



Horizon 2020
Programme

SCRREEN2

*This project has received funding from the European
Union's Horizon 2020 research and innovation programme
under grant agreement No 958211.*

Start date: 2020-11-01 Duration: 36 Months



FACTSHEETS UPDATES **BASED ON THE EU FACTSHEETS 2020**

GOLD

AUTHOR(S):

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GOLD

OVERVIEW

Gold (Au) is a dense, soft, malleable and ductile metal with a bright yellow colour and lustre. Gold, like silver and the platinum-group metals, is a noble and a precious metal. It has high thermal and electrical conductivity. It is rare in the Earth's crust with an estimated abundance of 0.004 ppm (Lide 2008). It is found in veins and alluvial deposits chiefly as the native metal, although it commonly occurs in a solid solution series with silver (as electrum) and alloyed with copper and palladium. Less commonly, it occurs in minerals as gold compounds, often with tellurium. Gold is a treasured material for jewellery, which is its most important use. In addition, gold is used as a common monetary standard in coins and bars, as a safe haven for storing wealth, for decoration, and as a plated coating on a wide variety of electrical and electronic equipment, as well as in dentistry and medicine (the radioisotope gold-198, with a half-life of 2.69 days, is used for radiotherapy in certain cancer treatments (Hainfeld et al. 2008)).

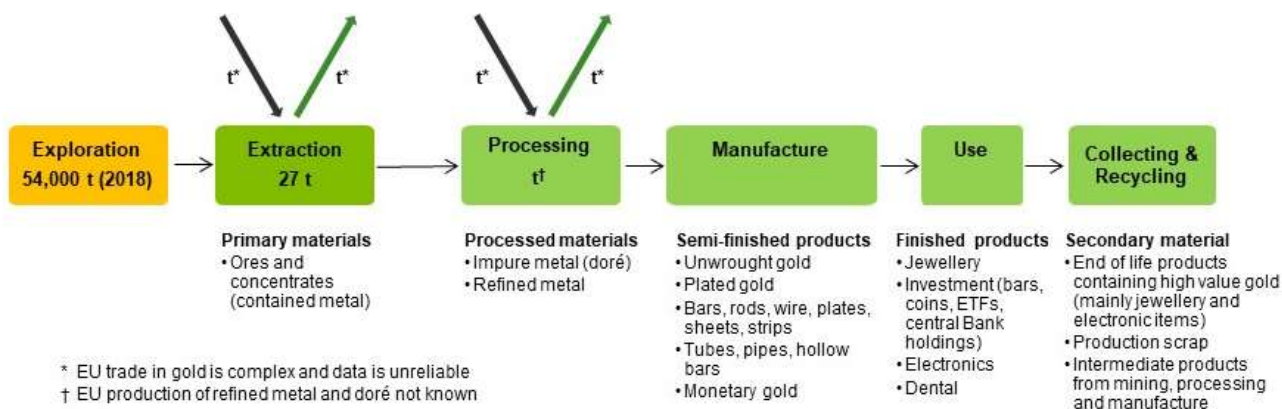


Figure 1. Simplified value chain for gold in the EU¹

Table 1. Gold supply and demand in metric tonnes (extraction stage), 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
3,302	China 12% Australia 9% Russia 9% USA 7% Canada 6% Ghana 4% Mexico 4% Peru 4% South Africa 4%	30	1%	Finland 27% Bulgaria 27% Sweden 24% Greece 6% Spain 5% Romania 2% Poland 2% Slovakia 1% RotW 5%	0

¹ JRC elaboration on multiple sources (see next sections)

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Prices: The gold price experienced an uptrend that commenced at the peak of the global financial crisis in 2008 reaching USD 1,600 per ounce levels in 2012. However, by 2013, the price fell down to USD 1,200 per ounce levels as investors stopped flocking to gold. In the first half of 2016, the gold price began to recover rapidly and peaked in the third quarter experiencing an increase of nearly 25% since the end of 2015. This price rise was due to increased investor demand resulting from global political uncertainties, particularly with the UK’s vote on EU membership and the US presidential elections. However, the price still remained below the average until the year 2019 when gold climbed meaningfully above the USD 1,300 per ounce mark. This was due to worries about an interest rate cut and the ongoing US-China trade war which increased investors’ interest in the precious metal (Healy, 2021).

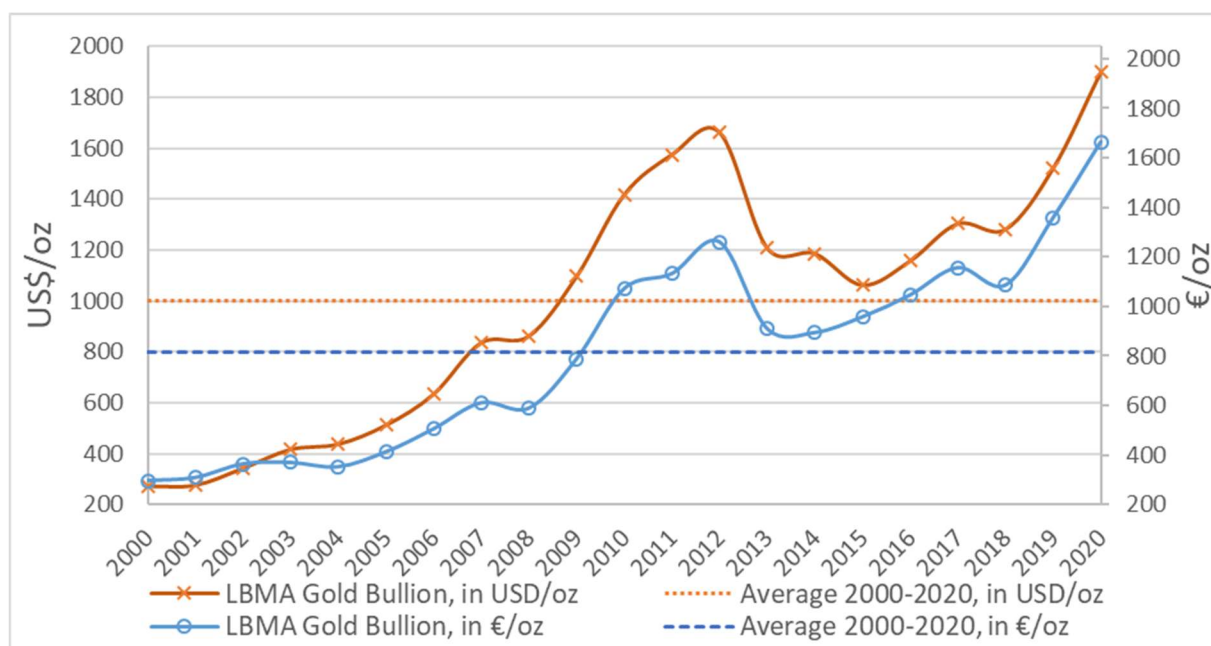


Figure 2. Annual average price of gold between 2000 and 2020 (USGS, 2021)².

Primary supply: The global gold production presents a significant increase the last decade. China, Australia, Russia, United States and Canada are the leading producers with 365, 327, 308, 193 and 182 tonnes, respectively in 2020. Gold produced in more than 80 countries in 2020, in most cases, at amounts ranged between few kg to few tonnes (WMD, since 1984). With annual production of 30 tonnes, the EU is self-sufficient in gold production at the extraction stage with Finland (29%), Bulgaria (28%) and Sweden (26%) for the main producers.

Secondary supply: While there are substantial stocks of gold in use comprising jewellery, central bank holdings, private investment and industrial fabrication, it is unlikely that much of this will ever re-enter the supply chain. The reasons for this are many and varied, but in general jewellery and religious artefacts are viewed either as sacred or as precious assets handed down from one generation to another. Central banks view gold as an important reserve asset and, in recent years, they have been more likely to buy than sell gold. In electronic devices, much of the gold is not recovered because they are not efficiently collected at the end

² Values in €/kg are converted from original data in US\$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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of their lifetime. The contribution of recycling to gold supply varies markedly with gold price. In 2009, as a result of high prices and global economic disruption, it peaked at 1,728 tonnes, equivalent to 42 % of total gold supply (Boston Consulting Group 2015). Since then, however, as prices have fallen and global economic recovery began, gold recycling has decreased. In 2014 it accounted for 26% of total supply. The total global gold supply in 2018 was 4,670 tons from which 23% come from refining of gold-containing scraps such as jewellery or coins and 3% came from the recycling of WEEE. However, it is difficult to obtain data on gold recycling processes, as the gold market as a whole tends to keep information intended for the public discreet. (Fritz et al., 2020; Hewitt et al., 2015)

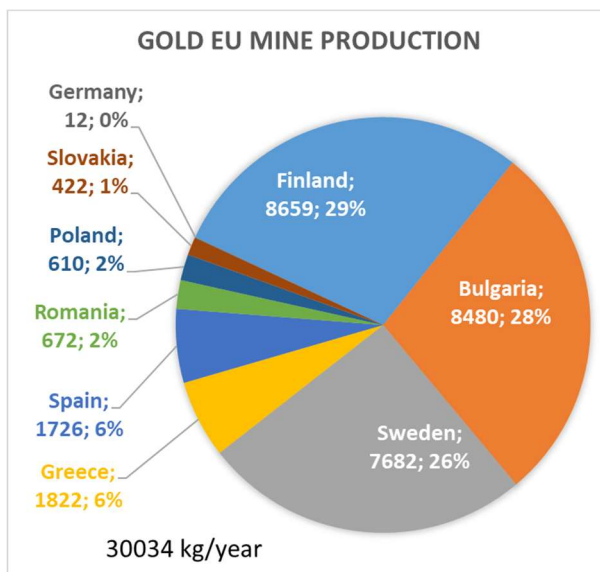


Figure 3: EU mine production of gold over 2016-2020 (WMD, since 1984)

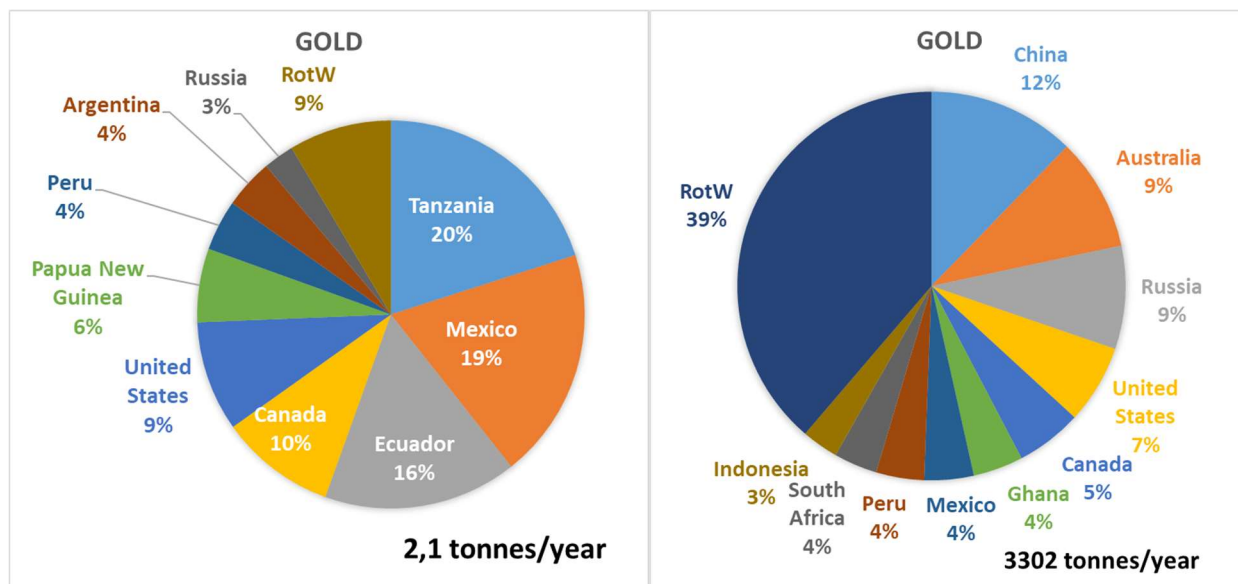


Figure 4. EU sourcing of gold (out of EU) and global mine production (2016-2020)

Uses: More than one third of the global gold demand in 2021 came from private investment and central banks (World Gold Council, 2022). For a criticality assessment, these ‘gold as an investment goods’ are not relevant,

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while the non-monetary and industrial applications are of interest. Accordingly, as in previous criticality assessments, only the latter applications will be taken into consideration. The major non-monetary end use of gold is jewellery, which accounted for more than 84 % market share.

Substitution: In jewellery, gold has no technical function and could theoretically be replaced by other precious metals such as silver or platinum, or by cheaper alloys. However, this is likely to be minimal in practice because the importance of gold in jewellery is long established and unlikely to change. In electronic devices, platinum, palladium and silver are possible substitutes for gold, but their uptake has been limited in the past, partly by their high prices. In dentistry gold is increasingly being replaced by ceramics and cheaper base metal alloys.

Table 2. Uses and possible substitutes

Use	Percentage*	Substitute	Comment on substitute
Jewellery	86.6 %	Silver, platinum, copper, and many more	Substitution unlikely due to cultural meaning
Electronics	11.2 %	Platinum, palladium, silver, copper	Similar or lower costs, similar performance**
Dental	0.5 %	Ceramics, base metal alloys	Similar or lower costs, reduced performance**

*Global non-monetary end use share in 2021 based in World Gold Council (2022)

** EC CRM 2023 data.

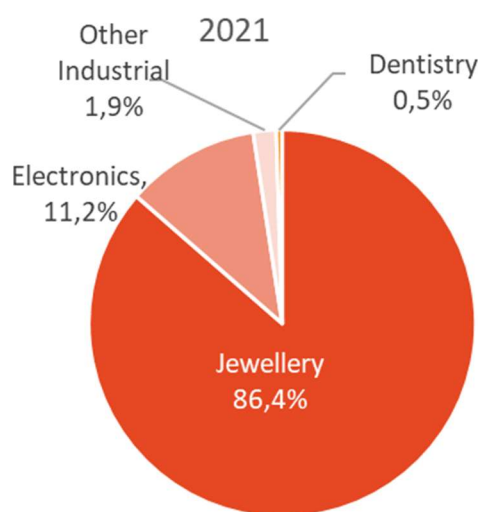


Figure 5: Global uses of gold

Other issues: In general, the toxic risks associated with gold are low in relation to the vast range of potential routes of exposure to the metal in everyday life, e.g. by wearing jewellery, dental devices or even through the food chain (Lansdown 2018). Gold falls under the scope of The Regulation (EU) 2017/821 (“Conflict Minerals Regulation”). The Regulation sets out legally binding due diligence requirements for EU importers of tin, tantalum, tungsten and gold that came into effect on 1 January 2021. The Regulation is to break the link between the trade in these minerals and metals, and armed conflicts and associated human rights abuses. The Regulation also provides transparency and certainty as regards the supply practices of EU importers sourcing from conflict-affected and high-risk areas. (EU 2022)

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MARKET ANALYSIS, TRADE AND PRICES

GLOBAL MARKET

Table 3. Gold (extraction) supply and demand in metric tonnes, 2016-2020 average

Global production	Global Producers	EU consumption	EU Share	EU Suppliers	Import reliance
3,302	China 12% Australia 9% Russia 9% USA 7% Canada 6% Ghana 4% Mexico 4% Peru 4% South Africa 4%	30	1%	Finland 27% Bulgaria 27% Sweden 24% Greece 6% Spain 5% Romania 2% Poland 2% Slovakia 1%	0

The way that gold is traded is quite complex and constantly evolving. The gold market is inherently global and gold is traded continuously throughout all time zones. The most important gold trading centres are the London OTC market, the US futures market and the Shanghai Gold Exchange (SGE). These markets represent more than 90% of global trading volumes and are complemented by smaller secondary market centres around the world (World Gold Council, 2022). Gold’s disparate trading centres around the world are linked as market participants drive convergence of local gold prices through arbitrage activity. However, there are still important distinctions across different countries such as trade restrictions, taxes on gold and differing bar standards such that a single integrated gold trading market does not exist (World Gold Council, 2019). In addition to that, the diversity of forms in which gold and its alloys are traded makes its marketability an even more complicated issue. Most gold is sold as refined gold bullion ranging in purity from 995-998 fineness, where fineness refers to the weight proportion of gold in an alloy or in impure gold, expressed in parts per thousand (“per mill”). By definition, 1000 fine is pure gold. Most gold bullion is traded on a 24-hour basis in over-the-counter (OTC) transactions. The governance of the market is maintained through the London Bullion Market Association’s (LBMA) publication of the Good Delivery List. This is a list of accredited refiners whose standards of production and assaying meet LBMA specifications. Only bullion conforming to these standards is acceptable in settlement against transactions conducted in the bullion market. Gold can also be traded in other forms including unwrought gold, plated gold, powder, granules, bars, rods, wire, plates strips, sheets, foils, tubes and pipes.

The global gold market is not dominated by any country. China is the leading producer of refined gold but its production is not that much higher compared to other producer countries. The most significant gold reserves are in Australia with about 20% of global share. The rest is distributed across various countries.

The biggest market players and top 5 producing companies are Newmont, Barrick Gold, Navoi Mining & Metallurgical, PJSC Polyus and Anglogold Ashanti (S&P Global, 2022). The global gold mining market was valued at USD 197.58 billion in 2021 (Research and Markets, 2022). 2020 was one of the most volatile years in modern history for the gold market due to various factors such as “*the pace with which the COVID-19 pandemic*

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spread, the severity of the lockdowns, the scope of global government stimulus efforts, and the extent of the equities market bounce” (Research and Markets, 2022). Gold is considered to always be in high demand irrespective of fluctuating economies which ensures that jewellery holds its value and is easy to liquidate when needed, thus propelling market growth.

Gold can be highly polished which, together with its colour and resistance to tarnishing, impart its ‘precious’ character, making it a treasured material for jewellery, which is its most important use. In addition, gold is used as a common monetary standard in coins and bars as a safe haven for storing wealth, for decoration, and as a plated coating on a wide variety of electrical and electronic equipment, as well as in dentistry and medicine (the radioisotope gold-198, with a half-life of 2.69 days, is used for radiotherapy in certain cancer treatments (Hainfeld et al. 2008)).

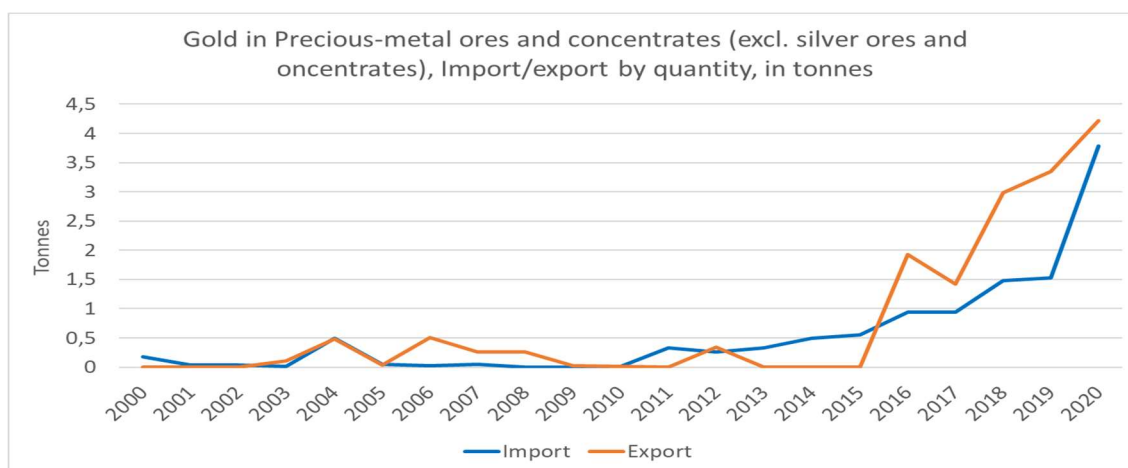
EU TRADE

The relevant commodities of Gold and their CN code are listed in 1.

Table 4. Relevant Eurostat CN trade codes for Gold.

Trade codes	
CN trade code	title
26169000	Precious-metal ores and concentrates (excl. silver ores and concentrates)
7108	Gold (including gold plated with platinum) unwrought or in semi-manufactured forms, or in powder form

EU imports and exports almost no Gold ores and concentrates but refined gold and gold articles. In the assessment, it is assumed that materials traded under CN code 261690000 contain 30ppm of gold³. The traded amounts remained below 500kg/year until 2015 and progressively increased up to 4,5 tonnes/year with exports higher than imports (Figure 6).



³ Communication with Andor Lips on average content of traded concentrates

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Figure 6. EU trade flows of Precious-metal ores and concentrates (excl. silver ores and concentrates), CN26169000, from 2000 to 2021, assuming a gold content of 30ppm (Eurostat, 2022)

The EU trade in Gold (including gold plated with platinum) unwrought or in semi-manufactured forms, or in powder form –HS 7108) shows that most of the exchanges are intra EU_27 (more than 70% for imports and 56% for exports) (Figure 7). Between 200 and 400 tonnes are traded between EU27 and the rest of the world, quite stable since 2009 (Figure 8).

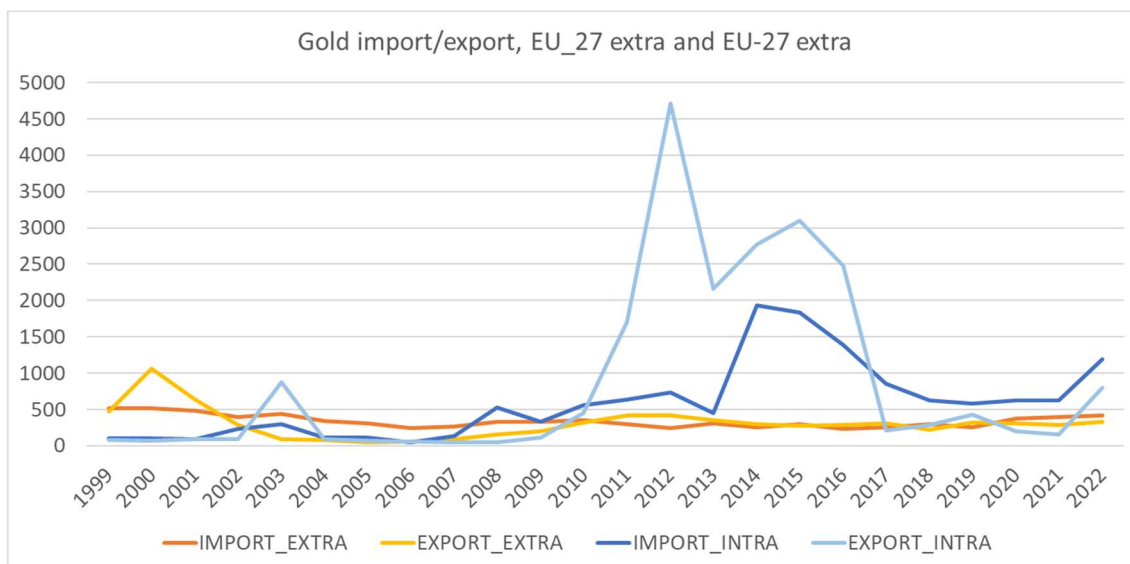


Figure 7. Trade flows of Gold (HS 7108), Intra vs Extra EU_27 from 2000 to 2021 (Eurostat, 2022)

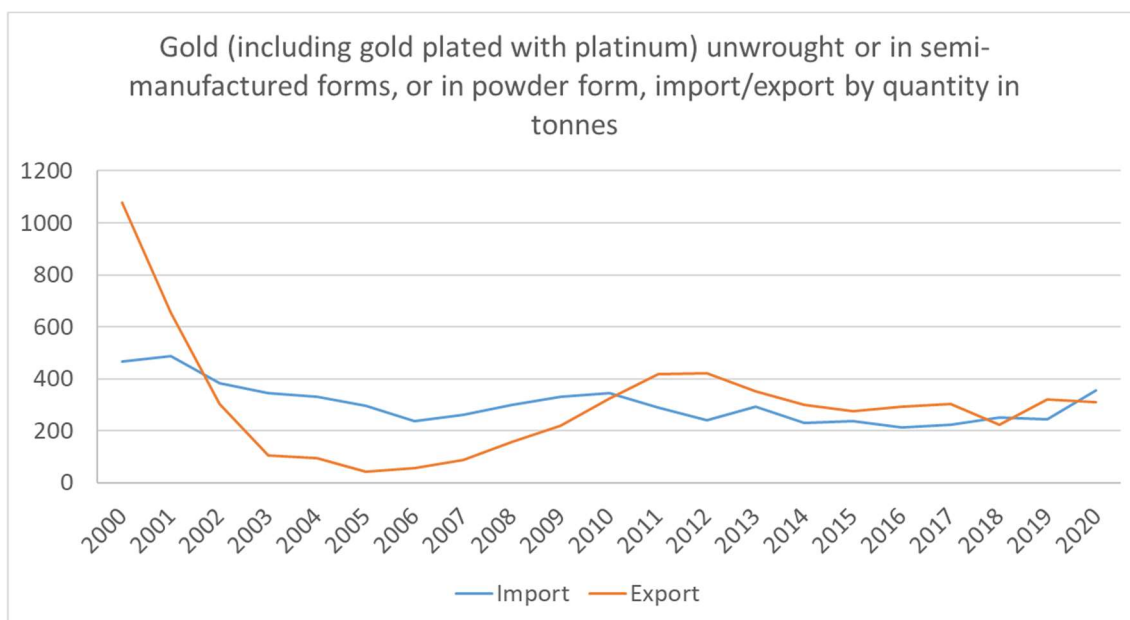


Figure 8. Trade flows of Gold (HS 7108), EU_27 vs rest of the world, from 2000 to 2021 (Eurostat, 2022)

The major source of EU’s import of Gold is Switzerland, supplying on an average 57% of EU’s total imports over 2016-2020, followed by USA (8%). South Africa, who was the second importing country until 2015 is now 4th

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with only 4%. Import from Switzerland decreased from about 300 tonnes in 2001 to less than 200 tonnes since 2009 and around 150 tonnes since 2012, with a minimum at 120 tonnes in 2006 and 2019. However, a sharp increase has been observed since 2020, with amounts above 350 tonnes, never reached since 2002.

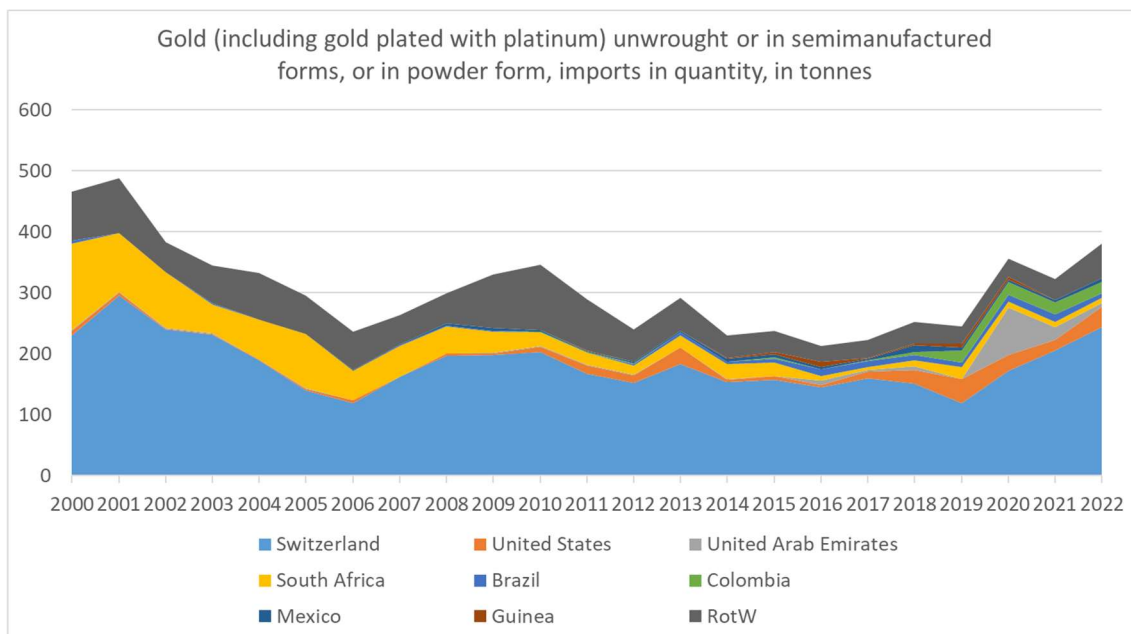


Figure 9. EU imports of Gold and Gold plated with Platinum (HS 7108) by country from 2000 to 2021 (Eurostat, 2022)

PRICE AND PRICE VOLATILITY

Price discovery is crucial for any commodity market. Gold not only has a spot price, but it also has the LBMA Gold Price, as well as several regional prices. The gold price in US dollars per fine troy ounce is set twice daily through the LBMA Gold Price auction. The LBMA Gold Price is used as an important benchmark throughout the gold market, while regional gold prices are important to local markets. Gold is considered a “safe asset” due to its store of value and safe haven properties and therefore functions as an anchor of stability for central banks, governments and individual investors. Despite its potentially stabilizing role, the price of gold is volatile and is influenced by various factors which include inflation, currency changes, interest rates, commodity prices, stock prices, safe haven demand (uncertainty) and central bank demand (Baur, 2013).

The gold price experienced an uptrend that commenced at the peak of the global financial crisis in 2008 reaching USD 1,600 per ounce levels in 2012. However, by 2013, the price fell down to USD 1,200 per ounce levels as investors stopped flocking to gold. In the first half of 2016, the gold price began to recover rapidly and peaked in the third quarter experiencing an increase of nearly 25% since the end of 2015. This price rise was due to increased investor demand resulting from global political uncertainties, particularly with the UK’s vote on EU membership and the US presidential elections. Very low interest rates across the world also provided a significant incentive for increased investment in gold. However, the price still remained below the average until the year 2019 when gold climbed meaningfully above the USD 1,300 per ounce mark. This was due to worries about an interest rate cut and the ongoing US-China trade war which increased investors’ interest in the precious metal (Healy, 2021). In addition, gold demand for safe-haven buying due to

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the continued COVID-19 pandemic as well as global investor uncertainty increased and low interest rates pushed the gold price to record high levels by 2020. In 2021, the metal failed to capitalize on inflation and the spot price fell about 4% due to a stronger US dollar and the success of COVID-19 vaccines which encouraged hopes of recovery from the pandemic (Spence, 2021). The downward trend in prices continued in 2022 as fewer investors have turned to gold as a hedge despite the threat of recession, inflation and further geopolitical instability from current issues such as Europe's energy crisis, China's COVID-19 restrictions and the ongoing conflict in Ukraine (Kuykendal, 2022).

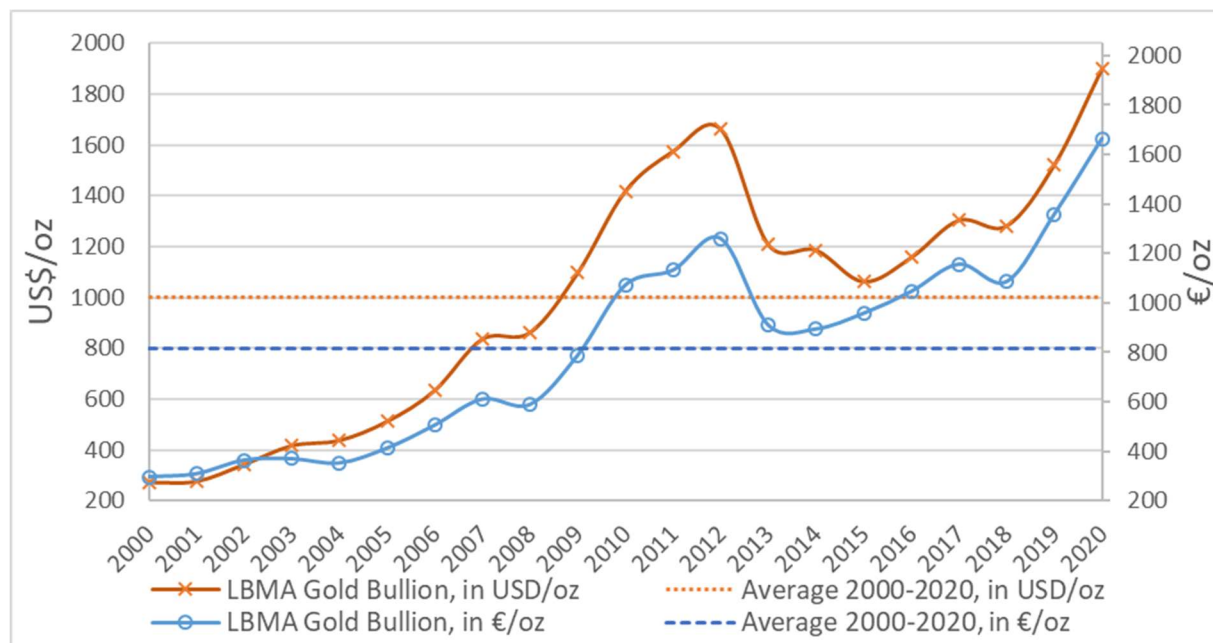


Figure 10. Annual average price of LBMA Gold bullion between 2000 and 2020, in US\$/oz and €/oz⁴. Dash lines indicates average price for 2000-2020.

OUTLOOK FOR SUPPLY AND DEMAND

Despite a strong first half of 2022, investment demand may be flat for the rest of the year, with potential for significant variability. There are opportunities for safe-haven demand to continue. The largest risk to jewellery comes from potentially weaker economic growth. Furthermore, China's lockdowns have dented demand and recovery will likely be slow due to the continued strict zero-COVID policy (World Gold Council, 2022). Gold prices are expected to remain under downward pressure for the rest of 2022 as central banks continue increasing interest rates to lower inflation to a target rate of 2.0%-3.0%. Higher interest rates could last longer than initially expected which will likely generate headwinds for the gold price in the short-to-medium term. The increasing likelihood of formal recessions in the U.S. and Europe may provide some support for gold prices in the short term (Goosen, 2022). Over the five-year period through to 2026, the gold price is expected to be at an average of USD 1,731 per ounce. Mine production which is expected to be at 107.06 Moz by the end of 2022 will grow to 110.88 Moz by 2026 (S&P Global, 2022).

⁴ Values in €/kg are converted from original data in US\$/kg by using the annual average Euro foreign exchange reference rates from the European Central Bank (https://www.ecb.europa.eu/stats/policy_and_exchange_rates/euro_reference_exchange_rates/html/eurofxref-graph-usd.en.html)

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DEMAND

GLOBAL AND EU DEMAND AND CONSUMPTION

World Gold Council estimates world gold consumption for 2021 as 4 000 tonnes (WGC, 2022).

Gold extraction stage EU consumption is presented by HS code CN 26169000 Precious-metal ores and concentrates (excl. silver ores and concentrates). Import and export data is extracted from Eurostat Comext (2022). Production data is extracted from WMD (2022). According to Eurostat Comext (2022), EU imports and exports are below 5 tonnes/year whereas the EU consumption is estimated at 30 tonnes/year over 2016-2020..

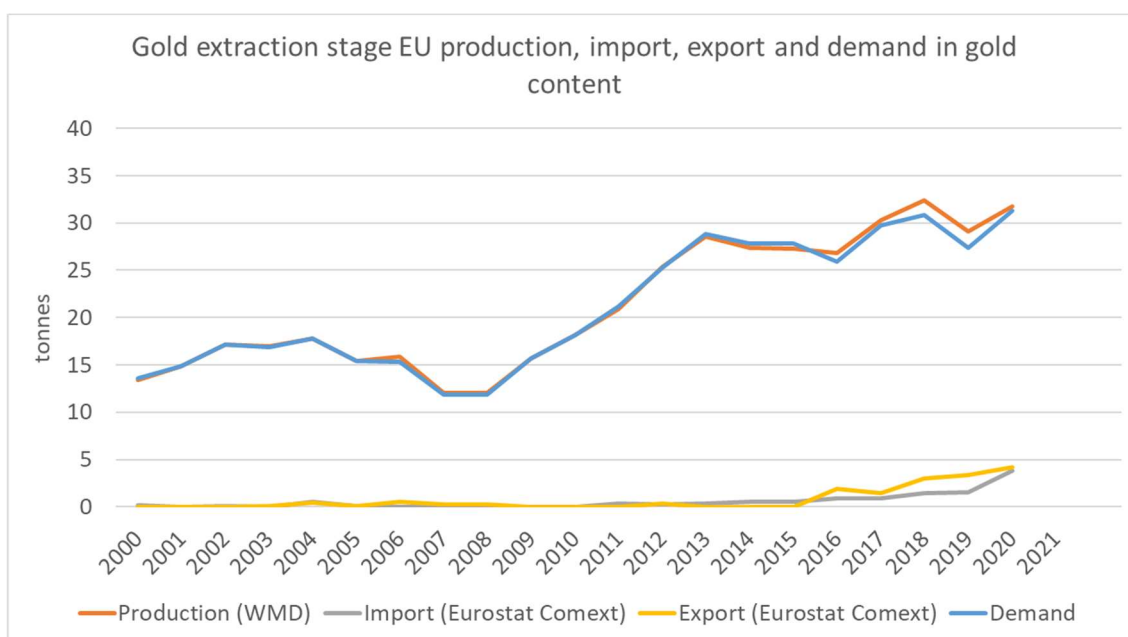


Figure 11. Gold (CN 26169000) extraction stage apparent EU consumption. Production data is available from WMD (2022). Consumption is calculated in gold content (EU production+import-export).

Based on Eurostat Comext (2022) and WMD (2022) average import reliance of gold at extraction stage is 0 % for 2016-2020.

GLOBAL AND EU USES AND END-USES

The end uses of gold products are multiple and both monetary and non-monetary.

More than one third of the global gold demand in 2021 came from private investment and central banks (World Gold Council, 2022). For a criticality assessment, these ‘gold as an investment goods’ are not relevant, while the non-monetary and industrial applications are of interest. Accordingly, as in previous criticality assessments, only the latter applications will be taken into consideration.

The major non-monetary end use of gold is jewellery, which accounted for more than 84 % market share in 2021, as shown in Figure 12. Further applications are:

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- 'electronic goods' (11 % in 2021),
- 'other industrial uses' (1.9 % in 2021); and
- 'dentistry' (0.5 % in 2021) (World Gold Council, 2022).

Between 2011 and 2021, the use share of jewellery increased by nearly 3 percentage points. Within the same time frame, the use share of gold decreased slightly for 'electronics' and significantly for 'dentistry' and 'other industrial uses' (World Gold Council, 2022). To the best of our knowledge, there is no end-use specific demand data for Europe available.

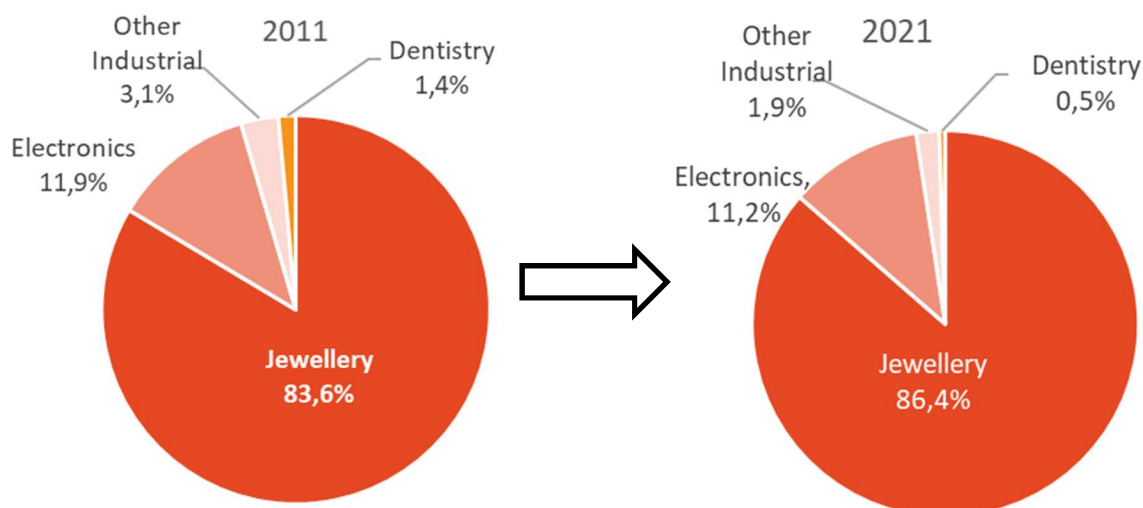


Figure 12: Global non-monetary end uses of gold in 2011 (left) and 2021 (right) (World Gold Council, 2022)

The relevant industry sectors and their 2- and 4-digit NACE codes are summarised in Table 5 and visualized in Figure 13.

Table 5: Gold applications, 2-digit and examples of associated 4-digit NACE sectors, and value-added per sector for 2014 (Eurostat, 2021).

Applications	2-digit NACE sector	Value added of NACE 2 sector (M€)	4-digit CPA
Jewellery	C32 - Other manufacturing	76.795*	C3212 - manufacture of jewellery and related articles
Electronics	C26 - Manufacture of computer, electronic and optical products	84.021	C2611 - manufacture of electronic components. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips.
Dental	C32 - Other manufacturing	76.795*	C3250 - manufacture of medical and dental instruments and supplies. Gold alloys are used for fillings, crowns, bridges, and orthodontic appliances.
Other industrial	C32 - Other manufacturing	76.795*	coating, electrical engineering, medicine, space technology, nanotechnology, etc.

*C32 plus C31 (Manufacturing of furniture)

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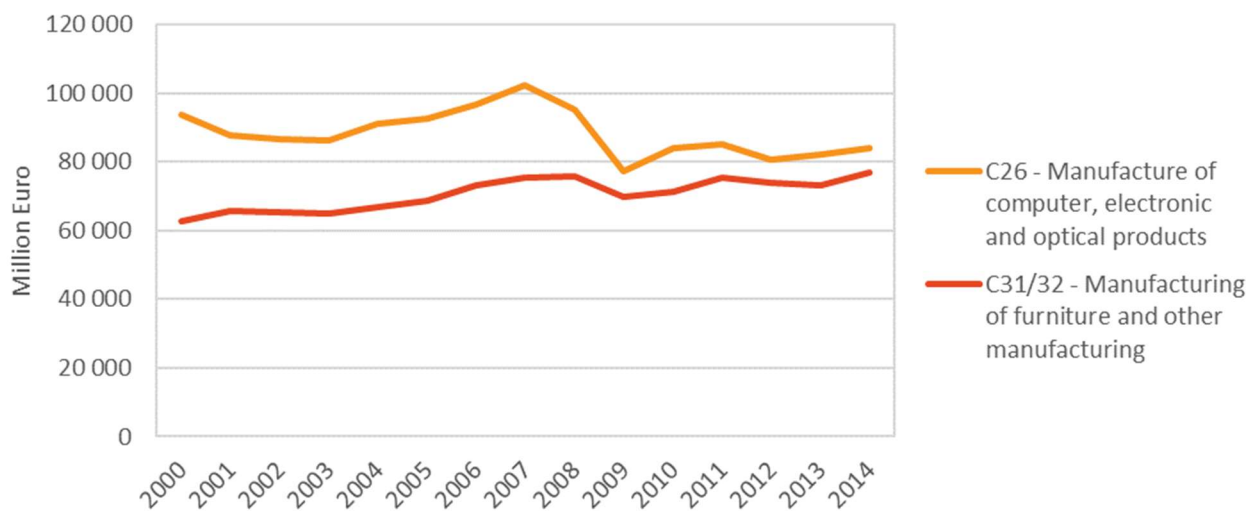


Figure 13: Value added per 2-digit NACE sector over time (Eurostat, 2021).

APPLICATIONS OF GOLD

JEWELLERY

The most important non-monetary use of gold is in jewellery. India and China are the two largest markets for gold jewellery, together representing over half of global consumer demand in 2018.

ELECTRONICS

Ca. 11% of the global non-monetary demand for gold comes from the electronic sector (Figure 2). The majority of this is used in electronic devices, where gold's conductivity and resistance to corrosion make it the material of choice for many high-specification and high-quality components. Gold is used in connectors, switch and relay contacts, soldered joints, connecting wires and connection strips.

DENTAL

Gold is used in dentistry as it is chemically inert, non-allergenic and malleable.

Either pure gold or gold alloys are used for fillings, crowns, bridges and orthodontic appliances. The latter are preferable since pure gold is soft (HV 25) and has a large elongation (45%).

Pure gold has recently been used in the electroforming process (Knosp et al, 2003). Tooth restorations such as porcelain veneered copings for crowns and bridgework can be electroformed with pure gold.

Nevertheless, alloys including gold are nowadays more and more used.

OTHER APPLICATIONS

There are numerous other minor uses of gold.

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These include:

- long-established applications such as coatings on various substrates to prevent corrosion and gas diffusion and for decorative purposes.
- Due to its very high malleability gold can be beaten into very thin sheets, so-called beaten gold, that are used to decorate picture frames, mouldings, furniture and parts of buildings.
- Small amounts of gold are used in various high-technology industries, in complex and difficult environments, including the space industry, in fuel cells, in auto catalysts and in the manufacture of chemicals.

SUBSTITUTION

Manufacturers are continually looking for ways to reduce the amount of gold (or other precious metals) required to produce goods or to find less expensive substitutes.

Table 6 summarises up the substitution options for gold, which are described in more detail below.

Table 6: Substitution options for gold by application.

Use	Percentage*	Substitute	Comment on substitute
Jewellery	86.6 %	Silver, platinum, copper, and many more	Substitution unlikely due to cultural meaning
Electronics	11.2 %	Platinum, palladium, silver, copper	Similar or lower costs, similar performance**
Dental	0.5 %	Ceramics, base metal alloys	Similar or lower costs, reduce performance**

*Global non-monetary end use share in 2021 based in World Gold Council (2022)

** EC CRM 2023 data.

JEWELLERY

In jewellery, gold has no technical function and could theoretically be replaced by other precious metals such as silver or platinum, or by cheaper alloys.

However, this is likely to be minimal in practice because the importance of gold in jewellery is long established and unlikely to change. The use of gold has been deeply entrenched for thousands of years in many cultures, especially in China and India, so it is very unlikely that consumers would accept these alternative materials and effect large scale substitution of gold.

ELECTRONICS

In electronic devices, platinum, palladium and silver are possible substitutes for gold, but their uptake has been limited in the past, partly by their high prices.

However, as gold prices have risen in recent years, while those of the platinum group metals (PGMs) have been less buoyant, this price differential has been eroded and substitution has taken place in increasing volumes.

Similarly, the use of base metals clad with gold alloys has long been employed as a way to reduce the amount of gold used in electronic devices. In some applications, copper may be a suitable alternative, but there is no data on sub-shares (Kamikoriyama et al. 2019).

DENTAL

In dentistry gold is increasingly being replaced by ceramics and cheaper base metal alloys.

INVESTMENT

In its monetary uses, for investment and reserve holdings by central banks, gold cannot generally be substituted with alternatives because it is gold itself that is specified for these purposes.

While exchange-traded funds, coins and bars based on platinum, and to a lesser extent palladium and silver, have become well established in recent years, their market shares remain very small by comparison with gold.

SUPPLY

EU SUPPLY CHAIN

The supply chain for gold in the EU is complex and difficult to quantify. Gold supplies are derived from primary sources (mines), both within and outside the EU, and from secondary sources (refineries), both within and outside the EU. Refineries in the EU process a wide range of gold-bearing materials including impure gold, end-of-life products and manufacturing waste (new scrap). By-products from the mining, processing and manufacturing industries, related chiefly to gold, silver, copper and lead extraction, also contribute to the EU supply of gold. These include a wide range of materials such as concentrates, slags, mattes, flue dust, ash, slimes and other residues.

The average annual gold production in EU at the extraction stage (using mined in EU and imported concentrates) during the period 2016-2020 was 60.6 tonnes and it was performed in the following countries: Sweden, Greece, Poland, Finland, Romania, Cyprus, Bulgaria and Slovakia (Eurostat, 2021).

Gold mining projects are at the permitting stage across Europe in the United Kingdom, Portugal, Romania, Slovakia and Greece. Exploration of gold deposits is also underway in other countries, for example, France, Italy and Austria.

Apparently, Europe is rich in economically viable gold mining deposits. Despite its gold mining potential, Europe is still lagging behind the rest of the world. In 2018, EU's gold mine production accounted for less than 1% of world's gold production (nearly 2% when including the Turkish gold mine production) (World Gold Council 2019d). As a result, Europe is still heavily dependent on gold imports (>90%) from other countries.

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Various gold mines exist in the EU countries, in particular in Sweden (8 Boliden mines, Blaiken mine, Svartliden mine and Faboliden mine), Finland (Pahtavaara mine, Kittila mine, Orivesi mine), Spain (2 Rio Narcea mines), Greenland (Nalunaq mine), Ireland (Omagh mine) and Portugal, with large mining projects and important gold exploration projects (TGM 2019).

In the Balkans, Bulgaria operates the Chelopech mine, the Kardzhali mine has been licensed and the Krumovgrad mine is expected to get its license. In Romania, the gold mine of Rosia Montana is expected to get its license, while in Serbia it has been announced that three state mines have been conceded to a major gold mining company for further exploration. The same happened recently in Kosovo (TGM 2019). In neighboring Turkey, the Turkish Gold Miners Association presents in its 2014 data at its website ten active gold mines. The gold mines of Cayeli, Mastra, Kisladag and Efemcukuru are operating, while two more mines are under development. There are currently approximately 70 active gold research and exploration projects in Turkey. Eldorado Gold, Thracean Gold Mining's parent company, developed and operates the Kisladag and Efemcukuru gold mines in Turkey.

The exploitation of Au-Cu Skouries deposit in Greece by Hellas Gold is expected to begin in short term. The life of the mine will be 28 years and it is estimated that 147 Mt of ore will be mined with an average of Au and Cu 0.77 g/t and 0.5 wt.%, respectively. It is estimated that about 528.000 ounces of gold will be produced as a Au-Cu concentrate. Au-Ag-Zn-Pb concentrate by Olympias project is expected to continue for >10 years. The Au amount contained in the Olympias concentrate was 58.000 oz in 2020 (Hellas Gold, 2020).

SUPPLY FROM PRIMARY MATERIALS

GEOLOGICAL OCCURRENCE/EXPLORATION:

Gold can be concentrated by a variety of geological settings and consequently occurs and is extracted from a number of different deposit types. Early mining mainly worked surface deposits of stream gravels, known as placers, also referred to as secondary deposits. From the second half of the nineteenth century, increased gold demand led to significant innovation in mining, beneficiation and extraction technologies that allowed the economic mining of gold from deposits in bedrock, referred to as primary deposits or lode gold deposits. Today the majority of gold is mined from primary deposits in which gold is the main product, but significant quantities are also produced as a co-product or by-product of base metal mining (chiefly copper, but also lead).

Gold deposits have been classified in many ways by different authors. Robert et al. (1997) distinguished sixteen common types of bedrock gold deposits based on their geological setting, the host rocks, the nature of the mineralisation and its geochemical signature. Among the most important types in terms of current production are: Orogenic gold, palaeoplacers, epithermal deposits, porphyry gold deposits, carlin type deposits, iron formation hosted deposits, gold-rich massive sulphides.

Extraction from placer deposits remains widespread. Where gold is extracted as the main product it is generally present in the ore at concentrations in the range 1-10 g/t (ppm). However depending on the size, location and type of deposit, grades considerably less than 1 ppm may be exploited, particularly if the gold is produced as a by-product of other metals. Porphyry deposits are particularly important in this regard: Some

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of the largest porphyry copper deposits are also important producers of gold. For example, the Grasberg deposit in Indonesia produces more than 330,000 t of copper per annum but also produces 1.2 million ounces of gold, making it one of the largest gold producing mines in the world (Freeport-McMoran 2016).

In primary deposits gold occurs chiefly as native metal, commonly alloyed with silver. The gold occurs in very small grains, rarely visible to the naked eye. Various gold telluride minerals are also known but these are seldom economic to mine.

Gold accounts for the major share of global exploration expenditure for non-ferrous metals. From an all-time high in 2012 of USD 10,500 million gold exploration, expenditure fell by about 60% to USD 4,200 million in 2015 (Schodde 2016). Latin America was the top destination for gold exploration with 27% of the total. This was followed by China, Africa and Canada, each with about 13% of the total exploration budget. About 3% of the total was spent in Western Europe. It is notable that of the 55 gold deposits containing more than 1,000,000 ounces of gold discovered in the period 2010-2013, only one was located in Europe, i.e. the Timok copper-gold deposit in Serbia (Schodde 2015).

RESOURCES AND RESERVES

GLOBAL RESOURCES AND RESERVES

USGS (2022) reports known global reserves of gold of approximately 54,000 tonnes. They are widely dispersed on all continents, with the largest amounts in Australia, Russia and South Africa (Table 7).

Table 7: Global reserves of gold in 2021 (USGS, 2022)

Country	Gold reserves (t)
USA	3,000
Argentina	1,600
Australia	11,000
Brazil	2,400
Canada	2,000
China	2,000
Ghana	1,000
Indonesia	2,600
Kazakhstan	1,000
Mexico	1,400
Papua New Guinea	1,100
Peru	2,000
Russia	6,800
South Africa	5,000
Uzbekistan	1,800
Other countries	9,200
World total	54,000

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EU RESOURCES AND RESERVES:

Resource data for some countries in Europe are available at Minerals4EU (2019) (Table 8) but cannot be summed up as they are partial and they do not use the same reporting code. Data on known gold reserves in the EU and adjacent countries were collected in the EU FP7 project Minerals Intelligence Network for Europe (Minerals4EU 2019). Data for gold were obtained from eight of the countries surveyed (Table 9). However, the data were reported according to eight different reporting systems and therefore cannot be aggregated to provide a partial total for Europe. We have no data on gold reserves in the other 31 countries that were surveyed during the Minerals4EU project.

The JORC-compliant resources of gold are located in the Scandinavian countries, as well as in the UK, Greenland, Ireland and Turkey. The resources in several Eastern European countries are based on national codes or on the Russian Classification. Some are based on the Canadian NI43-101 code, whereas for some others there is no known classification system.

Table 8: Gold resource data for the EU compiled in the European Minerals Yearbook at Minerals4EU (2019)

Country	Classification	Quantity (million t of ore)	Grade	Reporting code
Finland	Measured	16	0.83 g/t	JORC
	Measured	363	0.16 g/t	NI43-101
Sweden	Measured	32.45	1.08 g/t	JORC
	Measured	0.21	2.23 g/t	NI43-101
	Measured	513.4	0.12 g/t	FRB-standard
Norway	Indicated	7.86	0.53 g/t	JORC
Greenland	Indicated	5.08	1.25 g/t	JORC
UK	Measured	0.06	15 g/t	JORC
	Measured	0.161	9.1 g/t	NI43-101
Ireland	Indicated	4.927	1.64 g/t	JORC
Ukraine	P1	407.7	-	Russian Classification
Czech Republic	P1	60.2	-	Nat. Rep. Code
Slovakia	Verified (Z1)	7.335	1.59 g/t	None
Hungary	C1	34.59	-	Russian Classification
Romania	333	760	Ag + Au	UNFC
Serbia	Indicated	46.3	1.56 g/t	NI43-101
North Macedonia	A	37.16	0.64 g/t	Ex -Yugoslavian
Albania	A	0.01	1-4 g/t	Nat. Rep. Code
Greece	Indicated	81	0.06-0.08%	USGS
Turkey	Measured	32.8	2.4 g/t	JORC
Measured	96.1		0.97 g/t	NI43-101

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France	Historic resource estimate	0.17	-	None
Spain	Measured	17.3 x 10 ⁻⁶	3.99 g/t	NI43-101
Portugal	Indicated	4.233	1.57%	NI43-101

Table 9: Gold reserves data for the EU compiled in the European Minerals Yearbook of the Minerals4EU website (Minerals4EU 2019)

Country	Classification	Quantity (million t of ore)	Grade (% Cr)	Reporting code
Spain	Proven	8.479 x 10 ⁻⁶	-	NI43-101
Greece	Proven	0.2027	-	CIM
Turkey	Proven	20.51	2.51 g/t	JORC
	Proven	92.726	0.96 g/t	NI43-101
Northern Macedonia	A	37.161	0.64 g/t	Ex-Yukoslavian
Slovakia	Verified (Z1)	7.335	1.59 g/t	None
Czech Republic	Economic explored	0.0487	0.00019%	Nat. Rep. Code
Finland	Proven	8.9	1.3 g/t	JORC
	Proven	190	0.92 g/t	NI43-101
Sweden	Proven	0.41	2.2 g/t	JORC
	Proven	0.09	0.71 g/t	NI43-101
	Proven	517.1	0.16 g/t	FRB-Standard

WORLD AND EU MINE PRODUCTION

The global gold production since 1984 according to WMD and since 2000 according to USGS data can be seen in Figure 14 and Figure 15 (WMD, since 1984; USGS, since 2000). The global gold production presents a significant increase the last decade. China, Australia, Russia, United States and Canada are the leading producers with 365, 327, 308, 193 and 182 tonnes, respectively in 2020. Gold produced in more than 80 countries in 2020, in most cases, at amounts ranged between few kg to few tonnes (WMD, since 1984). The gold production in EU by country in 2020 presented in Figure 16.

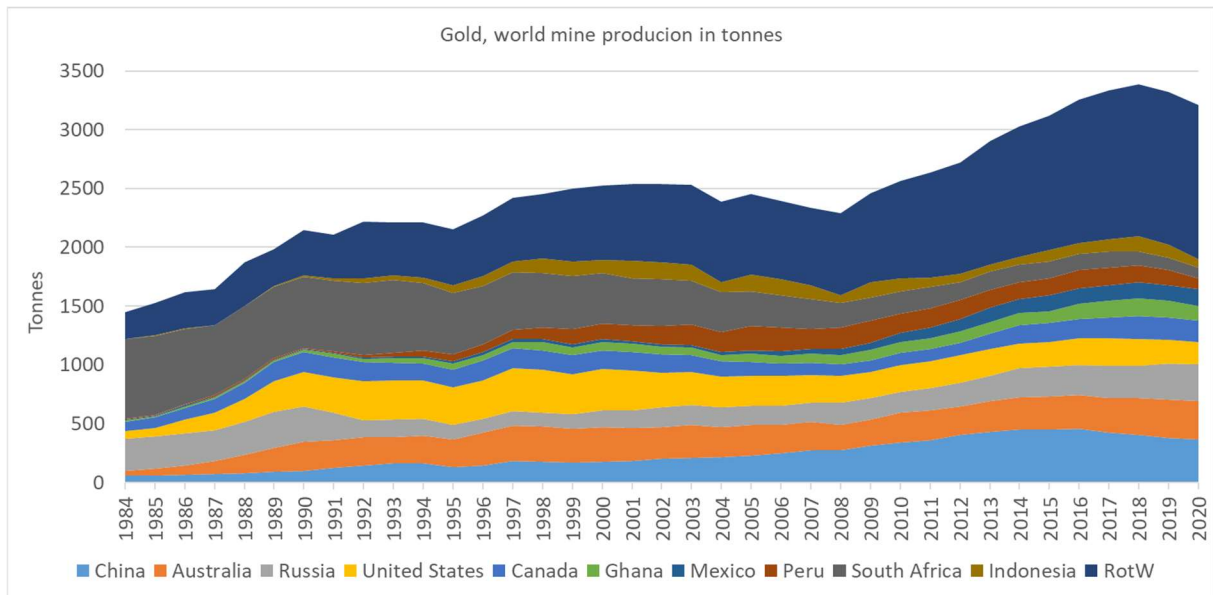


Figure 14: Global production of gold since 1984 according to WMD data (WMD, since 1984).

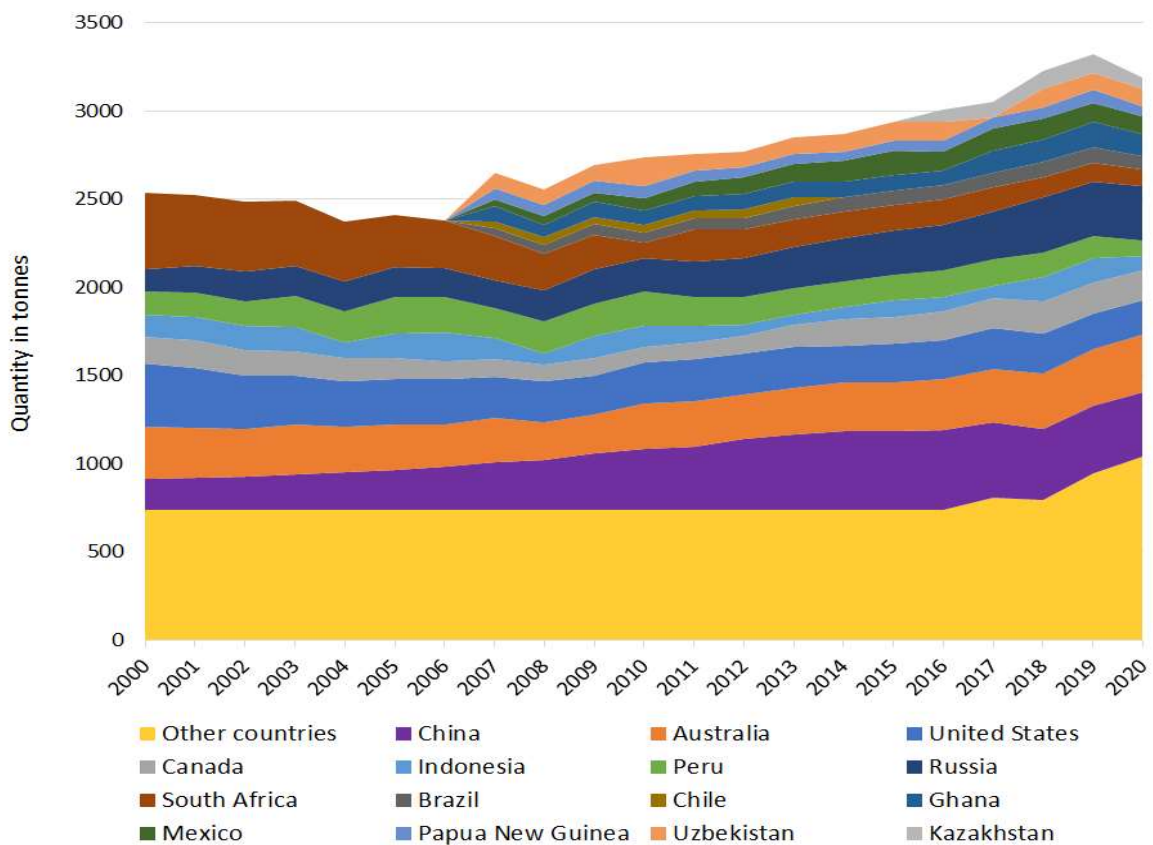


Figure 15: Global production of gold since 2000 according to USGS data (WMD, since 2000).

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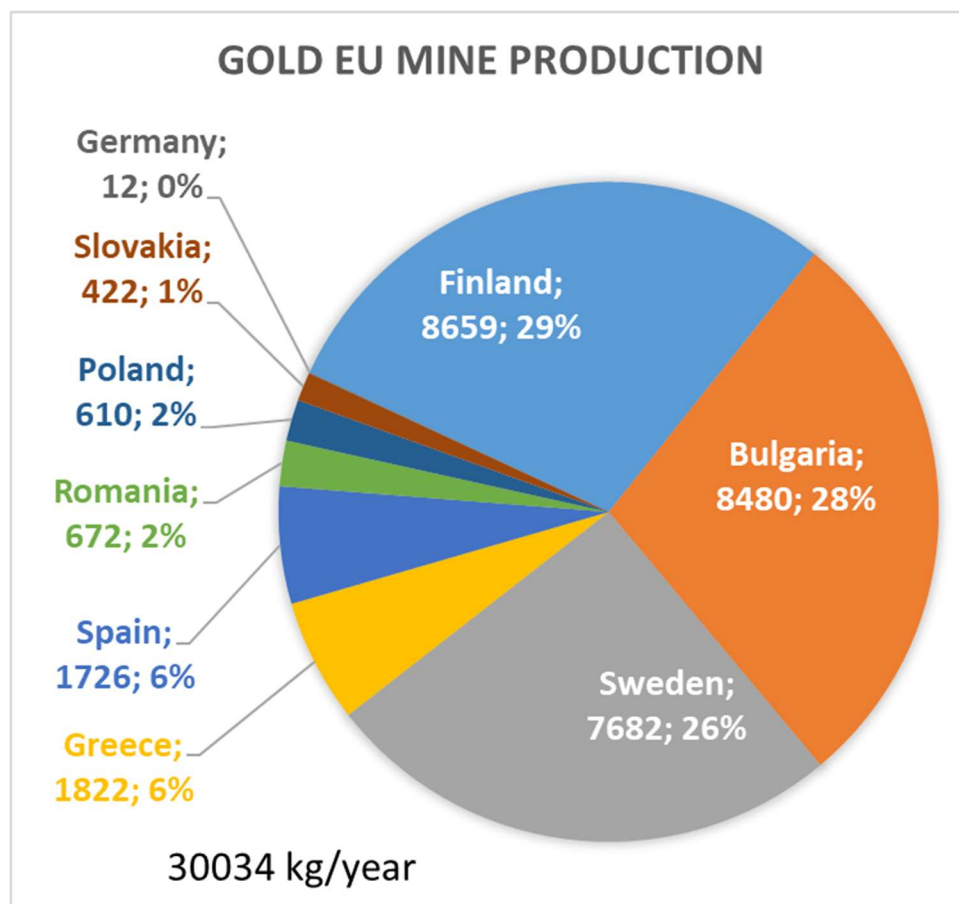


Figure 16: EU mine production of gold over 2016-2020 (WMD, since 1984)

OUTLOOK FOR SUPPLY

The world gold mine production is forecast to grow by 3.1% to 120.7 million ounces (Moz) in 2022 linked to post-pandemic recoveries and improvement in the global demand prospects. Canada will continue to remain the largest contributor to the growth in 2022, with output forecast to increase from an estimated 7Moz to 7.8Moz, an 11.4% increase. This will be followed by Australia (8.3%) and China (+5.9%). Russia is among the world's top three producers of gold, representing about the 9% of the global production in 2021, however the produced amount is expected to be affected by the Russia-Ukraine war in 2022 (**mining-technology.com, 2022**). Fitch Solutions forecasts that the global gold production will increase by a rate of 3.2% per year until 2030 to 141.7-million ounces. This growth rate is significantly elevated in comparison to the respective of the period 2016-2020 (0.8%) (**miningweekly.com, 2021**).

The current global stock of gold is over 200,000 tons. Although part of this stock will not return to the market, it equates to approximately 50 years of global demand. The largest part of gold globally (50%) is kept in jewelry accounting the 90% of the recycled amount. Gold supply by secondary resources could be increased via the exploitation of electronic wastes. About 53.6 million tons of electronic wastes were generated worldwide in 2019, while less than 17% of contained gold was recovered by them. It has been estimated that the recycling of 1 tonne of end-of-life mobile phones can produce 0.34 kg of gold (**quintet.com, 2022**).

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SUPPLY FROM SECONDARY MATERIALS/RECYCLING

While there are substantial stocks of gold in use comprising jewellery, central bank holdings, private investment and industrial fabrication, it is unlikely that much of this will ever re-enter the supply chain. The reasons for this are many and varied, but in general jewellery and religious artefacts are viewed either as sacred or as precious assets handed down from one generation to another. Central banks view gold as an important reserve asset and, in recent years, they have been more likely to buy than sell gold. In electronic devices, much of the gold is not recovered because they are not efficiently collected at the end of their lifetime.

The contribution of recycling to gold supply varies markedly with gold price. In 2009, as a result of high prices and global economic disruption, it peaked at 1,728 tonnes, equivalent to 42 % of total gold supply (Boston Consulting Group 2015). Since then, however, as prices have fallen and global economic recovery began, gold recycling has decreased. In 2014 it accounted for 26% of total supply. The total global gold supply in 2018 was 4,670 tons from which 23% come from refining of gold-containing scraps such as jewellery or coins and 3% came from the recycling of WEEE. However, it is difficult to obtain data on gold recycling processes, as the gold market as a whole tends to keep information intended for the public discreet. (Fritz et al., 2020; Hewitt et al., 2015)

The gold-recycling industry comprises two segments, each constituting a unique market with its own value chain: high-value recycled gold and industrial recycled gold (Hewitt et al., 2015) The majority of gold recycling, about 90%, is from high-value source materials such as jewellery, gold bars and coins which contain a significant proportion of gold alloyed with one or more other metals (Boston Consulting Group 2015). The techniques involved in recovering the gold from these materials are relatively simple and well established; although for some purposes where the desired purity of the output is critical, the techniques are available only in large-scale specialist refineries.

Gold derived from recycling industrial source materials, such as waste from electrical and electronic equipment (WEEE), provided the other 10% of secondary supply, up from about 5% in 2004 (Boston Consulting Group 2015). In printed circuit boards and mobile phones, the gold concentration is estimated to be between 200 and 350 g/t. Apart from the challenge of efficient collection of these devices at the end of their life, it is technically very difficult to extract the gold and other precious metals (palladium and silver). Although the technology required to handle these materials is now both technically efficient and environmentally friendly, it is highly specialised and not widely available.

Gold is also recycled from a wide variety of intermediate products and by-products from mining and metallurgical operations. These include, for example, anode slimes and flue dusts from copper and lead smelters, complex concentrates of lead, zinc, silver and gold, and by-products from gold mining such as sludges and residues.

UNEP (2011) estimates the average global end-of-life (EoL) recycling rate for gold to be in the range of 20%. This estimate does not include recycling of jewellery and coins because there is typically no end of life management for these products. On the other hand, the (World Gold Council 2019b) estimates that the recycling rate of gold is approximately 29%.

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There are regional differences in gold recycling. Mainly driven by the global financial crisis, in North America and Europe’s contribution to total recycling has grown from 27 percent in 2004 to 43 percent in 2011. Typically, the high-value gold-recycling market is generally served locally, and the industrial recycling market is mostly served globally, with pre-processed feedstock shipped from around the world to single smelting and refining sites (Hewitt et al., 2015).

PROCESSING OF GOLD

Gold-bearing ores may be extracted from either surface (open pit) or underground mining operations depending on many variables, chiefly the grade, size, shape and location of the deposit. Some gold-bearing ores are exploited at very big depths, exceeding 3 km from the surface. For example, AngloGold Ashanti’s Mponeng gold mine in South Africa is currently the deepest mine operation in the world, at a depth of 4km.

Flotation is the main technique that applied for the beneficiation/enrichment of sulfide Au-containing ores. Flotation has been used as a means to pre-concentrate refractory ores even before the 1930s in Canada, Australia, and Korea using oils as flotation collectors to produce bulk low-grade gold concentrates. Flotation of pyrite was a key focus in many South African gold operations to meet the needs of sulfuric acid market from the booming uranium industry. The gold boom in the 1980s and 1990s led to the processing of several refractory gold and copper-gold deposits in Australasia, Africa, and the Americas using flotation to produce concentrates with further treatment using bacterial and pressure leaching (Lakshmanan et al. 2019a).

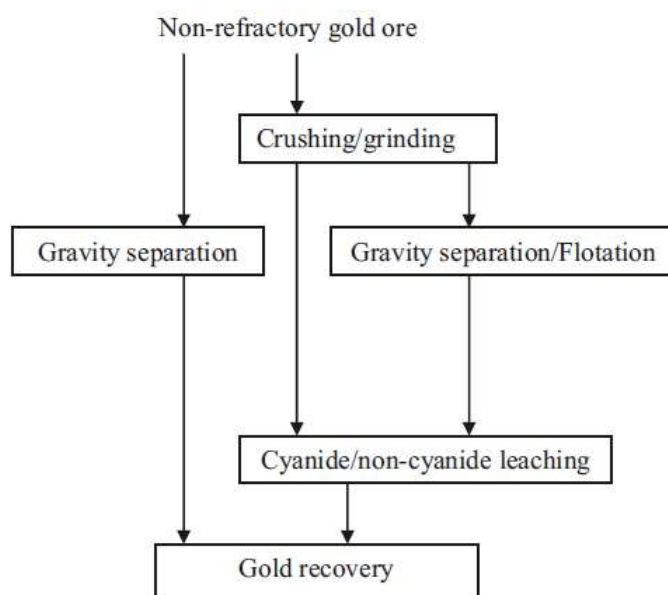


Figure 17: General simplified flowsheet of non-refractory gold ore (Lakshmanan et al. 2019b)

In case of non-refractory gold ores, cyanidation is used for the liberation of Au content by the primary ores. Au is recovered through the formation of the $Au(CN)_2^-$ complex (Lakshmanan et al. 2019b) (Figure 17). The gold is then collected from the solution by activated carbon pellets, typically made from charred coconut husks. This is referred to as the carbon-in-pulp process. The pellets are then recovered and the gold stripped from them by washing with hot cyanide solution. The gold and silver are recovered from the solution by

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electrochemical deposition. The cathode deposit is then refined into impure bullion or doré, a mixture of mostly gold and silver. Following conventional mining operations, some ores may be treated by heap leaching in which a weak cyanide solution is sprinkled onto an open pile of ore stacked on an impervious base (typical example is the Chovdar gold mine in Azerbaijan). Free milling gold can also be recovered by direct flotation (since gold is naturally hydrophobic).

In a refractory ore, very fine grained gold is enclosed in the bearing mineral (usually sulphides or carbonaceous material) that is impervious to cyanide leaching. The gold cannot therefore be dissolved directly and some form of pre-treatment is required before the gold can be liberated. Roasting, bacterial oxidation, pressure oxidation, ultrafine grinding and chemical oxidation the most common forms of pre-treatment of refractory gold ores (Coetzee et al. 2011; Lakshmanan et al. 2019b) (Figure 18).

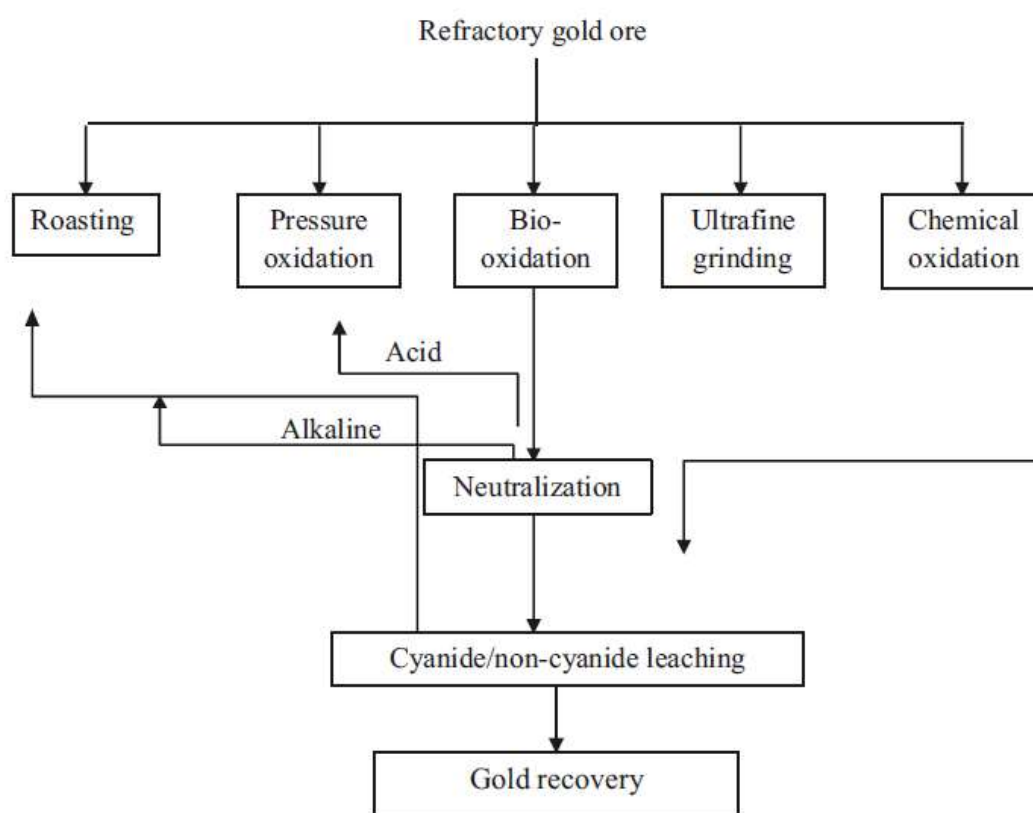


Figure 18: General simplified flowsheet of refractory gold ore using alternative pre-processing techniques (Lakshmanan et al. 2019b).

Pressure oxidation is the most widely applied pretreatment methodology of refractory gold ores. Depending on the mineralogy and the carbonate content of the ores, either acidic or alkaline pressure oxidation process can be used for whole ore treatment. For autogenous operation, the minimum sulphide sulphur target for autoclave feed ranges from 5 to 7%. Figure 19 presents a schematic of a typical pressure oxidation circuit to treat pyrite concentrates (Lakshmanan et al. 2019b).

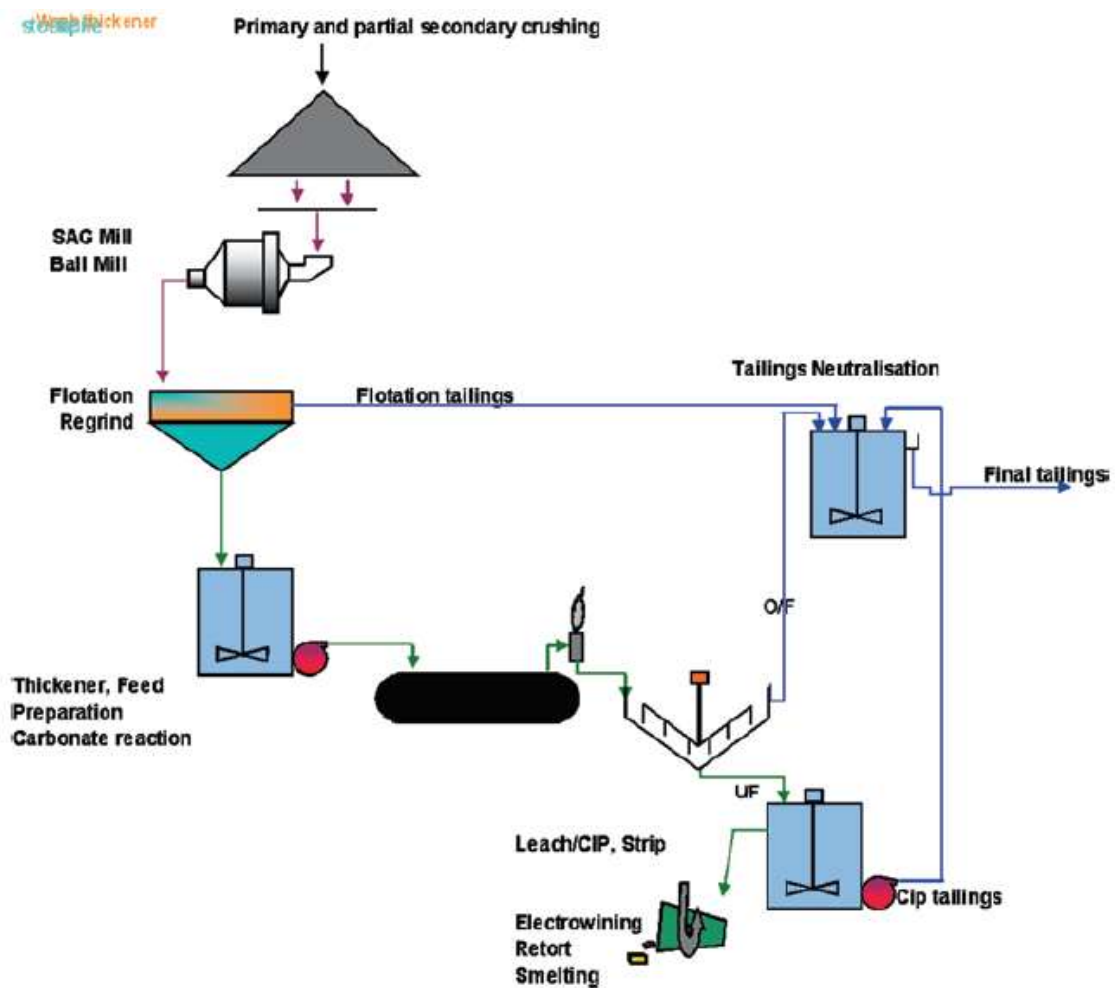


Figure 19: Flowsheet of a typical pressure oxidation circuit treating pyrite concentrates (Lakshmanan et al. 2019b).

In gold-silver doré, the gold is recovered at a precious metals refinery. This typically involves two stages of processing, chlorination which yields gold of 99.5% to 99.8% purity, followed by electrorefining which produces gold with a purity of 99.9% or greater. By-product gold in base metal ores is normally recovered with the other metallic minerals by flotation. The flotation concentrates are shipped to smelters where the gold is ultimately recovered as a by-product of smelting or refining. Gold is smelted in a crucible furnace to oxidise the base metal impurities. The resulting ingots are refined to produce pure gold.

OTHER CONSIDERATIONS

HEALTH AND SAFETY ISSUES

Gold can present risk of explosion in contact with ammonia, hydrogen peroxide and ammonium salts. In addition, it can react dangerously with alkali cyanides, aqua regia and chlorine-containing oxidants (GESTIS 2022).

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Gold compounds have been used, for many years, in medical treatment such as of rheumatoid arthritis. The incidence of gold therapy associated with toxicity has been estimated in order of 30-50 %, with approximately 10 % of patients experiencing severe problems and withdrawing from the therapy (Kean 1992).

In general, the toxic risks associated with gold are low in relation to the vast range of potential routes of exposure to the metal in everyday life, e.g. by wearing jewellery, dental devices or even through the food chain (Lansdown 2018). On the contrary, there are far greater risks related to the exposure to gold in mining and processing gold ores (Fankte 2017 ; McWhorter 2017).

Miners and the community are exposed to different types of risks, throughout the overall mining process. This can be divided into the mining/excavation phase and the gold extraction (McWhorter 2017). Damages are not caused directly by gold but can be considered collateral: lack of personal protective equipment (PPE) can affect miners' health, for instance the lack of breathing masks can cause harm when workers are exposed to inhalation of metals such as silica dust, which has been classified as a human lung carcinogen (US Department of Labor 2002). Also, during the final stage of the gold extraction process, the workers use mercury to isolate gold from fine grain ore – which can cause elevated risks for mercury-related health impacts (McWhorter 2017).

Health problems of gold miners working underground include increased frequency of cancer (trachea, bronchus, lung, stomach and liver), increased frequency of pulmonary tuberculosis, silicosis, pleural diseases; malaria and dengue fever; diseases of the blood, skin and musculoskeletal system – among others (Eisler 2003).

ENVIRONMENTAL ISSUES

The production of gold, being a major metallurgical production, has significant environmental impacts on the ecosystem. (Chen et al. 2018) highlights in a life cycle assessment of gold production in China that resource depletion contributes most to the total environmental impact of gold production. Other factors include climate change, terrestrial acidification, human toxicity, particulate matter formation, marine ecotoxicity and fossil depletion.

Policy proposals have been developed to promote more sustainability in the gold production, including the promotion of gold recycling, implementing ecological compensation, or maximising the resource efficiency – among others. (Chen et al. 2018)

NORMATIVE REQUIREMENTS

Regulation (EU) 2017/821 (“Conflict Minerals Regulation”) stipulates for gold the alignment of due diligence requirements with the 5-step framework for risk-based due diligence developed by the Organisation for Economic Co-operation and Development (OECD) - ' Due Diligence Guidance for Responsible Supply Chains from Conflict-Affected and High-Risk Areas' (OECD 2016).

The World Gold Council, a market development organization for the gold industry, developed a set of standards which address different parts of the gold-related value chain, from mining to central bank gold

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holdings. The intention is to set minimum standards to expand access to gold by ensuring sustainability. In 2019, they launched the Responsible Gold Mining Principles (RGMPs) – a framework that sets out clear expectations as to what constitutes responsible gold mining, elaborated with more than 200 stakeholders from different sectors. These are also in line with the overall International Council on Mining and Metals (ICMM) Mining Principles. (WGC 2019)

The complex gold supply chain makes transparency challenging and involves risks related to financial crimes, money laundering, theft etc. For this reason, the Responsible Minerals Initiative (RMI) developed a Due Diligence guide in the Gold Supply Chain, which is in line with the general OECD due diligence guidance. (RMI 2018)

Other international (and voluntary) responsible mining standards include the Initiative for Responsible Mining Assurance (IRMA) Standard for Responsible Mining, adopted in 2014 and applicable to all types of industrial mines including gold; the Responsible Jewellery Council (RJC) Code of Practices adopted in 2009 and accepted also within the gold supply chain; the International Cyanide Management Code (ICMC) developed in 2000 under the guide on UNEP – following a major cyanide spill at a Romanian gold mine (UNDP 2018).

SOCIO-ECONOMIC AND ETHICAL ISSUES

ECONOMIC IMPORTANCE OF GOLD FOR EXPORTING COUNTRIES

Table 10 lists the countries for which the economic value of exports of **GOLD ore** represents more than 0.1 % in the total value of their exports.

Table 10: Countries with highest economic shares of gold (ore) exports in their total exports

Country	Export value (USD)	Share in total exports (%)
Kyrgyzstan	1863531157	6.52
United Rep. of Tanzania	6076410130	5.89
Bulgaria	3,1915E+10	2.17
Ecuador	2,0355E+10	1.77
Kazakhstan	4,6949E+10	1.52
Georgia	3344474035	1.19
Lao People’s Dem Rep	5086886923	0.72
Australia	2,4505E+11	0.51
Armenia	2332082153	0.50
Peru	3,8757E+10	0.35
Gambia	25860014	0.30
Greece	3,507E+10	0.27
Russian Fed	3,371E+11	0.22
Finland	6,5607E+10	0.12
Turkey	1,6966E+11	0.11

Source: COMTRADE (2022), based on data for 2020

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For Kyrgyzstan (6.52 %), Tanzania (5.89 %), Bulgaria (2.17 %), Ecuador (1.77 %) Kazakhstan (1.52 %) and Georgia (1.19 %) the value of gold ore exports represents more than 1 % of the total value of their exports. Lao People's Democratic Republic (0.72 %), Australia (0.51 %), Armenia (0.50 %), Peru (0.35 %), Gambia (0.30 %), Greece (0.27 %), Russian Federation (0.22 %), Finland (0.12 %) and Turkey (0.11 %) export gold, whose value still accounts for more than 0.1 % of their total exports. For all other exporting countries, this share is below 0.1 %.

In terms of GDP contribution, of the 60.1 billion USD revenue from gold production by WGC member companies, 63 % (37.9 billion USD) contributed to the GDP of host countries. This equates to almost 1,100 USD in value added locally for every ounce of gold produced. In addition, WGC members support more than 3 % of GDP in five countries through their mining operations, and in 8 countries they fund more than 5 % of all government income (WGC 2021).

SOCIAL AND ETHICAL ASPECTS

Gold falls under the scope of The Regulation (EU) 2017/821 ("Conflict Minerals Regulation"). The Regulation sets out legally binding due diligence requirements for EU importers of tin, tantalum, tungsten and gold that came into effect on 1 January 2021. The Regulation is to break the link between the trade in these minerals and metals, and armed conflicts and associated human rights abuses. The Regulation also provides transparency and certainty as regards the supply practices of EU importers sourcing from conflict-affected and high-risk areas. (EU 2022)

The gold industry presents social and ethical issues both in the origin country and in the countries/region where its consumption mainly takes place, including in the EU.

Artisanal and small-scale mining (ASM) accounts for 20 % of gold mining. ASM, in general, creates socio-economic opportunities including job creation, rural development, market linkages, natural resources management and biodiversity (World Bank 2013).

Gold production is also contributing to the economic transformation of host countries, by increasing the productivity of existing sectors and catalysing investments from both the private and public sectors. Fiscal revenues from the extractive industry are one of the major reasons why governments seek to promote the growth of this industry (WGC 2021).

In the origin countries, the main ethical issues are related to the impacts of gold mining on the population and on the environment. In the Amazon region of Ecuador, ASM of gold has been accompanied by the formation of precarious settlements built by miners, which constitutes areas with minimal sanitary conditions and high levels of natural risks. Social conditions are characterized by an increased social disorder, including an absence of social organizations and public authorities. Communities consider that ASM of gold does not contribute to the development of local communities, on the contrary they bring health problems and conflicts among the population (Ramon et al. 2022)

There are risks associated to illegal gold mining (Interpol 2022), where organized crime is involved. Illegal gold mining devastates the environment, causing deforestation, biodiversity, and habitat loss as well as pollution

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of water, air and soil through the release of toxic chemicals. Local communities also suffer through forced population displacements, corruption, human rights violation and health issues associated to illegal mining (Interpol 2022).

From an EU perspective, in addition to the law enforcement efforts to combat transnational organized crime involved in illicit gold mining, the industries, retailers and consumers can also play an important role. Using recycled gold can be an option, even though this is generally not reducing the demand for newly mined metal.

Another option is buying certified gold from responsible ASGM (Alliance for responsible mining 2019). If the ASM extraction is controlled and certified (eg. Fairmined standards for gold mining 2014), certified ASM gold can become a development tool for the involved communities.

RESEARCH AND DEVELOPMENT TRENDS

RESEARCH AND DEVELOPMENT TRENDS FOR LOW-CARBON AND GREEN TECHNOLOGIES

- Renewable Energies for Water Treatment and REuse in Mining Industries (H2020).⁵

Water is essential for the mining industry – for the mineral extraction and cleaning, as well as for the needs of the miners and the people lives around the mines. This makes the treatment of wastewater important. In this context, the EU-funded REMIND project will develop an innovative framework of interplay between renewable energy sources and innovative water treatment technologies. Specifically, it will forge a collaborative network among the EU, Chile and Ecuador in line with EU policy and strategy for raw materials supply. Among the project's main aims is to create a rational use of water resources in the logic of a circular economy and to promote a carbon-free technological approach (water-energy nexus) for reducing conventional energy resources requirements.

- GoldTrace: tracking the origin and transport of gold beneath seafloor arc volcanoes (H2020).⁶

With an increasing importance of green technologies, today's world relies on an increasing supply of minerals. As the discovery of large deposits of strategic minerals—such as copper and gold—is becoming rare, explorers now focus on the deepsea to ensure demand is met. We know since decades that large copper, silver and gold-rich volcanic-hosted massive sulphide deposits are associated with seafloor arc volcanism. Therefore, understanding arc volcanism and in particular the source and transport of copper, silver and gold in arc lavas is critical in understanding how, when and why these deposits form [...] The processes surrounding the source and transport of copper, silver and gold remain unknown. To fill this knowledge gap the project will analyse, at high precision, copper, silver and gold in volcanic glasses (and melt inclusions) at GEOMAR/University of Kiel and compare the results from the northern and southern Kermadec arc. This will enable, for the first time, to determine the extent to which the thickness and composition of the subducting slab influences copper, silver and gold contents within arc volcanoes.

⁵ <https://cordis.europa.eu/project/id/823948>

⁶ <https://cordis.europa.eu/project/id/793807>

- Crystal phase engineering of Au nanoparticles for enhanced solar fuel generation (H2020).⁷

Producing fuel from sunlight, carbon dioxide and water could help satisfy the growing energy demands worldwide and point to a more sustainable future. Photocatalysts decorated with noble metal nanoparticles as catalysts have widely been investigated for their ability to speed up the generation of chemical fuels from water and carbon dioxide. However, it is currently unknown how the crystal phase of the noble metal nanoparticles affects the photocatalytic activity. The EU-funded C[Au]PSULE project will combine various experimental techniques to examine the relationship between the crystal phase of gold nanoparticles and the photocatalytic activity of gold–perovskite photocatalyst composites. It also plans to introduce non-standard crystal phases to improve catalyst efficiency.

OTHER RESEARCH AND DEVELOPMENT TRENDS

- Reliable, real-time process monitoring solutions for gold mines to reduce costs, reagent use and increase gold production (H2020).⁸

Extracting gold from ore involves an extremely dangerous practice. Cyanide salts in solution are used to leach the gold out from its ore but the use of cyanide in mining is rather controversial. Unfortunately, alternatives to cyanide produce lower quality and none are widely used. The EU-funded CyanoSmart project is developing a mobile IoT read-out device that uses single-use test cartridges to detect cyanide. The handheld devices can be used anywhere in the mine. What is more, its data-driven, connected monitoring system will help optimise gold extraction processes, while reducing operating costs and minimising their environmental footprint. Ultimately, the new devices will reduce cyanide consumption and the associated costs, and consolidate all data points in one platform.

- Thermally stable nonporous gold for improved automotive catalytic converters (H2020).⁹

Engines warm up after the ignition is turned on and particularly while the vehicle is in motion. While this is of benefit to cats lucky enough to find a freshly parked car on a cold winter night, it has been an obstacle to increasing the performance of catalytic converters. Gold nanoparticles have superior catalytic capability compared to currently used platinum group metals, particularly at lower temperatures, and could therefore significantly decrease toxic emissions during engine ignition. However, they lose their activity at elevated temperatures at which the conventional materials do an excellent job. The EU-funded np-Gold project is developing ways to integrate bulk gold with nanopores into converter products instead. It exhibits the same catalytic properties as gold nanoparticles at lower temperatures and withstands the heat during driving, a winning combination for our health and the environment.

- Photochemistry and radiolabelling of gold(III) anticancer prodrugs (H2020).¹⁰

The use of light to activate anticancer prodrugs is nowadays a reality in clinics around the world. Photodynamic therapy is an effective treatment for the localised destruction of cancer cells in a range of tissues and organs. Triggering the antiproliferative activity of chemotherapy agents with spatial and temporal control offers the

⁷ <https://cordis.europa.eu/project/id/891276>

⁸ <https://cordis.europa.eu/project/id/881444>

⁹ <https://cordis.europa.eu/project/id/957551>

¹⁰ <https://cordis.europa.eu/project/id/746976>

This project has received funding from the European Union's Horizon 2020 research and innovation programme under grant agreement No 958211

advantage of reducing side effects and resistance. On the bases of the great success of metal-based drugs (e.g. cisplatin and its derivatives), photoactivatable metal complexes have been investigated for their potential in light-activated therapy. This promising class of molecules is characterised by outstanding photophysical and photochemical features, which can result in novel cytotoxicity mechanisms. Among transition metals, gold has shown promising anticancer features, however no attempt to exploit Au photochemistry for medicinal use has been reported yet. This project aims at exploring such potential by investigating the development of innovative photoactivatable gold complexes that can be used as effective prodrugs for photochemotherapy and simultaneously act as imaging agents.

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