott, Dericks,and Mitchell. *Stranded Assets: A Climate Risk Challenge* (2016), Ben Caldecott, Elizabeth Harnett, Theodor Cojoianu, Irem Kok, A. Pfeiffer; editor, Ana Rios, IADB. Also, *Unburnable Carbon Reports,* Carbon Tracker Initiative, and *Barclays: German coal 'worthless' by 2030,* cleanenergywire.org, 18 March 2016.

9 See the Glossary for fuller description of climate-related physical and transtion risks.

10 As quoted at www.reuters.com/article/us-global-climatechange-investment-idUSKBN17Q1U2

11 www.worldbank.org/en/topic/extractiveindustries/brief/climate-smart-mining-minerals-for-climate-action

12 *Mineral supply for sustainable development requires resource governance,* Saleem H. Ali et al, *Nature,* volume 543, pages 367–372 (16 March 2017).

While gold was not specified by the World Bank as a strategic 'climate-smart' mineral, the range of scientific and technological applications for gold currently under development suggest this might be reconsidered. There are promising signs[13] (as documented previously by the World Gold Council) that gold as an industrial product or input may play a useful role in technological advancements that will help mitigate climate change.

> While there are many significant challenges, energy transition and climate risk mitigation will also create substantial opportunities.

Better understanding

In 2018, the World Gold Council, recognising the importance of climate change and the need to transition to a net zero carbon economy, undertook preliminary research to better understand the climate-related impacts of the global gold market.[14]

Focusing primarily on GHG emissions associated with the production of gold, our initial findings demonstrated that despite limited published data on gold's global carbon footprint, total GHG emissions from newly-mined gold are significantly lower than those from other major metals and mined products. And when analysed on a 'per US$ value' basis, gold has among the lowest emissions intensity of all metals and mined products. We hypothesised that recycled gold and gold already in circulation, for example in bullion form, has significantly lower emissions than newly produced gold but, at that stage, could find little data to validate our assumption.

> When analysed on a 'per US$ value' basis, gold has amongst the lowest GHG emissions intensity of all metals and mined products.

However, we did uncover early-stage research[15] that tentatively concluded that an investment in gold may potentially help reduce the carbon footprint of an investor's portfolio. The research suggested that a more detailed examination might determine whether gold could contribute less to climate change than other investments and whether gold might be less exposed to climate-related risks than other asset classes.

We have focused on these issues in this report, specifically seeking to better understand:

- The impact of the gold supply chain on climate change (i.e. gold's Scope 1, 2 and 3 emissions)
  - Section 1 (*Gold's carbon footprint*) builds on our introductory report of 2018 by analysing Scope 1, 2 and 3 emissions utilising larger and more detailed data sets, allowing us to comment on the carbon footprint of the entire gold market.
- How the gold supply chain and, specifically, gold mining might adapt as it seeks to transition to a net zero carbon economy
  - Section 2 (*Net zero transition pathways for the gold supply chain*) investigates net zero transition pathways for the gold supply chain and offers a high level, indicative analysis of the opportunities – as well as costs and returns – of decarbonising gold production.
- How climate-related risks might affect gold's risk/return profile and performance as an investment asset.
  - Section 3 (*Gold as an investment and climate-related risks*) examines gold as an asset, focusing on its potential exposure and relative sensitivity to climate-related risks as compared with other mainstream assets.

13 See also *'Gold's role as a key component in low-carbon technologies'* in *Gold and climate change: an introduction* (2018), World Gold Council.

14 *Gold and climate change: An introduction* (2018), World Gold Council.

15 *The Role of Gold and the VIX in Investment Portfolios – A Financial and Sustainability Perspective* (2017), Baur & Oll.

1: Gold's carbon footprint

World Gold Council's 2018 report *Gold and climate change: An introduction* set out a series of estimates of the GHG footprint of gold, which indicated that total emissions from newly-mined gold are significantly lower than those from other major metals and mined products. However, the estimates were based on a relatively limited number of academic studies and conservative assumptions, largely due to a lack of data. This study addresses that. It sets out to arrive at improved and more comprehensive estimates of the Scope 1 and Scope 2 GHG emissions associated with gold production and bring Scope 3 emissions (both upstream and downstream) into consideration.

Gold mine production – Scope 1 and 2 emissions

Methodology

To arrive at a comprehensive overview of gold mining's GHG emissions profile, a number of alternative data sources and models were considered. Ultimately, the most accurate dataset was derived from the emissions and energy reported by the mining companies to either CDP (formerly the Carbon Disclosure Project) or via other public platforms, together with their own company and sustainability reporting. We sought to utilise data representative of activity at the individual mine level and focused on primary gold mine production from the large-scale, industrialised producers. Small scale/artisanal (ASM) gold mining[16] was ruled out of scope, not least due to its relative opacity and a lack of robust data.

Table 1: Scope 1, 2 and 3 GHG emissions

Scope 1 – Direct GHG Emissions	Scope 2 – Indirect Electricity Emissions	Scope 3 – Other Indirect Emissions
GHG emissions occurring from sources owned or controlled by the organisation, such as: • emissions from combustion in owned or controlled boilers, furnaces or vehicles • emissions from chemical processes in owned or controlled equipment • emissions from land owned or controlled by the organisation.	**GHG emissions at power plants generating electricity purchased by the organisation.**	**GHG emissions that occur as a consequence of the activities of the organisation, from sources not owned or controlled by it, such as:** • emissions from third-party transport of purchased materials or finished goods • emissions from the use of products sold.

Source: The Greenhouse Gas Protocol, World Gold Council

16 We acknowledge ASM gold production has very substantial environmental and social impacts, but it is very different from mainstream production and there is very limited data available to support a consistent analysis. ASM gold production data is included in the overall global gold production figures we used when extrapolating from our sample to size the total market and capture gold's overall carbon footprint.

Scope 1 and 2 estimates

The table below shows CO_2e emissions (tonnes) per tonne of gold produced for both 2017 and 2018. Two years were examined to compensate for variances in the annual samples and gaps in more recent data. These are weighted averages – taking total emissions for the sample and dividing by total gold production for the sample. These estimates were then scaled up using data for all global listed production.[17] Using a simple average of emissions per tonne by mine gives very similar results.[18]

Table 2: Gold production; annual Scope 1 and 2 GHG emissions

Year	CO_2e emissions, t per tonne of gold produced		
	Scope 1	Scope 2	Scope 1 and 2 total
2017	13,197	15,931	29,128
2018	17,951	14,738	32,689

Further details of this approach and data coverage issues can be found in *Methodology note 1: calculation of Scope 1 and 2 emissions.*

In Section 2 *(Net zero carbon transition pathways for the gold supply chain)* we explore the primary sources of gold mine production emissions in more detail and consider the potential opportunities for emission levels to be substantially reduced much further.

Refining and recycled gold emissions

Emissions data reported by a major precious metals refiner based in Switzerland was used to estimate emissions associated with refining and recycling gold. The refiner obtains feedstock gold from primary (mines) and secondary (e.g. industrial and jewellery) sources, but when considering energy use and likely emissions, it is assumed that the processes are broadly similar.[19]

Emissions for Scopes 1 and 2 were arrived at using total economic value of gold and silver processed to obtain a CO_2e, tonnes per dollar value, from which we derived the estimated emissions per tonne of gold processed. In practice, this may result overestimating the emissions attributable to gold.

17 The data drawn from all listed gold mines in the S&P Global Market Intelligence mining and minerals database.

18 The dataset was not representative of production ranges – small producing mines (under 5 tonnes per year) were considerably under-represented. However, this was not deemed significant for this study.

19 We acknowledge that extraction and refining of gold from industrial and electronics products is likely to be a more complex and energy intensive process than recycling gold products, such as jewellery, but the reported emissions data does not differentiate inputs so we are conflating them and treating refining as a single process.

Scope 1 emissions intensities are estimated to be 0.84 tonnes CO_2e per tonne of gold and Scope 2 emissions 1.09 tonnes CO_2e per tonne of gold. Scope 3 (goods and services purchased by refiners) emissions are 1.69 tonnes CO_2e per tonne of gold.

Scope 2 emissions for this refiner may be lower than average as it uses a high proportion of renewable energy. However, even allowing for this, emissions from gold refining are still four orders of magnitude less than primary gold production.

Applying the Scope 1, 2 and 3 emissions figures to total recycled gold supply in 2018 (1,168 tonnes) results in total annual GHG emissions of 4,228 tonnes CO_2e.

Upstream (gold production) and downstream (gold products) Scope 3 emissions

We have included the following sources of Scope 3 emissions: upstream emissions from purchased goods and services, including upstream emissions related to the production and distribution of fossil fuels and electricity which are used by the gold industry; and downstream emissions related to processing of sold products (jewellery, investment bars and coins, and electronics). We analysed other sources of Scope 3 emissions as set out in the GHG Protocol, and concluded that these were either not material or simply not applicable.

Upstream

The most significant source of upstream Scope 3 emissions are those from purchased goods and services utilised by the reporting gold mining and refining companies; that is, the main materials and inputs supplied for use in the process of gold production – these make up 21% of total emissions. By far the most significant source of these Scope 3 emissions are those related to the production and distribution of fossil fuels and electricity used by the gold industry.

We also estimated GHG emissions from waste, including wastewater treatment processes and direct waste management[20] associated with gold mining and, to a lesser extent, refining. The main element is clearly purchased goods and services, consisting primarily of various key chemicals used in gold mining and production. By emissions per kilogram (kg) of gold, the most significant are blasting (814kg per kg of gold) and sodium cyanide (509kg per kg of gold).

Looking at other upstream sources of Scope 3 emissions, we considered transportation, capital goods, and business and employee travel. A high-level estimation was performed using average transportation data[21] as applied to the location sources of gold production. This suggests that emissions from transport are around five orders of magnitude smaller than those from production. In view of their relative immateriality, they are excluded from our calculation of gold's carbon footprint.

20 Using data from the Ecoinvent database.

21 Ibid.

Table 3: Annual global gold market GHG emissions

	GHG Intensity	Gold volume, (t)	Total GHG emissions	Gold volume (t)	Total GHG emissions
	tonne of CO_2e per tonne of gold(tCO_2e/tAu)		($t\ CO_2e$)		($t\ CO_2e$)
PRODUCTION (upstream)			**Corporate/Listed mine production**		**Total global gold mine production**
Scope 1	13,197	2,115	27,911,655	3,447	45,490,059
Scope 2	15,931	2,115	33,694,065	3,447	54,914,157
Scope 3 (upstream)	7,287	2,115	15,412,005	3,447	25,118,289
Refining/recycled gold	**3.62**	**1,168**	**4,228**		**4,228**
CONSUMPTION (downstream)					
Scope 3 (downstream)					
Jewellery	370	2,237	827,690		827,690
Technology	0.84	200	168		168
Investment	3.62	1,252	4,532		4,532
Total	**36,793**		**77,854,343**		**126,359,123**

Source: Anthesis, S&P Global Market Intelligence, World Gold Council

Downstream

To evaluate downstream emissions, we calculated separate estimates for:

- Jewellery fabrication and distribution
- Investment products (bars and coins)
- Gold as a component in electronics.

Where data was unavailable we sought to identify closely aligned proxies and cross-checked or aggregated these with less specific or higher-level data sources.

Further details of this approach can be found in *Appendix 1 – Methodology note: calculation of Scope 3 emissions*

Findings

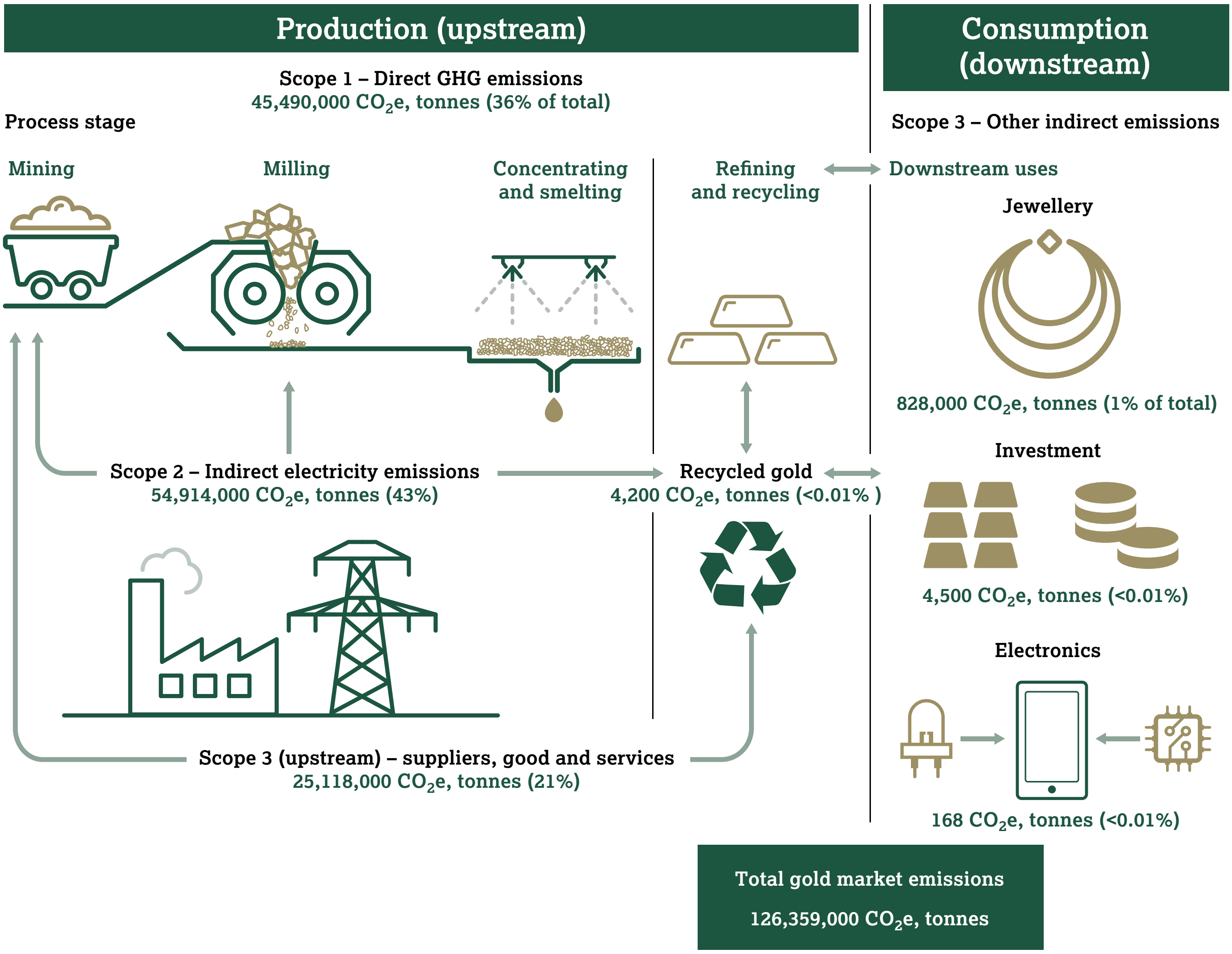
Table 3 shows our calculations for the total GHG emissions for the gold industry. Including all segments of the gold supply chain, but only data for corporate gold mine production (therefore very closely aligned with our sample data set for gold mining), we arrive at an annual emissions total for the gold market of around 78 million tonnes of CO_2e. But when this is scaled to include all global gold production (including ASM sources[22]) **our estimate of gold's annual emissions total equates to around 126 million tonnes of CO_2e.** While this extrapolation is likely to introduce a greater degree of uncertainty it is more representative of gold's total market size.

We also acknowledge that there may be a substantial element of double-counting in the downstream Scope 3 emissions totals.[23] But we have elected to retain these elements as they ensure our approach is comprehensive and therefore serves to reinforce the validity of our findings.

22 While we have included estimates of annual total gold production including ASM to arrive at an estimate of gold's global carbon footprint, we acknowledge that ASM is likely to have a very different GHG emissions profile from that exhibited by the large-scale industrialised gold mining sector on which ore core estimates are based.

23 For example, the emissions we associate with the refining process and those associated with the production of gold investment – bullion – products may, in practice, relate to a single process.

Figure 1: Global gold market GHG emissions



Comparison with previous findings

Analysis performed in the World Gold Council's 2018 report *Gold and climate change: An introduction* centred around an average estimate of Scope 1 and 2 GHG emissions intensity of 38,100t CO_2e/tAu, with a wide upper and lower error range, reflecting the highest and lowest figures in the academic literature (55,000t CO_2e/tAu and 11,500t CO_2e/tAu, respectively).

Here, we have been able to further refine our GHG emissions intensity estimates for gold – to an overall figure of 36,793 CO_2e/tAu – by scrutinising more granular data in addition to LCA data references. We have also analysed all major aspects of the gold supply chain (recycled gold, mining's Scope 3 upstream emissions and downstream gold consumption) previously excluded from our earlier research, allowing us to take a more holistic view of the carbon footprint of the entire gold market.

Our estimate of the overall annual carbon footprint of gold is now revised up slightly to 126 million tonnes CO_2e per annum, from our 2018 estimates, which averaged 124 million tonnes CO_2e per annum (from a very wide range). However, our previous figures focused only on gold mine production emissions, whereas our new estimates include all aspects of the gold market - production and consumption.

In 2018, gold's GHG intensity per US$ of value was calculated to be 0.9 $kgCO_2$. Using our wider and more granular data set, covering all aspects of the gold supply chain (Scope 1, 2 and 3 emissions, upstream and downstream), our estimate remains constant.[24]

We believe these figures represent the most comprehensive view of gold's GHG emissions intensity produced to date.

Downstream emissions are very small

Whilst reliable data is still severely limited, we are able to show that Scope 3 downstream impacts associated with the end-use of gold are extremely small, making up less than 1% of gold's overall annual GHG emissions. This is true even if, for the sake of completeness, we include an element of double-counting and we size the market to include gold production from ASM (Artisanal Small-scale Mining). Refining and recycling is immaterial, contributing a miniscule proportion of gold's total annual emissions. We believe this analysis represents a significant step forward in our understanding of the climate change impacts of the gold market.

The minimal level of GHG emissions associated with gold in storage or circulation has significant implications when we consider how investors and wider stakeholders might perceive gold in relation to climate-related risks and, in particular, how they might evaluate its overall contribution to climate change and climate change mitigation. These issues are explored further in Section 3 *(Gold as an investment and climate-related risks).*

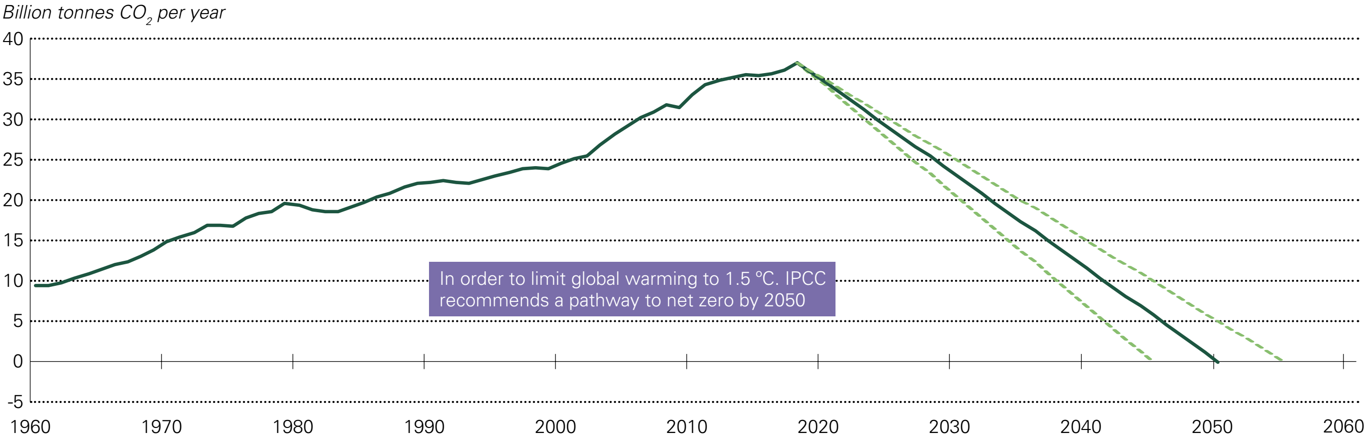
Scope 3 downstream GHG emissions associated with the end use of gold are extremely small.

24 The gold market is sized by annual 2018 demand in volume terms and value is calculated based on the 2018 annual average gold price (pm benchmark, US$/oz).

2: Net zero carbon transition pathways for the gold supply chain

If the signatories to the 2015 Paris Agreement are to meet their commitments to keep the increase in global temperature to well below 2°C, major changes will be required of the global economy. To have a chance of keeping global warming to 1.5°C, net global greenhouse gas (GHG) emissions must reach zero by 2050.[25]

Chart 1: Carbon emissions pathway to limit warming to 1.5°C



Note: Scenario represents global pathway to limit warming to 1.5ºC above pre-industrial levels with no or low overshoot, with 66% likelihood. Main pathway represents median range of models, range represents interquartile range of models (25th and 75th percentiles).

Source: Le Quéré, C. et al., "Global Carbon Budget 2018" Earth System Science Data, 10, 2141-2194, 2018

Achieving this will require rapid reductions in emissions of more than 5% per year, globally, starting now. Action is required in every country and sector of the economy, including: complete decarbonisation of power, transport, heating and cooling, and industry; decarbonisation of agriculture; reforestation, afforestation and other techniques to increase global carbon sinks,[26] and, almost certainly, some level of carbon capture and storage and other "negative emissions technologies" to remove previously emitted GHGs from the atmosphere – technologies that are either unproven at the mass scale required, or simply do not yet exist.[27]

25 The global carbon budget required to allow a 66% chance of keeping global warming to 1.5°C shows that net global anthropogenic GHG emissions must reach zero by 2050 (i.e. within a range of 2045-2055).

26 'Carbon sink' refers to a forest, ocean, or other natural environment viewed in terms of its ability to absorb carbon dioxide from the atmosphere.

27 For a discussion of how gold might play a role in technologies currently under development, that may contribute to emissions reduction, see 'Gold's role as a key component in low-carbon technologies' in *Gold and climate change: an introduction* (2018), World Gold Council.

Implications for the gold industry

If the gold supply chain is to take action to reduce emissions and contribute to climate stability, key market participants will need to define a structured pathway that includes specific objectives towards achieving net zero emissions.

The Oxford Martin Principles for Climate-Conscious Investment[28] provides a reference framework by which companies can orientate their climate-conscious actions. This initiative, which builds on long-term climate science, recommends that companies shape their strategies around the following key principles:

- **Commitment to net-zero emissions**
  Companies should commit to a date or a temperature increase (such as 1.5°C) before which the net CO_2e emissions associated with their activities will be zero. (All industries must eventually reach net-zero emissions, even if some industries do so before others.)
- **Profitable net-zero business model**
  Companies must have business plans that ensure the profitability of their business, and manage supply chain risks appropriately once emissions reach net zero
- **Quantitative medium-term targets**
  Companies should set mid-term targets that are directly relevant to achieving a net-zero business model.

Science-based targets

The commitment to specific emissions targets, and the ability for companies and their stakeholders to measure the progress in achieving them, clearly require well-defined – that is, science-based – reference points.

The Science-Based Targets initiative (SBTi) is a joint initiative by CDP, the UN Global Compact (UNGC), the World Resources Institute (WRI) and World Wildlife Fund (WWF), with the goal of increasing corporate ambition on climate action by mobilising companies to set GHG emission reduction targets consistent with the level of decarbonisation required by science to limit warming to less than 2°C compared to pre-industrial temperatures.

The SBTi represents a robust approach for companies to manage their emissions over the long term, and to align with the commitments of the Paris Agreement (to limit temperature rise to well below 2°C and pursue efforts to limit temperature rise to 1.5°C). The benefits of setting a SBTi include an increase in innovation, a reduction of regulatory uncertainty, strengthening of investor confidence and credibility, and improving profitability and competitiveness.

Gold mining companies have already made progress in defining reduction targets. Many companies have established an intensity target (such as metric tons of CO_2e per metric ton of ore processed), and some have defined an absolute emissions reduction target. Overall, the majority of companies that have disclosed a target appear to be on track to achieve their goal, having accomplished, on average, around 70% of the reductions required.

However, to extend the consideration of general emissions reduction targets beyond specific mining company initiatives, we have set out to establish a feasible global reduction objective for the gold sector, aligned with the Paris Agreement.

While our aim is to present a pathway to net zero emissions for the whole gold supply chain, given that the vast majority of emissions are associated with gold production (see section 1 – Gold's carbon footprint), these targets are of specific relevance to the global gold mining sector.

We proceed using the following steps:

- Defining net zero emission reduction targets for the gold industry
- Defining the options available to gold mining companies to achieve these targets
- An indicative analysis of the costs and returns for the gold mining sector in transitioning to renewable energy sources
- Providing examples of the progress being made by the gold mining sector.

28 www.oxfordmartin.ox.ac.uk/downloads/briefings/Principles_For_Climate_Conscious_Investment_Feb2018.pdf

Target setting

The SBTi gives two targets – "well below 2°C" and "1.5°C" in line with the Paris commitments. The targets are set according to a (global) fixed carbon budget; the total amount of greenhouse gases that can be emitted before the target temperature thresholds are broken. These have been turned into linear reduction rates, consistent with this budget, to illustrate the level of ambition required each year.

Using the "Well below 2°C" target, annual emissions need to be reduced by 80% by 2050, equating to a linear reduction rate of 2.5% (that is, over three million tonnes CO_2e for the gold mining sector) per year. To be aligned with a 1.5°C scenario by 2050, the gold industry's sectoral emissions would have to be reduced by 92% by – or shortly after – 2040.

Steps towards a net zero carbon gold supply chain by 2050

As we have shown, gold mining is by far the most carbon-intensive part of the gold supply chain. However, when compared with some sectors of the economy (such as agriculture, cement, steel, chemicals, shipping or aviation), the gold industry may be relatively easy to decarbonise. That is, there are already options available to the sector that appear both practical – in that the relevant technologies and processes required are increasingly mature and ready to be deployed at sufficient scale – and cost-effective.

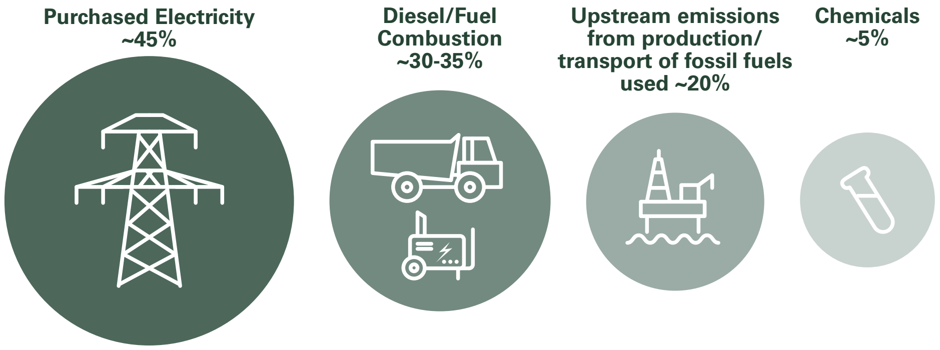
The emissions intensities of gold production operations may vary considerably, depending on the location, ore type and grade, and specific processes used. While each mine and producer will be different, the overall majority of GHG emissions appear to come from purchased electricity (~40-45%), diesel/fuel combustion used in powering vehicles and machines or to generate electricity on-site (~30-35%), and upstream scope 3 emissions related to the production and transportation of fossil fuels used by the gold industry (~20%) . We believe only a small percentage – a maximum of 5% – of emissions are due to direct GHG emissions from chemicals.[29]

I. Process improvement and energy efficiency

The first option – one that most companies are already looking at – is process improvement and energy efficiency. Reducing energy consumption immediately reduces GHG emissions. Schemes can be assessed on a cost-benefit basis, ensuring they have a clear financial business case as well as longer-term sustainability benefits. Technologies currently being deployed or developed in the mining sector include:[30]

- Use of advanced asset management strategies combining real-time operational data (using Internet of Things devices) with predictive analytics, to reduce energy consumption (e.g. from reducing the need for back-up diesel generation)
- Use of unmanned drones to survey sites and operations, leading to fewer transportation overheads and more efficient processes
- Upgrading to energy-efficient technologies such as LED lighting and variable-frequency drives
- Advanced processes such as mechanical rock excavation, advanced fragmentation, bulk sorting, in-pit crushing and conveying, coarse particle recovery, and even biomining.[31]

Origin of GHG emissions in gold production



29 See Haque, N & Norgate, T, *The greenhouse gas footprint of in-situ leaching of uranium, gold and copper in Australia,* Journal of Cleaner Production 84 (2014) 382-390; Norgate, T, Haque, N, *Using life cycle assessment to evaluate some environmental impacts of gold production,* Journal of Cleaner Production 29-30 (2012) 53-63.

30 Kirk, Thomas and Jessie Lund, *Decarbonization Pathways for Mines: A Headlamp in the Darkness,* 2018, Rocky Mountain Institute, https://rmi.org/mining-for-emissions-reductions-strike-while-the-earth-is-cool/

31 Biomining is the process of extracting valuable metals from ores and mine tailings with the assistance of micro-organisms.

II.Decarbonising electricity

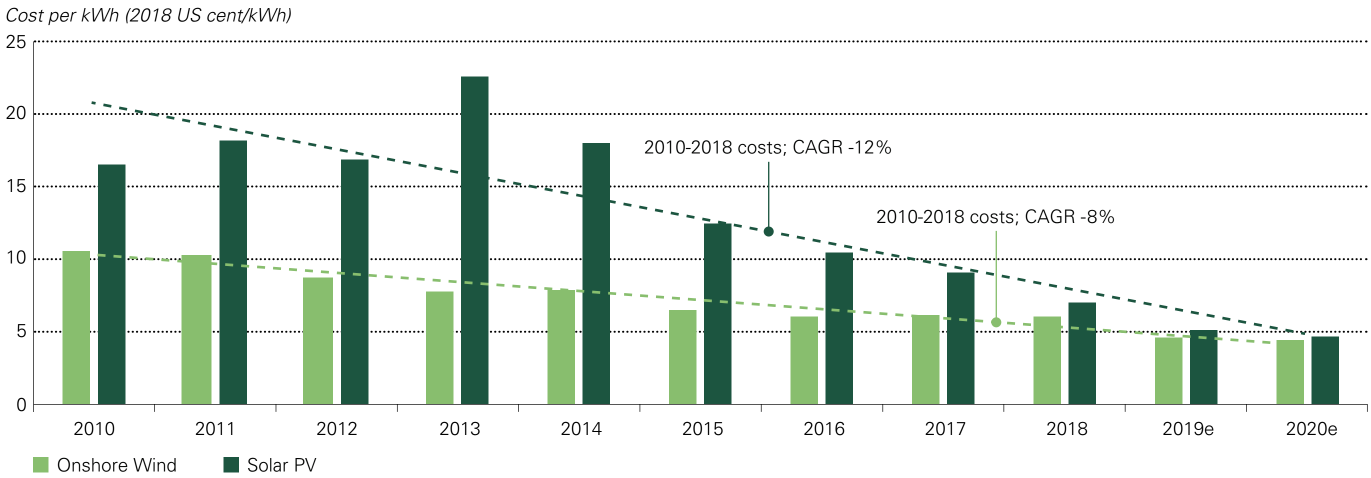
The second option is to use the existing clear path to decarbonise electricity.

Costs for renewable energy have reduced rapidly and consistently over the past decade, driven down with the huge increase in deployment. Globally, between 2010 and 2018, contracted levelised (life-time) costs per kWh for solar PV and onshore wind fell by 12% and 8% per year, respectively.

As a result, renewable sources of electricity generation (e.g. solar, wind, hydro) already have lower lifetime cost than new-build conventional electricity generation in most parts of the world,[32] and lower lifetime cost than grid electricity in some parts of the world.

> "In most parts of the world today, renewables are the lowest-cost source of new power generation… New solar PV and onshore wind will increasingly be cheaper than the marginal operating cost of existing coal-fired power plants."
>
> Source: IRENA (2019), *"Renewable Power Generation Costs in 2018,"* International Renewable Energy Agency

Chart 2: Global weighted average lifetime cost of electricity from solar PV and onshore wind, 2010-2020

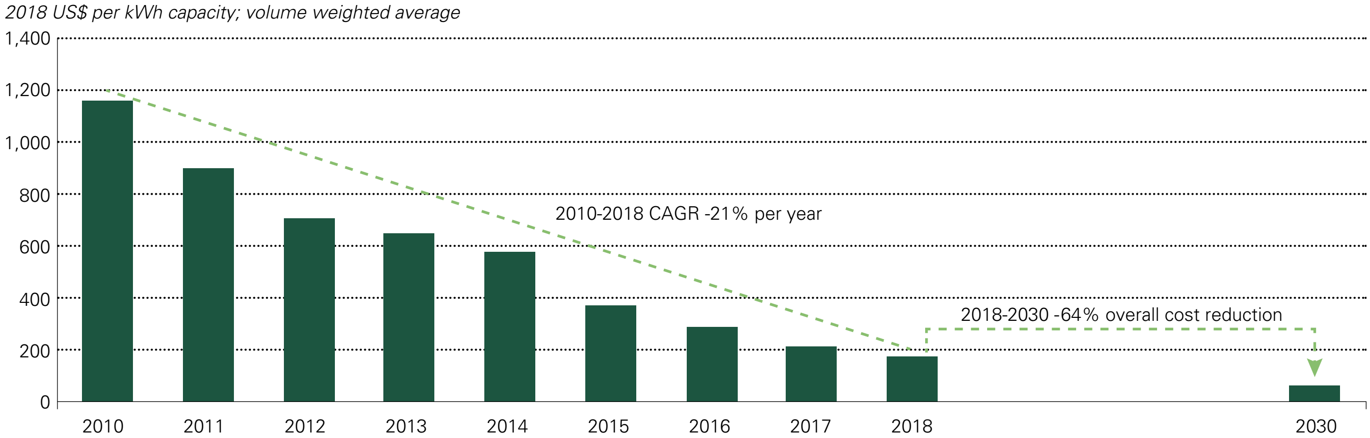


Note: Data from IRENA auction database; data represent contracted prices for projects commissioned/to be commissioned in the relevant year.

Source: IRENA (2019), *Renewable Power Generation Costs in 2018*, International Renewable Energy Agency, Abu Dhabi; www.irena.org/publications/2019/May/Renewable-power-generation-costs-in-2018

32 Lazard, *Lazard's Levelized Cost of Energy Analysis – Version 12.0*, November 2018. www.lazard.com/media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

Chart 3: Lithium-ion battery pack prices, 2010-2018 (actual) and to 2030 (forecast)



Source: Bloomberg New Energy Finance, *A Behind the Scenes Take on Lithium-ion Battery Prices*, 5 March 2019, https://about.bnef.com/blog/behind-scenes-take-lithium-ion-battery-prices/

At the same time, energy storage technologies – in particular batteries, but also pumped hydro, flywheels, compressed air and potentially hydrogen – have seen huge growth in investment and deployment, and corresponding reductions in costs. Lithium-ion battery prices fell by 21% per year between 2010 and 2018, and are forecast to continue falling a further 64% by 2030.

Continuing double-digit annual cost reductions will move the economics of electricity generation decisively in favour of renewables and storage on a worldwide basis during the 2020s.

Miners, refiners and other players in the gold supply chain using grid electricity have a range of options for sourcing renewable electricity, including:

- Purchase of renewable electricity from their supplier (along with appropriate certificates to guarantee origin)
- Signing up to a power-purchase agreement for supply of renewable electricity with a renewable energy supplier/ developer
- Depending on capital availability, risk/reward appetite and technical capabilities, developing their own on- or near-site renewable energy generation assets (e.g. solar or wind farms, perhaps backed up by battery storage).

Where diesel is used to generate electricity, this can be replaced by renewables and storage in the same way and over the same time-frame as grid electricity. In fact, given the high cost of diesel-powered generation the business case is likely to be even more positive in this situation, especially in remote locations. Research by Lazard[33] shows that, on a worldwide basis, the total levelised (life-time) cost[34] of both wind and solar is typically lower than the variable cost of diesel fuel alone.

> "There is a clear business case for the rapid replacement of diesel power with renewables."

Moreover, prices for diesel have remained broadly flat over the last decade, and there is no credible path for technology development that would cause them to decrease (though improvements in energy efficiency are possible, and indeed desirable). In contrast, as we have seen, costs for solar PV and onshore wind have declined rapidly and are likely to continue to do so. Furthermore, operational costs such as maintenance for solar PV and wind are much lower per kWh than for diesel generation. From a purely economic perspective, therefore, there is a clear business case for the rapid replacement of diesel power with renewables.

33 Lazard, *Lazard's Levelized Cost of Energy Analysis – Version 12.0,* November 2018. www.lazard.com /media/450784/lazards-levelized-cost-of-energy-version-120-vfinal.pdf

34 That is, capital investment plus ongoing operational cost.

2010 - 2018 costs per kWh for electricity from onshore wind fell by 8% per year. Image©Chaiviewfinder/Shutterstock.com

Where diesel or other fuels power engines used in the mine or mill, these can be replaced with electric motors – which can then be powered by renewables or other zero-carbon sources. As well as their environmental benefits, electric motors have significant advantages for use in mining: they tend to be quieter, require less maintenance, and have lower ventilation requirements than diesel equivalents, as they have no exhaust or particulate emissions and produce less heat. Reduced ventilation requirements have the potential to create US$ multi-million reductions in both CAPEX and OPEX costs.[35] In addition, a number of companies are developing automated electric hauling systems, which promise higher energy efficiency and lower maintenance than traditional systems.

(Further evidence of the cost benefits of transitioning to renewables is presented in *Appendix 2 – Net zero carbon transition pathways for the gold supply chain*.

III. Decarbonising transport

The options for decarbonising vehicles that currently use diesel or other fossil fuels are also increasingly accessible.

Where diesel is used, decarbonisation options are likely to come down to replacement with battery-electric or fuel-cell vehicles powered by zero-carbon electricity. As with renewable energy generation, huge growth in the market over the past decade has been accompanied by rapid cost reductions. The price of lithium-ion batteries fell by an estimated 85% between 2010 and 2018 – almost tenfold – and prices are forecast to continue to fall by 8-10% per year to 2030.

Over the next decade, the low or marginal cost of electricity generated from renewables will further enhance the cost effectiveness of electric vehicles over their diesel-powered counterparts. For example, analysis by the European Federation for Transport and Environment expects that total cost of ownership for battery-electric heavy-duty trucks (such as the Tesla semi-truck) will be lower than that of comparable diesel trucks when they are introduced.[36]

35 See e.g. https://im-mining.com/2018/09/13/caterpillar-talks-future-battery-electric-vehicle-offering/

36 Thomas Earl et al., *Analysis of long-haul battery electric trucks in EU*, 8th Commercial Vehicle Workshop, Graz, 17-18 May 2018. www.transportenvironment.org/sites/te/files/publications/20180725_T%26E_Battery_Electric_Trucks_EU_FINAL.pdf

This eDumper runs on 700kWh batteries and regenerates excess energy to the power grid. © e-Mining AG Andreas Sutter.

The development of battery or fuel-cell alternatives in the large/specialist vehicle sector – specifically, the heavy hauling trucks that make up a large part of gold miners' energy costs and GHG emissions – has been gathering pace. More generally, the use of battery-electric vehicles is growing rapidly across the globe, with commercially-available applications now widespread across cars, buses, trucks and ferries. The following examples show that suppliers are already innovating to meet the decarbonisation needs of heavy vehicle users:

- Swiss researchers working with eMining AG and the owners of a quarry in Bern, Switzerland, have prototyped a 65-tonne payload battery-electric dump truck, re-built on a Komatsu HD 605-7 vehicle body[37]
- Companies including CAT and Komatsu are reported to be working on battery-electric versions of their own mining vehicles – for both underground and above ground use.[38]

And, recently, we have seen a more co-ordinated effort to accelerate the development of such vehicles. In late 2018, the International Council on Mining and Metals (ICMM) and leading mining vehicle suppliers launched the Innovation for Cleaner Safer Vehicles (ICSV) programme[39] to create a new generation of mine vehicle, which, among other things, would be GHG emission free.

As a result of these developments, gold mining should be able to start deploying electric vehicles (and/or other low-carbon transport technologies, such as fuel-cell powered vehicles) cost-effectively from the middle of the next decade, if not before.

37 See e.g. www.electrive.com/2018/04/23/empas-edumper-is-the-worlds-largest-electric-truck/; https://edition.cnn.com/2019/07/16/sport/edumper-electric-vehicle-supercharged-spt-intl/index.html

38 See e.g. https://im-mining.com/2018/09/13/caterpillar-talks-future-battery-electric-vehicle-offering/

39 www.icmm.com/en-gb/news/2018/icsv_pr

IV. Self-sufficient energy and mini-grids
Mines already run diesel-powered "mini-grids," especially in remote locations, to supply their demanding energy needs (such as MW-scale power requirements; 24/7 supply; an instantaneous energy buffer for large fluctuations in power needs; voltage and frequency stability; cost-effective operation). Modern, containerised systems based on renewables and storage (e.g. batteries, potentially supported by technologies such as flywheels, or even renewable-diesel-hybrid systems) can allow mining companies to "leapfrog" development with a more resilient infrastructure that has much lower operating costs and maintenance needs, at the same or lower lifetime cost.

Even where grid supply of electricity is available, these 'self-sufficient' systems have a number of benefits, including: high levels of reliability (avoiding the need for diesel backup in case of black- or brown-outs); avoiding high grid connection costs, and hedging uncertain and increasing grid electricity costs. As in other industries, alternative energy suppliers are increasingly offering "turnkey" solutions involving "plug and play" containerised equipment, remote monitoring technology and EPC contracts – which allow customers in the gold industry to address potential barriers to deployment, such as the operational challenges of ensuring trained personnel are available on site to run the equipment.

Ultimately, we believe that electrification of vehicles and other equipment, powered by renewables and combined with energy storage, will make it feasible and cost-effective for the gold industry to reduce emissions by up to 95% over the time-scale required. The technology, economics, and practicality of these solutions are set to continue improving rapidly over the next decade and are already becoming increasingly accessible and cost-effective compared to fossil-fuelled alternatives.

As an example, Bushveld Minerals in South Africa is developing a mini-grid project at the Vametco (vanadium) mining and processing facility in South Africa. The new mini-grid, consisting of solar photovoltaic and battery generation, will be able to deliver up to one MW of power (the largest size permittable without a national generation licence). The project, financed on an unsubsidised, commercial basis, reflects the current potential economic viability of both renewable energy and energy storage technologies.

Moreover, these technologies can make mines much more attractive to regulators, potential investors and wider stakeholders, especially if considered as part of end-of-life mine planning. In a recent discussion broadcast by *Mining Review Africa,* representatives of the African Development Bank stated that renewables-based mini-grids based on robust technologies can be more "bankable" than legacy fossil-fuelled projects – especially if they form part of end-of-mine-life planning in a way that enables mining companies to engender a sustainable local economy beyond the life of the mine, for example through "over-planting" and providing electricity at cost-reflective tariffs to local communities.[40]

V. Chemical processes
Finally, this leaves the final ~5% of direct emissions that come from chemical processes. These may be hard to eliminate entirely (though direct air capture may, in time, become a practical solution). In this case, the gold industry may need to reach net-zero through investing in decarbonisation projects in other sectors of the economy. One potentially attractive opportunity may lie in afforestation and other environmental remediation and carbon sink-creation programmes on mine sites and/or undeveloped land owned by mining companies. These are likely to offer cost-effective GHG mitigation opportunities, along with other benefits, e.g. to local communities, that may enhance mining companies' social licence to operate.

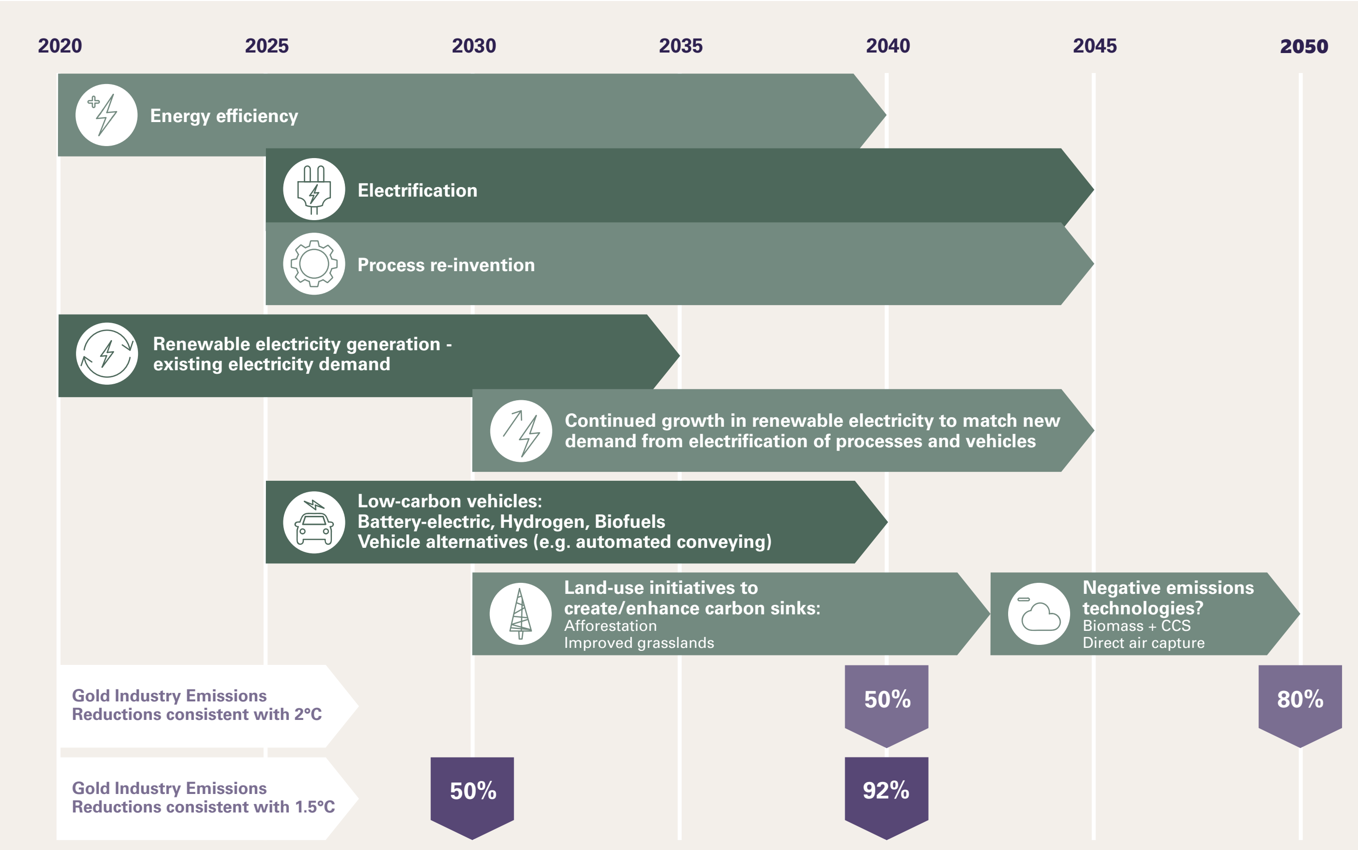
Our overall analysis thus allows us to combine our understanding of:

- The scale and sources of GHG emissions within the gold sector
- The emissions reduction targets required for the industry to be compatible with global scenarios limiting overall warming to a 66% chance of not exceeding the 1.5°C or 2°C
- The current and future prospects of technologies and other initiatives that can be deployed to reduce emissions.

Taken together, these allow us to develop indicative pathways by which the gold industry and, specifically, gold mining can reduce emissions.

40 Mining Review Africa, *Gridlocked – how can mining companies reduce their reliance on grid power?,* Webcast 18 July 2019.

Chart 4: Illustrative potential emissions reduction and transition pathway for the gold industry



Note: Emissions reductions for the gold industry based on sectoral decarbonisation approach of science-based targets initiative.

Source: World Gold Council analysis based on Anthesis estimates of gold carbon footprint

The majority of gold mining emissions are due to fossil fuels used in electricity production, whether bought from the grid or generated on-site. Most remaining emissions are due to on-site fossil fuel use in vehicles or machinery. Technology and economics are therefore on the gold industry's side. Renewable energy sources, combined with energy storage, are increasingly economically advantaged against fossil fuels, and this advantage is growing every year. This not only makes it cost-effective to decarbonise power, it will drive the potential for further cost-effective electrification of machinery and vehicles over the coming decade, powered from renewable sources.

Furthermore, a significant reduction in the gold industry's use of fossil fuels, and the Scope 1 and 2 emissions associated with this use, should also help reduce upstream Scope 3 emissions associated with the production of those fossil fuels, further decarbonising the gold supply chain.

> "The electrification of vehicles and other equipment, powered by renewables and combined with energy storage, will make it feasible and cost-effective for the gold industry to reduce emissions by up to 95% over the time-scale required."

Implementing a practical and cost-effective net zero carbon strategy for gold production

To understand the implications of the dramatic transition needed in energy for the gold industry, we have developed a high-level, indicative analysis of the investment requirement and economic returns of replacing *all of the electricity currently used in gold mining* with renewables and storage.

Clearly, a wide variety of technologies and commercial models could be used to achieve this, all of which will affect the economics, including:

- Renewable electricity generation technologies – including wind, solar PV, concentrated solar, biomass
- Electricity/energy storage technologies – including batteries (lithium-ion, lead-based, flow batteries, etc.), flywheels, compressed air, gravity-based systems
- A wide range of commercial models – including outright ownership, build-and-operate, power-purchase agreements (e.g. "private wire"and synthetic contracts)
- A range of ancillary revenue models – including grid balancing services and demand-side-response.

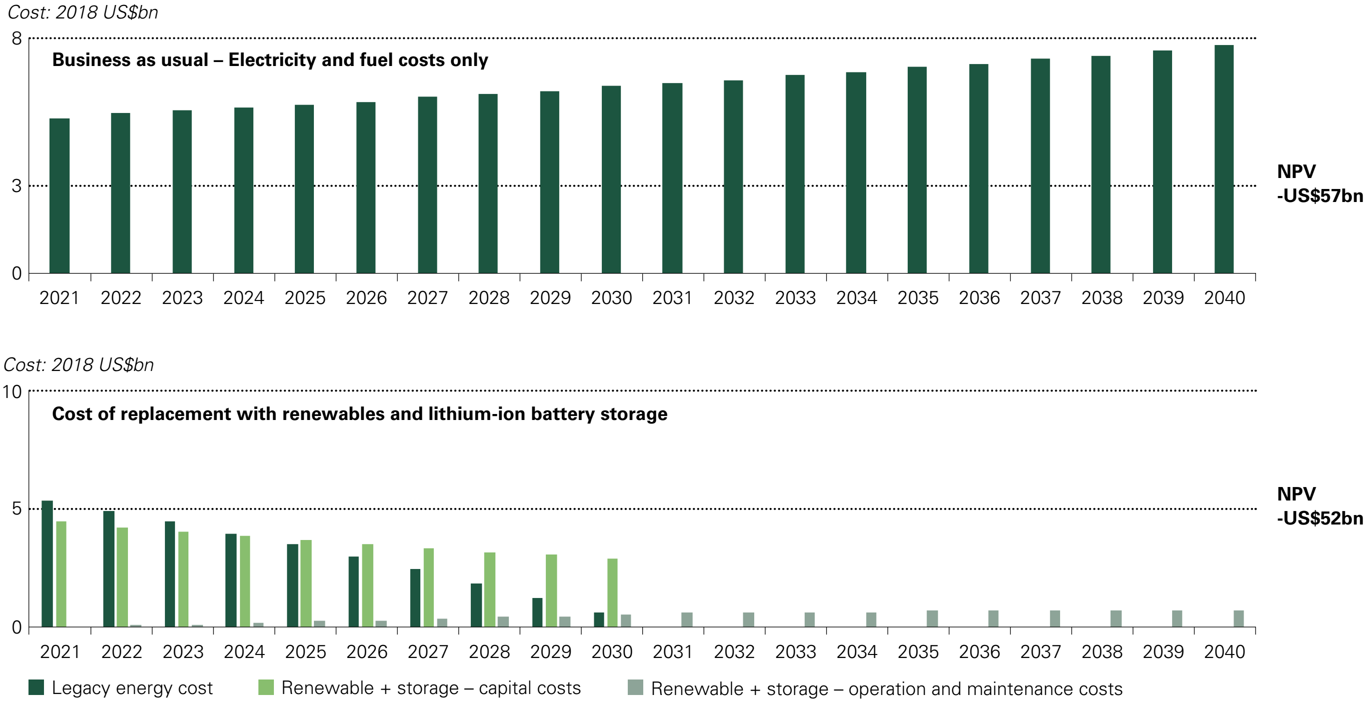
In addition, each mine site and each company will have its own specific set of factors that will determine which technologies and commercial factors are relevant and attractive.

In order to keep our approach simple, we modelled the economics of replacing all electricity demand with a mix of onshore wind and solar PV, backed with lithium-ion batteries. These are currently the most widespread and best-performing technologies on a global basis, and we believe it is reasonable to assume that any alternative technologies would have to reach at least the same cost and performance to compete – and, hence, that our economic model is conservative with respect to alternative energy technologies.

(Further details regarding our assumptions in calculating energy demand can be found in *Appendix 2 – Methodology note 4 – Assumptions in energy demand calculations.)*

We recognise that there is considerable uncertainty around the future costs of energy from both conventional and renewable sources. Nonetheless, given the ongoing trends in the costs of renewables and storage, our analysis indicates that replacing conventional electricity supplies with renewable energy and storage over the next decade is likely to be NPV positive for the gold industry, with net discounted cashflows potentially around 10% lower than the cost of purchased electricity and/or fuel purchased for electricity generation over the period.

Chart 5: Estimated costs of current electricity demand from gold production 2021-2040, business as usual vs. replacement with renewables and storage (50M MWh per year demand)



Source: World Gold Council analysis. Assumptions and underlying data sources are set out in Appendix 2; *Methodology note 3 – Assumptions in energy demand calculations*

Many gold mining companies already understand the business case supporting the move to renewables and have taken significant steps in this direction, as described in more detail in the comments on *Gold industry progress* below.

This indicative analysis suggests that deploying the scale of renewable energy and storage required by the gold industry might require in the order of US$35bn-70bn from 2021-2030 – that is, US$3.5bn-7bn per year. This value-creating investment should, in theory, be attractive to shareholders and/or providers of finance. It is nonetheless a significant capital requirement compared to current industry capital expenditure of the order of US$20bn[41] per year. (For details of the methodology behind these figures and our modelling of the economics of renewable energy sources, see *Appendix 2; Methodology note 4 – Assumptions in energy demand calculations.*)

Gold industry progress

The gold industry – and the mining industry more widely – is already starting to take advantage of the opportunities to reduce emissions. For example, The Rocky Mountain Institute's *"Sunshine for Mines"* programme is partnering with mining companies to help them integrate renewable energy, zero-carbon hauling, and process innovation into their businesses. As part of this initiative, they track global installations of renewable energy at mine sites. As of 2018, their data shows 62 metal mines with a combined 2.2GW of renewable generation commissioned or announced; 21 of these are at gold-producing mines, with a combined total of 500MW renewable generation capacity.[42]

Our member companies[43] have made significant progress in recent years in implementing greater energy efficiency and transitioning to renewable energy sources. We described a number of such industry initiatives in our previous report,[44] but there has been substantial progress since then, including the following examples, which we believe are indicative of a clear commitment to strategic change across the gold mining sector.

Image: Johanna Montoya on Unsplash.

Agnico Eagle is currently working with a coalition of Inuit representatives and businesses to look at alternative energy sources in Nunavut. At present the region is totally reliant on diesel fuel for energy. The long-term goal of the coalition is to build hydroelectric transmission and fibre-optic infrastructure to deliver a cleaner, more sustainable energy across the region and for the benefit of future generations. A similar initiative in Mexico is poised to bring a steady supply of electrical power to the La India mine, while also benefiting local communities and families.

Barrick, recognising that adapting to climate risks is an opportunity, – to reduce energy usage, maximise renewables and make significant cost savings – has implemented a number of key changes at its mines, including:

- Enabling 64% of the energy requirements at the Kibali mine in the DRC to be met by three hydropower stations
- Introducing solar power to the Loulo-Gounkoto complex
- Introducing sensors to the Kibali and Loulo-Gounkoto properties to automatically switch off lighting and ventilation when no workers or machinery are present
- Using waste heat recovery systems to achieve higher efficiencies from the natural gas fired generators at the Nevada site and at the Pueblo Viejo off-site power plant
- A commitment to setting a science-based greenhouse gas emissions reduction target in 2019.

41 Extrapolating from the 2018 and 2109 capital expenditure of the world's top 30 gold mining companies, as estimated by S&P Global Market Intelligence, April 2019.

42 Kirk, Thomas and Jessie Lund. *Decarbonization Pathways for Mines: A Headlamp in the Darkness,* Rocky Mountain Institute, 2018. https://info.rmi.org/pathways_for_mines/

43 www.gold.org/who-we-are/our-members

44 *Gold and climate change: an introduction* (2018) World Gold Council.

Centerra, at its Mount Milligan mine in British Columbia, Canada, has recently entered into a partnership with local electricity company, BC Hydro, aimed at delivering more energy efficient methods. BC Hydro will fund research into energy-related solutions and delivery mechanisms, such as variable speed motors for milling operations.

Of immediate practical impact, Centerra has also implemented a 'no idling policy' for on-site vehicles. This policy is becoming recognised good practice at gold mine sites. It ensures unnecessary fuel consumption is eliminated – and when one considers a single 797F haul truck consumes 50 litres of diesel an hour when idling, the significance becomes obvious.

Eldorado has been improving energy efficiency at its Kisladag site in Turkey, upgrading its fleet of mining equipment to use electric power. This has resulted in a significant decrease in diesel costs and an increase in energy efficiency (with an estimated 26% reduction in loading energy consumption per tonne of rock moved).

IAMGOLD's hybrid 15MW solar-diesel plant at its Essakana mine in Burkina Faso, described in our previous report, has proved a great success. The largest solar plant in sub-Saharan Africa, it was expected to contribute to a reduction in the mine's fuel consumption of approximately six million litres per year, reducing its annual CO_2e emissions by nearly 18,500 tonnes. As of 31 December, 2018, with only seven months of service, it was exceeding expectations and targets, saving approximately 3.9 million litres of fuel and reducing CO_2e emissions by approximately 12,000 tonnes.

Kinross reported that the energy efficiency projects it implemented in 2018, such as the mine road redesign at the Tasiast mine in Mauritania (which reduced the length of hauls and lowered diesel fuel use), resulted in an annual reduction of 10,000 tonnes of CO_2.

Kirkland Lake Gold's Macassa Mine in Canada first introduced electric trucks and scoops underground in 2012. Currently, Macassa has 24 electric scoops and 8 electric haul trucks, resulting in 80% of the production being handled by battery electric vehicles. This significant commitment to battery equipment reduces greenhouse gas emissions at Macassa by approximately 2,400t CO_2e/year compared to if the mine used only diesel equipment. Macassa has achieved some of the lowest carbon intensity rates in the industry, approximately 50kg of CO_2-e per ounce of gold. In addition to lower emissions, battery-powered equipment offers Macassa many other benefits, including improved economics (lower operating and ventilation costs), as well as better, cleaner and quieter working conditions. With the success at Macassa, Kirkland Lake Gold is now looking to introduce battery mobile equipment at other sites, both in Canada and Australia.

Newcrest announced a new Climate Change Policy in 2019 and several associated measures to mitigate climate-related challenges, including a GHG emissions intensity target of 30% reduction by 2030 and the introduction of internal shadow carbon prices of US$25 and US$50 per tonne of CO_2e in jurisdictions where there is no formal carbon pricing regime.

Essakana mine. Image courtesy of IAMGOLD.

Electric underground equipment at Macassa mine. Image courtesy of Kirkland Lake Gold.

The company is assessing options to use renewable power generation and low emission technologies, which will reduce its GHG emissions intensity, while improving productivity. Innovative mine design also has the potential to reduce energy demand at site, and other initiatives to reduce emissions include:

- Coarse ore flotation, which allows grind size to be coarser, reducing power usage
- Autoclave partial oxidation, which reduces oxygen and power needs
- Opportunities for liquid natural gas to replace heavy fuel oil
- Oxygen storage bullet to reduce oxygen venting and save power
- Ore sorting to reduce the amount of material to grinding circuit, which lowers power
- Geothermal upgrades to increase geothermal production.

Newmont Goldcorp has set a public target to reduce its GHG emissions intensity by 16.5% by 2020[45] and has implemented a range of initiatives, as part of an integrated global energy and climate strategy (and the company's Full Potential continuous improvement programme) aimed at delivering on this commitment. It is also assessing science-based targets and potential transition pathways to 2030.

Kisladag mine. Image courtesy of Eldorado.

In our previous report we described the company's Tanami power project in Australia, which was nearing completion. The plant has since been successfully commissioned, providing the mine with a reliable energy source while lowering associated costs and carbon emissions by 20%.

In Ghana, Newmont Goldcorp has installed a 120-kilowatt (kW) solar plant that will power the Akyem mine camp and mess hall during daylight hours. It has a 25-year asset life and is re-deployable, so it can be disassembled and moved to another location at closure. Initial data show considerable cost, environmental and social benefits. Over five months, the plant produced more than 75,000 kWh of solar energy, resulting in an emissions reduction of more than 32,000 kg of CO_2e. The plan is expected to produce energy at half the cost of grid power.


Newmont Goldcorp's Borden mine has been designed to integrate a range of energy efficiency technologies, including ventilation on demand, electric underground equipment, the elimination of compressed air networks and a switch to compressed natural gas instead of propane for heating.

45 Measured from a 2013 base year.

In Argentina, over 20% of the electricity supply at Cerro Negro now comes from renewable energy produced by a third-party wind farm. During the first eight months of the project approximately 12,000 tonnes of CO_2e was saved, which is an 18.5% reduction in emissions intensity (kg CO_2e/tonne moved). Over the next decade, the percentage consumption of clean energy at Cerro Negro will gradually increase to 38,000 MWh/year, meaning that 35% of electricity used at the site will come from renewable energy.

Pretivm Gold are reducing their diesel consumption at the Brucejack mine in Canada via construction of a transmission line to connect the site to the provincial hydro-based power grid.

Beyond our membership, other gold mining companies are also making substantial progress in implementing energy transition strategies. Use of solar PV technology has been rapidly making an impact. For example:

B2Gold has installed a 7MW solar plant at its Otjikoto mine in Namibia. Prior to this, the mine obtained all its energy requirements from heavy fuel oil (HFO) diesel generators. Both B2Gold and the local government perceive the solar plant as delivering positive economic, environmental and social impacts that are likely to outlive the life of the mine. B2Gold has also initiated the construction of a 30MW solar power plant at its Fekola mine in Mali, expecting to substantially reduce operating costs and greenhouse gas emissions.

Gold Fields continues to develop an onsite 40MW PV array at its South Deep site in South Africa, using a long-term power purchase agreement with a renewable developer, to provide nearly 20% of its electricity needs.

Gold Fields also recently commissioned a gas (16MW)/solar(4MW)/wind(18MW) and battery (13MW/4MWhr) micro-grid at its Agnew Gold Mine in Western Australia. The micro-grid can provide up to 54% of the mines' electricity needs, abating some 40,000 tonnes of CO_2-eq per annum. And at its Granny Smith Mines, also in Western Australia, Gold Fields has started construction of 7MW with a 2MW/1MWHr battery unit, expected to abate some 9,500 tonnes of CO_2-eq per annum.

Beyond the mine

In outlining the practical options available to the gold sector that could facilitate the move towards net zero carbon targets we have, as explained above, focused on mining as it generates the bulk of emissions. However, in gathering the data for this study, we have encountered evidence that other market segments – namely, refiners and jewellery fabricators – are also seeking to reduce emissions, even though their emissions levels are relatively low. Although many market players are taking their very first steps towards decarbonisation, and as yet little data exists on their progress, we hope some of the options for energy efficiency and transition highlighted here may also prove applicable to their operations.

3: Gold as an investment and climate-related risks

Gold is increasingly used as a mainstream financial asset by a wide range of institutional investors. For example, the world's central banks have, over the last decade, become regular buyers of scale, purchasing around 4,750t of gold since 2010, currently worth around US$200bn. Since the launch of gold-backed exchange-traded funds in 2003, the total assets under management of these products has grown to represent 2,600t of physical gold. Private investors have accumulated even larger volumes of gold; in excess of 16,200t of bars and coins, valued at around US$685bn, since 2000. Over the same period, total annual investment demand in gold has grown 438% in tonnage terms and over 2,346% in US$ value.[46]

The increased use of gold in investment portfolios and gold's more strategic role in global finance mean investors need a better understanding of the potential impacts of climate-related risks – and opportunities – as they might impact gold, alongside the other assets they own or manage.

Investor and regulatory pressure

As the World Gold Council has previously noted,[47] a range of investor-led groups has emerged in recent years, focused on ensuring effective action on climate change, and the collective influence of institutional shareholders (with a combined AUM of well over US$34trn)[48] is now reshaping the energy and climate-related policies of many industries.

Investment strategies and asset allocation decisions are now reshaped to ensure portfolios are more resilient to the financial impacts of climate change. In 2017, the United Nations' PRI (Principles for Responsible Investment) investor group published a guide[49] detailing many of the avenues currently available to institutional investors who want to align their portfolios with the transition to a lower carbon economy. The guide also offered plentiful examples of how major investors are seeking to benefit from shifting cost curves for renewable energy, advances in technology (such as battery storage and electric vehicles), and rapidly evolving regulatory and societal expectations.

46 Investment volumes and values at 1 August 2019.

47 *Gold and climate change: an introduction* (2018), World Gold Council.

48 US$34trn is the AUM currently associated with the members of Climate Action 100+; other key investor groups include the UN-backed Principles for Responsible Investment (PRI); Transition Pathway Initiative; the Sovereign Wealth One Planet Initiative, and many more. These groups have numerous members and co-ordination between them has become a feature of investor stakeholder engagement on climate action in recent years.

49 *How to invest in the low-carbon economy* (2017), PRI.

Closely related to these initiatives, the Taskforce on Climate-related Financial Disclosures (TCFD) now plays a pivotal role in offering companies a coherent platform for their responses to the ever-growing demands for greater consistency and transparency on climate-related risks and opportunities. Around 800 public- and private-sector organisations now publicly support the TCFD's work, including global financial firms responsible for assets in excess of US$118trn.

Climate change is now recognised not only by companies, but also by their investors and clients, as material to operations and of potential impact on both the asset and liability sides of their balance sheets. Consequently, companies must demonstrate their understanding of the relevant risks and opportunities, and reveal their plans for appropriate action.

Financial regulators are also increasingly formalising these requirements for greater disclosure, with the expectation that investors should now consider the materiality of climate-related risks as a core component of their fiduciary duties. There are strong indications that climate-related financial disclosures are likely to become mandatory over time.

Climate scenarios and economic performance

The potential macro-economic impacts of the IPCC climate scenarios are varied and far-reaching, but nearly all suggest a significant disruption to supply and demand dynamics, productivity and economic growth. This has important implications for investor considerations of how to protect the value of long-term portfolios.

"Our findings demonstrate that changes in temperature have substantially shaped economic growth in both rich and poor countries over the last half century, and that future warming is likely to reduce global economic output, relative to a world without climate change."

Global Non-linear Effect of Temperature on Economic Production; Burke, Hsiang and Miguel, Nature (2015).

"Impacts on future assets will come not merely through direct, physical harms but also from weaker growth and lower asset returns across the board. The interconnected nature of the problem will reduce returns, even on investments unharmed by physical damage… Although direct damage will be more localised, indirect impacts will affect the entire global economy."

The cost of inaction: Recognising the value at risk from climate change (2015), Economist Intelligence Unit.

The Economist Intelligence Unit has previously calculated that the value of global investment portfolios to 2100 would likely fall between US$4.2trn and US$13.9trn due to inaction on climate change.[50] Losses in warmer scenarios would be far greater, and these estimates relate purely to portfolio values – they do not include probable associated social costs. Analysis by academics at the University of Cambridge Institute for Sustainability Leadership suggested market valuations driven by growing awareness of future climate risks could lead to economic shocks and losses of up to 45% in the value of an equity portfolio (and 23% in a fixed income portfolio).[51] Citigroup, seeking to quantify the cost of inaction on climate change, estimated that the cumulative 'lost' GDP to 2060 equated to around US$44trn.[52] And a report from Stanford University and UC Berkeley,[53] published in the same year (2015), found that climate change impacts, if not tempered by intervention and adaptation strategies, could result in a 23% drop in total global income by the end of the century.

50 US$ values as at 2015. *The cost of inaction: Recognising the value at risk from climate change* (2016), EIU.

51 *Unhedgeable risk: How climate change sentiment impacts investment* (2015) CISL.

52 *Energy Darwinism II: Why a Low Carbon Future Doesn't Have to Cost the Earth* (2015), Citigroup.

53 *Global Non-linear Effect of Temperature on Economic Production*, Burke, Hsiang and Miguel, *Nature* (2015). See also https://news.stanford.edu/news/2015/october/climate-change-cost-102115.html

Climate-related risks and portfolio performance

There is clearly a pressing need to integrate a greater understanding of the physical and transition risks associated with climate change within wider investment thinking.

Two key perspectives should be considered when evaluating an investment in the context of climate change: how it might contribute to climate change and how it might be affected by particular climate-related risks. We may also question how this asset compares with other investments within a portfolio and how it contributes to the portfolio's overall risk-return profile.

We have already described in an earlier section (see Section 1: *Gold's carbon footprint*), the relatively small scale of gold's total emissions, particularly when viewed from a value perspective, and how gold's downstream (Scope 3) emissions are relatively immaterial.

We have also described (in Section 2: *Net zero transition pathways for the gold supply chain*) how the gold supply chain might take practical and cost-effective steps to reduce its carbon footprint much further.

We therefore focus here on how gold's value and profile as an investment asset might be affected by specific risks associated with climate scenarios. Our analysis also considers how other mainstream assets which represent a substantial proportion of current portfolio holdings perform under the same scenarios.

Our initial research into gold's possible climate change impacts uncovered preliminary analysis into how a gold holding might impact the carbon footprint of a mainstream (US equity) portfolio over time. This work concluded, tentatively, that gold ownership, due to the minimal ongoing emissions likely associated with bullion investments, might help balance or offset the accumulated emissions associated with the majority of other assets in a portfolio.[54]

While we have made significant contributions to the substantial body of empirical work able to demonstrate that gold has a measurable positive impact on the risk-adjusted returns of a balanced portfolio of diverse assets, we have not previously considered how climate-related impacts might affect these findings.

Although our previous research highlighted a dearth of reliable data on gold's climate change impacts and we found very little discussion of climate-related impacts on gold's performance as an asset, there has, fortunately, been significant work over recent years on the climate change implications for wider portfolio performance. Many of the major investment and risk management advisory consultancies[55] have produced detailed analytical frameworks to guide their institutional clients in incorporating climate risk management into their strategic plans and metrics. We have therefore sought to align our analysis and methodology to these approaches, focusing on the assessment of asset sensitivity to climate-related risks and scenarios.

Asset sensitivity to climate-related risks and scenarios

This analysis examines the exposure of different investment assets, including gold, to four different IPCC climate-related scenarios: 1.5°C, 2°C, 3°C; and 4°C, and the potential impact on returns to year 2030, 2050, and 2100 in comparison to the current base year of 2019. The climate-related impacts of a 1°C global average increase in temperatures are already being felt and impacts are going to increase no matter which scenario transpires. This analysis examines the potential impacts on assets, in terms of return sensitivity, in addition to any climate-related factors that we are already experiencing. Climate change impacts will not be evenly distributed; some sectors will be more profoundly affected than others, putting some economic activities and assets more at risk than others. For example, fisheries and countries in the tropics are expected to be particularly susceptible to impacted economic growth.[56]

54 Baur & Oll, *The Role of Gold and the VIX in Investment Portfolios – A Financial and Sustainability Perspective* (2017).

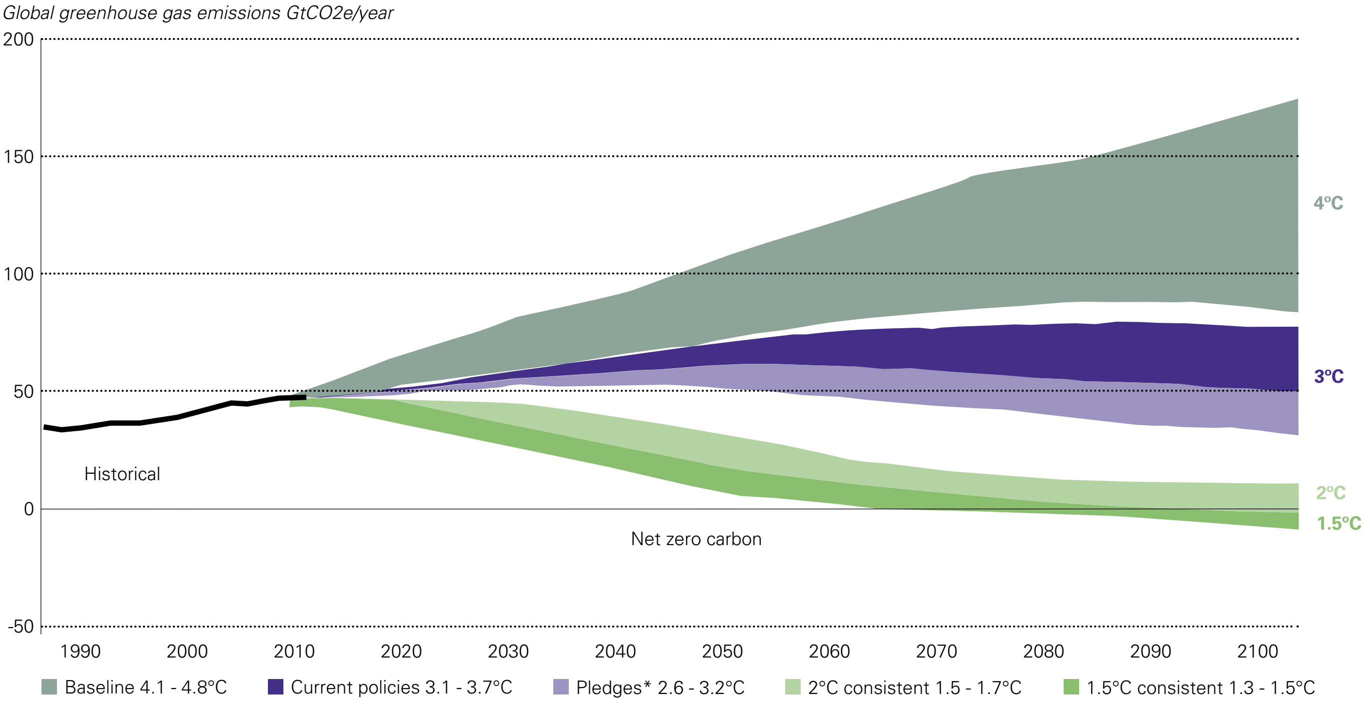
55 Mercer has been the most significant source of research on climate impacts on asset allocation: *Climate Change Scenarios – Implications for Strategic Asset Allocation* (2011); *Investing in a Time of Climate Change* (2015); *Preparing for Transformation: Assessing the Prospective Investment Impacts of Low Carbon Economic Transition* (2017); *Investing in a Time of Climate Change; The Sequel* (2019), all Mercer. But consideration of climate change as a major investment risk is now becoming more widespread – see, for example, *Risks and Opportunities From the Changing Climate – Playbook for the Truly Long-Term Investor* (2015), Cambridge Associates; Schroders' *Climate Progress Dashboard* – specifically, its Carbon VaR framework (www.schroders.com/en/about-us/corporate-responsibility/sustainability/climate-progress-dashboard/carbon-var/)

Note that climate-related liability issues are now preoccupying major insurance companies and many major legal and tax advisory firms have published strategic guidance on climate-related risk management issues.

56 *Special Report on Global Warming of 1.5°C* (2018), IPCC; www.ipcc.ch/sr15/

2100 Warming Projections

Chart 6: Emissions and expected warming based on pledges and current policies



* Government pledges, targets and nationally determined contributions (NDCs).

Source: Climate Action Tracker

Methodology

Our approach is broadly similar to that taken by several leading investment consultancy firms,[57] in that it assesses climate-related implications for an investment based on an evaluation of asset sensitivity to risk factors and scenario pathways. At the methodological level, we have developed an approach based on established risk assessment techniques to assess the assets in terms of the likelihood of them being impacted by the transition and physical criteria under each scenario, and the likely magnitude of that impact. This is in line with commonly used risk assessment weightings and is the same as the definitions used for climate-related risk disclosures by CDP (formerly the Carbon Disclosure Project).

To enable clearer analysis and accentuate the results, we initially focused on the two extreme positions of 1.5°C scenario transition impacts in 2030, and 4°C physical impacts in 2100.

Our analysis also included consideration of a range of mainstream asset classes and key sectors, as summarised below. This allowed us to arrive at a comparative evaluation of gold's relative sensitivity to specific climate-related risks, as measured against the return expectations for other assets under the same scenarios.

(For further details on our methodological approach and asset class definitions see *Appendix 3 – Climate scenarios and macro-economic impacts* and *Physical damage and transition milestones.*)

Sensitivity of asset class returns to climate-related scenarios

- In general, transition impacts will be more prominent in earlier timeframes and therefore affect asset classes more acutely in rapid transition (1.5°C and 2°C) scenarios. However, physical-related risks are then most prominently borne out in the higher temperature (3°C and 4°C scenarios) where impact overshadows transition aspects.

57 See *Investing in a time of climate change* (2015) and *Investing in a time of climate change: the sequel* (2018), both Mercer.

Table 4: Key findings – asset sensitivity to climate scenarios and return expectations

Sensitivity of annual returns	2030				2050				2100			
	1.5 °C	2 °C	3 °C	4 °C	1.5 °C	2 °C	3 °C	4 °C	1.5 °C	2 °C	3 °C	4 °C
US Bond Aggregate	↓	↓	↓	↑	↓	↓	↓	↓	↓	↓	↓	↓
US Stocks	↓	↓	↓	↑	↓	↓	↓	↓	↓	↓	↓	↓
EAFE Stocks	↓	↓	→	↑	↓	↓	↓	↓	↓	↓	↓	↓
Emerging Market Stocks	↓	↓	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓
Commodities	↓	↓	→	↑	↓	↓	↓	↓	↓	↓	↓	↓
Gold	↑	→	↑	↓	↑	↑	↑	↑	↑	↑	↑	↑
Real Estate	↑	↑	↑	↑	↓	↓	↓	↓	↓	↓	↓	↓

Assets that are relatively neutral in the context of a particular scenario, and may be expected to deliver similar annual average returns to those expected under current/historical market conditions.

Assets that may be more robust and benefit from specific factors or opportunities associated with a scenario, potentially delivering increased returns.

Assets that are more vulnerable to scenario 'downside' risks, less likely to be able deliver expected returns (and more likely to be loss-making).

Source: Anthesis; World Gold Council

- Bonds are expected to be generally less affected by transition or physical-related impacts than Stocks because they comprise assets such as Sovereign Bonds that are not deemed to be as sensitive to climate risk at an aggregate level (they are driven by other macro-economic factors), with possible exceptions, such as Japan and New Zealand.[58]

- Fossil fuels and carbon intensive industries, such as industrials and mining, are expected to perform worst under rapid transition (1.5°C) scenario to 2030, but better under slower transition scenarios. These sectors relate significantly to Stock and Commodity assets/indexes. Strategic metals needed to support urgent transition infrastructure may be the exception, as demand will likely surge.

- US stocks (see <u>*Appendix 3* – *Asset selection*</u> for further details) are diverse, but the US economy appears to be less prepared than the European markets for rapid transition, so broad equity performance may fare worse than EAFA and Emerging Market Stocks that are more flexible to policy changes.

- While Commodities are likely to be significantly impacted across the board, they are stronger in 2030 3°C and 4°C scenarios because there are limited physical impacts through this period and only minor transition changes (i.e. limited change in policy, regulations and carbon tax with respect to fossil fuels, mining, and farming; therefore, financial returns on these commodities remain positive).

- 3°C to 4°C scenarios will negatively affect most Stocks in 2050 to 2100 where physical impacts cause damage to physical infrastructure, supply chains and reduce productivity. This is particularly noticeable for Agriculture/Food/Soft Commodities, and Energy and Utilities but also plays through to sectors such as Finance due to impacts on economic growth. In terms of Infrastructure, some sectors, such as Information Technology and Telecommunications, may be less impacted, partially buoyed by their diversity.

- Gold may lose some investment flows to low carbon transition sectors in 1.5°C scenario (due to the very substantial volumes of investments required in low carbon transition sectors). However, it generally performs well across most scenarios, due in part to its traditional role as a safe haven market insurance. (See *Gold – implications and explanations,* below, for a more detailed discussion of gold's likely response in the face of climate-related risks.)

- Real Estate has less immediate sensitivity to transition risks and only suffers more negative impacts related to physical risks in more extreme, higher temperature weather scenarios.

- However, climate-related impacts on the valuation of coastal property are already starting to become evident, suggesting Real Estate climate risk sensitivity may be far more acute and immediate in some regions.

58 *Investing in a time of climate change* (2015), Mercer.

Gold – implications and explanations

Our key finding relating to gold is that it is likely to exhibit a relatively robust performance across all climate scenarios (see key findings below).

Negative impacts on return expectations

Risk factors that could negatively impact gold's performance as an asset include an erosion of consumer confidence and shrinking discretionary spending levels, particularly in developing economies. And the urgent diversion of investment to either build net zero carbon infrastructure (as part of transition strategies) or to repair, replace or reconstruct resources in the face of physical damage, may significantly limit gold investment demand.

The scale of this latter challenge – the potential 'crowding out' of private investment and the disruption to funding and credit that might be associated with the diversion of capital – is substantial. For example, the World Economic Forum (WEF) estimated in 2013 that US$5.7trn would need to be invested annually in green infrastructure to 2020 to enable the move towards a 2°C scenario. The majority of this sum was expected to be transferred from 'business-as-usual' investments. The fact this trend has not been witnessed in any substantial way since the WEF authored its report suggests any such shift in investment will have to be scaled-up and accelerated aggressively if it is to be effective. We might expect these transitional periods – characterised by the rapid redirection of capital and investment flows – to potentially depress the near-term prospects for gold. But gold mining companies, rather than bullion-based assets, are likely be the most immediately impacted. In rapid transition scenarios many mines may not have the financial resources to decarbonise at speed. This may result in mines shutting down or reducing production due to, for example, high carbon taxes.

However, many of these risks are perceived as a lower probability, and of less magnitude or duration, when applied to gold; when considered in association with most other assets and sectors the likely impacts are typically more pronounced.

"Gold is likely to exhibit a relatively robust performance across all climate scenarios."

"Climate-related physical risks are less likely to threaten the relative stability of overall gold supply than is probably the case for most commodities."

Reasons for gold's resilience

Gold's robust response is, at least in part, likely a reflection of some of the structural factors regarding gold market dynamics and drivers that have traditionally underpinned the investment case for gold. Unlike most other metals, demand is uniquely diverse and not concentrated in any particular sector or geographic region. Furthermore, as a commodity, a culturally significant luxury good and a monetary asset, gold's value drivers are not simply an expression of the supply/demand balance. This makes it remarkably robust as a store of value, even in the face of extreme conditions and duress in the wider markets and economy.

And supply is similarly diverse, spread across all continents and not limited to newly mined gold. As discussed above (in section 2, *Net zero transition pathways for the gold supply chain*), gold mining is potentially well placed to adopt energy transition and emissions reduction strategies. The industry already has a history of having to adapt to relative self-sufficiency in inhospitable locations and conditions. While the physical risks associated with the more punishing climate scenarios would doubtless impose significant challenges to many operations, these are less likely to threaten the relative stability of overall supply than would likely be the case for most other commodities. The very significant and well-established role of recycled gold to supplement mine production and offer a relatively elastic source of supply, is another stabilising aspect of the gold market. Any climate-related decline in mine production levels, perhaps associated with severe physical risks, is therefore less likely to have a direct impact on gold's volatility and value.

Another factor that supports gold's ability to outperform under periods of market stress is that it is underpinned by a far more liquid market than is the case for many other commodities, 'real' assets or portfolio diversifiers. The growth in multiple regional trading venues for gold across the world may also help ensure continuity of access and trading.

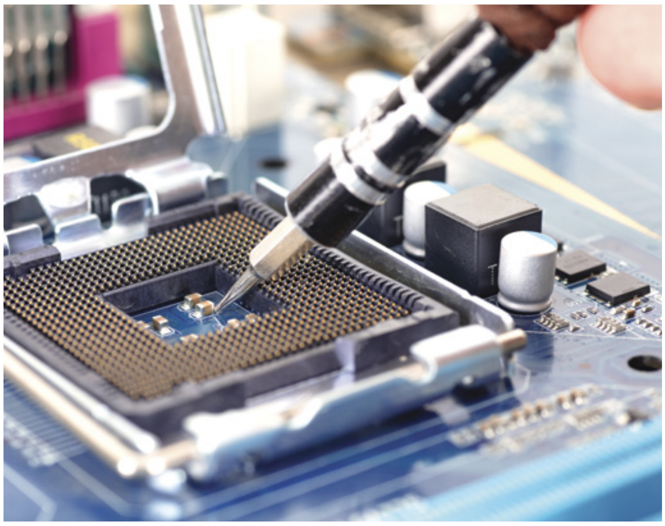
Gold as a climate risk mitigation asset

The case for gold as potentially helping to reduce over time, portfolio contributions to climate change rests on the following:

- On a value basis, gold's GHG intensity is relatively low
- Gold's downstream uses – gold in bullion, jewellery, and electronic products – have no material impact on either gold's overall carbon footprint or global GHG emissions
- The current primary source of GHG emissions in the gold value chain – energy use in gold production – can transition towards a net zero pathway in a practical and cost-effective manner
- Gold's risk-return profile and its sensitivity to climate-related physical and transition risks looks relatively robust, particularly in comparison to many other mainstream assets.
- Gold's roles as a risk hedge, portfolio diversifier and market insurance asset are well documented; heightened market volatility and uncertainty from climate-related risks should therefore be supportive of gold.

These findings, and our explanation of the relatively robust outlook for gold in the face of climate-related risks, are also broadly compatible with a range of research from the World Gold Council on gold's role in contributing to optimal portfolio performance. We have repeatedly demonstrated gold's potency as a diversification asset and its relative outperformance of many mainstream assets when specific risk factors impact their valuations.

Suggestions that climate change will likely be an additional constraint on global economic growth, which has already proven to be weak and vulnerable over the last decade or so, might support further investor interest in gold. The likelihood that return expectations could be lowered across a wide range of asset classes, except for sectors potentially boosted by the transition economy, may reinforce trends we have seen in recent years when investors, faced with an expanding set of zero or negative yield-bearing assets, have turned to gold as an alternative source of returns. The prospect that market volatility could also be amplified by, for example, extreme physical impacts on particular sectors and supply chains, should also bolster gold's safe haven appeal.



Over the longer-term, one of the primary drivers of gold market growth and value is economic expansion and wealth creation in its key physical markets. Any climate-related risks which may consequently, depress local economies and consumer confidence and therefore dampen or disrupt physical demand for gold, could a represent a headwind. However, the growing significance of gold as an investment (and risk management) asset may well offset any such headwinds and, given the range and magnitude of potential climate-related risks and their likely impacts across different asset classes, gold's relative insulation from these risks could emerge as a key driver of value.

Furthermore, the substantial opportunities for gold mining to accelerate moves towards decarbonisation (as documented in Section 2, *Net zero transition pathways for the gold supply chain*), suggest our previous estimates of the point in time at which a holding in gold will make a demonstrable contribution to reducing the overall carbon footprint of a mainstream portfolio[59] may now be judged to be overly conservative.

These considerations are all supportive of previous suggestions that gold, in addition to its traditional role as a diversification and market insurance asset, can play a positive role in balancing – and, over time, moderating – the climate risk exposure in a portfolio.[60]

Future portfolios

The World Gold Council has produced extensive research over many years analysing gold's contribution to optimal portfolio composition, with remarkably consistent results. Incorporating climate risk scenarios and associated return expectations into similar portfolio optimisation analysis is an area that warrants further examination. It may also offer investors some cause for optimism. There are already indications that redefining strategic asset allocation to focus on 'smart carbon portfolios'[61] with higher energy efficiency weightings could help investors avoid sacrificing financial returns as the global economy moves to decarbonise.

59 We previously calculated, using our best estimates of gold's annual GHG emissions, that if an investor holds an investment in newly-mined gold for nine years or more, the annualised GHG footprint of the investment is lower than the annual GHG footprint of an equivalent-value investment in the S&P 500.

60 Baur & Oll, *The Role of Gold and the VIX in Investment Portfolios – A Financial and Sustainability Perspective* (2017). Also, *Gold and climate change: an introduction* (2018), World Gold Council.

61 *Climate Change Investment Risk: Optimal Portfolio Construction Ahead of the Transition to a Lower-Carbon Economy* (2018), Benedetti et al. SSRN: https://ssrn.com/abstract=3281390 or http://dx.doi.org/10.2139/ssrn.3281390

Conclusions

This report has sought to address a number of issues first highlighted in our initial research on gold and climate change, by advancing our understanding of gold's current GHG emissions profile. However, we have also extended the scope and depth of our analysis to examine a range of key factors that might shape gold's future prospects in the face of climate change; namely, the gold industry's potential capacity to transition to a net zero carbon future and gold's potential resilience as an asset in the face of climate-related risks.

Specifically, our analysis has provided more accurate GHG emission estimates for all key parts of the gold supply chain. Using more granular and comprehensive data we have produced estimates for gold's overall carbon footprint and GHG intensity, on both a volume and value basis, that are more precise than our previous figures, but largely confirm and validate our 2018 findings.

We have also confirmed that gold's downstream carbon footprint is very small and relatively insignificant in terms of its likely contribution to climate change.

Looking more closely at GHG emissions levels within the gold supply chain, we have described what a net zero carbon pathway for the gold industry, aligned with Paris Agreement targets, may look like. This includes a detailed examination of the opportunities available to the industry, and gold mining in particular, to decarbonise and transition to a net zero carbon future. Our analysis also provides a range of evidence to indicate that these options are can be practical and cost effective.

Finally, we have explored how gold as an investment asset may perform in relation to a range of climate-related risks and scenarios. Our findings suggest that gold will likely demonstrate a strong degree of resilience, offering relative stability and consistency of returns in the context of both physical and transition risks. This contrasts with the relative vulnerability of many mainstream assets when exposed to a range of climate change scenarios, and the potentially significant negative climate impacts on portfolio returns over the medium and long term.

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Published: October 2019