Research-Based Sustainability Brief on Lab-Grown Diamonds from Chemical Vapor Deposition Technology

Authors:
Shannon Boonzaier
Dr. Johannes Gediga

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About this Statement

This statement identifies environmental and social impacts in the value chain of lab-grown diamonds from Chemical Vapor Deposition (CVD) process technology. The stages considered in the value chain are raw material acquisition, synthesis of the rough diamond, and cutting and polishing.

This statement is based on detailed literature research and uses background data[1] from the GaBi database 2020[2] to quantify Greenhouse Gas (GHG) emissions along the value chain.

Other potential environmental impacts along the value chain can be quantified by undertaking a complete Life Cycle Assessment (LCA) based on sector-specific data including a sensitivity analysis of the variation of input parameters within the lab-grown diamond sector.

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1 Background data – carbon footprint data for power generation, raw material acquisition, transportation, etc.

2 Sphera Inc., "GaBi LCA Database Documentation," 2021. [Online]. Available: http://www.gabi-software.com/international/support/gabi/gabi-database-2021-lci-documentation/.

The Production of Lab-grown Diamonds

Lab-grown diamonds[3] are chemically and structurally identical to naturally occurring diamonds but can be produced in laboratories within weeks rather than billions of years. Lab-grown diamonds are mainly produced in China, India and the United States of America (USA)[4].

There are two major technologies used for lab-grown diamonds that have some differences regarding the raw materials used, and thus their primary social and environmental impacts: High Pressure High Temperature (HPHT) process and Chemical Vapor Deposition (CVD) technology. This statement focuses on the value chain of lab-grown diamonds from CVD technology.

Chemical Vapor Deposition (CVD)	High Pressure High Temperature (HPHT)
Chemical Vapor Deposition (CVD) is a technique by which diamonds can be grown from a hydrocarbon gas mixture. In the CVD process, a thin slice of diamond seed (often a synthetically produced diamond slice) is placed in a sealed vacuum chamber and heated to around 800 degrees Celsius. The chamber is then filled with a carbon rich gas (e.g. methane) along with other gases (e.g. hydrogen). The gases are then ionized into plasma using microwaves, lasers, or other techniques where a high amount on electricity is required. The ionization breaks the molecular bonds in the gases and the pure carbon adheres to the diamond seed and slowly builds up into a crystal, atom by atom, layer by layer.	The HPHT process begins with a small diamond seed that is placed into pure carbon (e.g. graphite). The seed is then exposed to high pressure (~60 kbar) and intense heat (~ 2600 degree Celsius) to simulate the temperature and pressure in the earth where natural diamonds are formed. The carbon melts and a diamond begins to form around the seed. In a next step, the substance is cooled to grow a diamond.

3 Lab-grown diamonds are also known as man-made diamonds, cultured diamonds or synthetic diamonds

4 China is currently the world's largest producer of lab-grown diamonds, accounting for an estimated 56% of the global lab-grown diamond market based on production in 2019 (Market share of lab-grown diamonds worldwide in 2019, by country: https://www.statista.com/statistics/1077662/global-market-share-lab-grown-diamonds-by-country/). India and the United States of America (USA) are the next biggest producers with 15% and 13% respectively.

The value chain for the production of CVD lab-grown diamonds covers three main phases: raw materials acquisition, diamond synthesis, and cutting & polishing. In addition, raw materials and semi-finished products are transported; as seen in Figure 1.

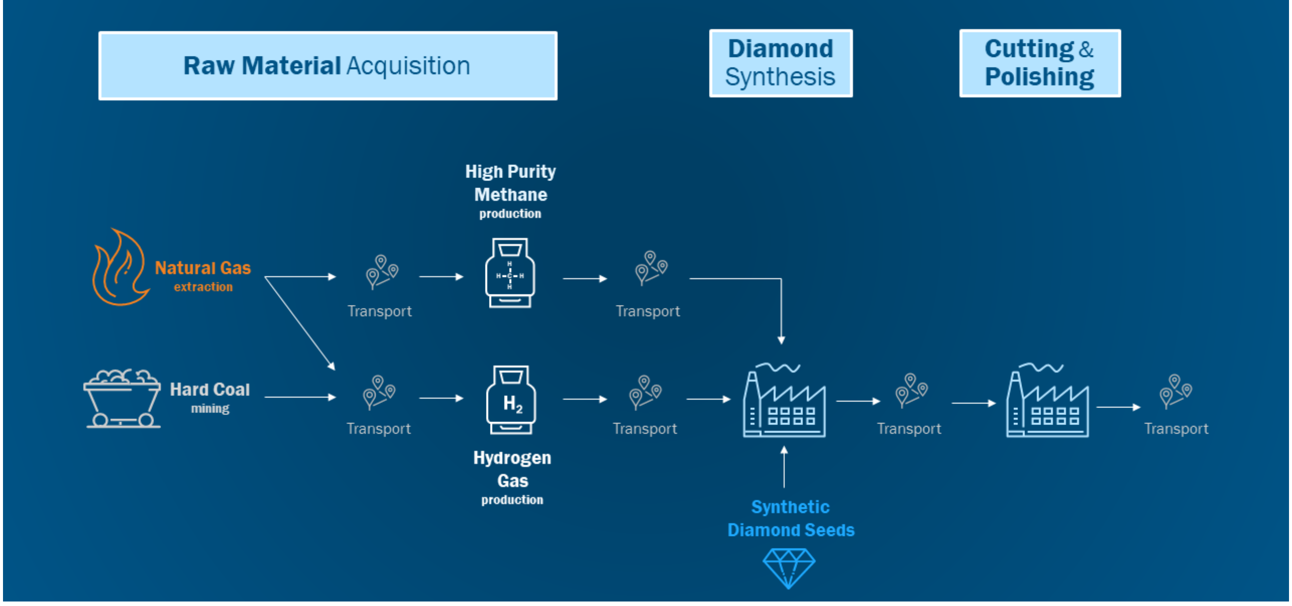

Figure 1: Value chain of lab-grown diamonds

Raw materials acquisition

Raw materials acquisition covers the extraction of the raw materials that feed into the processes to manufacture the primary gases (hydrogen and methane) required in the synthesis. High purity methane and hydrogen are assumed to be the main process gases used in this technology to produce lab-grown diamonds.

High purity methane gas is assumed to be produced from Liquified Natural Gas (LNG)[5], and therefore raw material acquisition begins with the extraction of natural gas.

In Europe, hydrogen is typically produced from natural gas via steam methane reforming whereas in China, the world's largest hydrogen producing country, it is mainly produced via coal gasification using hard coal[6].

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[5] https://www.liquidgas.co.jp/english/product/methane.html

[6] China is the world's largest hydrogen producer, producing the equivalent of about one-third of the world's total[6]. In China 62% of hydrogen[6] is produced from hard coal. The gasification of coal is a method that can produce power, liquid fuels, chemicals, and hydrogen. Coal gasification is the process of reacting coal with oxygen and steam under high pressures and temperatures to form synthesis gas - a mixture consisting primarily of carbon monoxide and hydrogen.

Diamond synthesis

The production of the lab-grown diamond is a high-technology manufacturing process that uses significant amounts of electricity. Other than high purity methane and hydrogen no raw materials are used in material volumes. The production results in the creation of a rough diamond.

Cutting and polishing

The rough diamond is shipped to a cutting & polishing facility, typically a separate business entity, that will cut and polish the rough diamond into finished diamonds. Most diamonds, lab-grown and mined, are cut and polished in India (72%[7]).

Social and Environmental Impacts in the Value Chain

The social and environmental impacts in the lab-grown diamond value chain occur at the three main phases of raw materials acquisition, diamond synthesis, and cutting & polishing. Each of the phases are characterized by distinct inherent impacts.

In Table 1, potential primary inherent risks[8] in each of the three phases are identified based on literature. In Table 2, the potential residual risk once appropriate and market conform risk mitigation measures[9] have been put in place are shown. It is noted that the identification of risks does not constitute a risk assessment and that the identification is based on a literature research, while the classification is based on judgement of the researched information[10]. Further, the identification of residual risks serves to demonstrate that risks can be mitigated, however it is not an expression of opinion on whether such risk mitigation measures have been adopted or are being widely adopted in the lab-grown diamond supply chain.

Text Box 1: Attributing impacts

Around 6% of globally extracted natural gas and 2% of the worldwide coal production is used to produce hydrogen – and only 6% of the produced hydrogen is used in industries other than oil refining and ammonia production, of which the lab-grown diamond industry is a fractional industry. A further estimated 3% of natural gas ends up in non-energy industrial applications which may include the use of high purity methane for various applications.

It is complex to attribute upstream impacts (particularly social aspects) from raw materials extraction to down-stream finished goods. For potential environmental impacts, a Life Cycle Assessment would be supportive.

[7] https://www.statista.com/statistics/588958/diamond-cuttng-and-polishing-global-distribution/

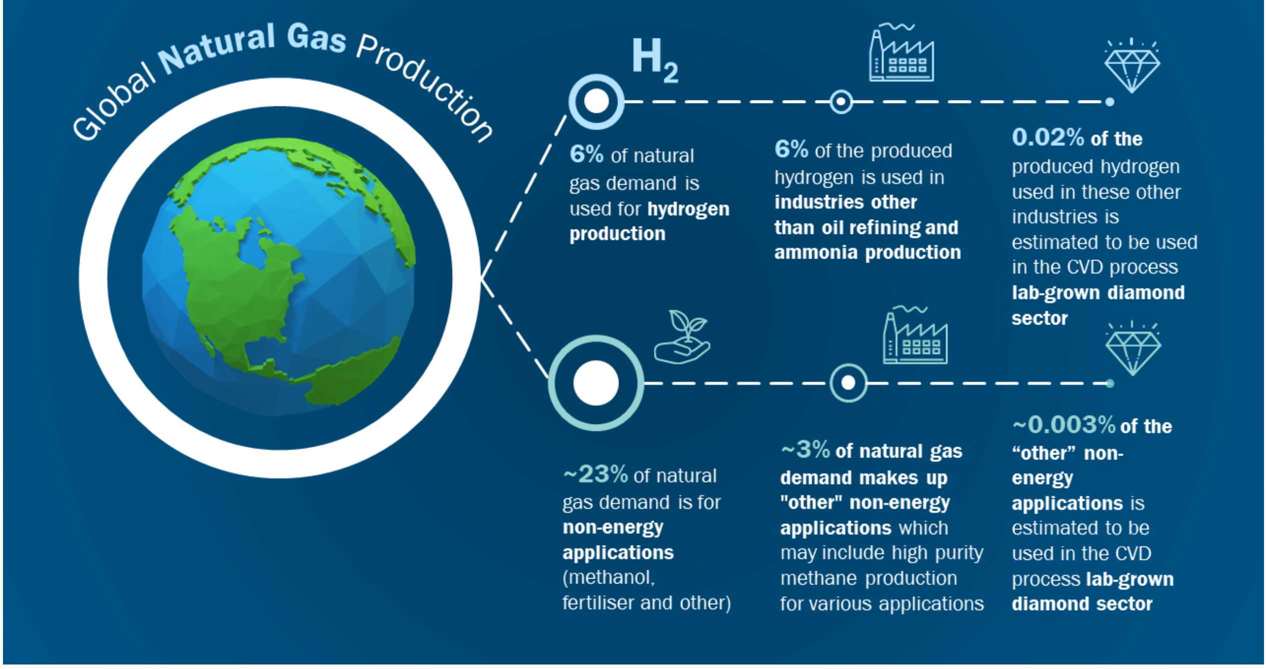
[8] Risks are grouped into collective categories – in reality, various aspects under each category is assessed in industry. E.g. Water risks would include groundwater contamination, surface water contamination, depletion etc. Additionally, the risks here also do not represent all possible risks that would be assessed for the respective industries and risks which could occur during various phases of the project (e.g. such as during installation or commissioning). Risks shown here are mainly related to risks arising during production

[9] The measures shown are not exclusive, and may also vary depending on country regulation

[10] Risk classification should be done by the respective industry experts, and done based on materiality of issues to stakeholders concerned

In raw materials acquisition, the potential social and environmental impacts are associated with the extraction of raw materials such as natural gas and/or coal for the production of high purity methane and hydrogen. The extraction of natural gas and coal can be associated with significant inherent social and environmental impacts. Such inherent social and environmental impacts can be mitigated to a low-medium risk level. It is also appropriate to note that the risks 'attributable' to the lab-grown diamonds from the CVD process is potentially minimal given the industry's share of total produced natural gas (to high purity methane and hydrogen) is negligible; see Text Box 1 and Figure 2[11].

Figure 2: Estimated share of natural gas used in the CVD lab-grown diamond sector in 2019



In diamond synthesis, the potential primary social and environmental impacts are associated with GHG emissions as well as general working conditions including human rights and health & safety. Such inherent social and environmental impacts can be mitigated to a low risk level, e.g. through use of renewable energy (GHG emissions) in the case of climate change.

In cutting & polishing, the potential primary social and environmental impacts are associated with GHG emissions as well as general working conditions including, in particular, health and safety risks linked to inhalation of dust. Such inherent social and environmental impacts can be mitigated to a low risk level by being certified against certain standards, such as those proposed by the Responsible Jewellery Council [35].

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11 Sources: https://www.iea.org/fuels-and-technologies/hydrogen
https://www.iea.org/data-and-statistics/charts/global-natural-gas-demand-per-sector-2007-2025
https://www.statista.com/statistics/1076048/global-market-share-of-lab-grown-diamonds/
https://www.bain.com/insights/global-diamond-industry-2020-21/

Based on literature review it is evident that the lab-grown diamond value chain is associated with material inherent social and environmental impacts at all three of the considered phases of the value chain. In particular, indirect GHG emissions associated with significant consumption of electricity in the diamond synthesis phase is a significant impact. However, measures for effective risk mitigation including for mitigating GHG emissions from production and cutting & polishing exist.

Table 1: Inherent risks

		Coal	Natural Gas / LNG[12]	Hydrogen	CVD process	Cutting & polishing
Environmental	**Air pollutants and climate change**[13]	heavy metals, dust, methane	methane & respiratory	Climate CO_2 through conversion from fossil fuel[14]	Process emissions are assumed to be only methane	Not known
		Medium	*Medium-high*	*Medium*	*Low*	
	Water	Ground water contamination (acid drainage)	Ground water contamination (associated with leakage)	Freshwater consumption[15]	Cooling water is recirculated [16]	Not known
		Medium	*Medium-high*	*Medium*	*Low*	
	Waste rock / tailings	Stockpiles (acid drainage)	Not applicable	Not applicable	Not applicable	Not applicable
		Low-medium				
	Waste	Coal gangue (acid drainage)[17]	Drill cuttings[18]	Not known	Not known	Not known
		Medium	*Medium-high*			
Social	**Human rights**	Work conditions and access to land[19]	Work conditions, (access to land in the case of onshore activities)	Not known	Work conditions	Work condition
		Medium-high	*Medium-high*		*Low-medium*	*Medium-high*
	Health & Safety	Dust, underground safety aspects, explosion risk, noise, mud slides[19]	Silica exposure; inhalation of hydrogen sulphide, explosion risk	Explosion risk	Explosion risk	silicate dust exposure (<PM 10 levels) directly linked to lung damage (silicosis)[20]
		Medium-high	*Medium-high*	*Medium-high*	*Medium-high*	*Medium-high*

12 It is assumed that the synthesis of LNG carries the upstream risk from the extraction of natural gas, since compression is the next step to produce LNG
13 Considers only direct emissions in the value chain and not those from power plants
14 https://www.forbes.com/sites/rrapier/2020/06/06/estimating-the-carbon-footprint-of-hydrogen-production/
15 https://www.hydrogen.energy.gov/pdfs/review16/sa039_elgowainy_2016_o.pdf
16 https://www.researchgate.net/publication/324037907_Microwave_Plasma_CVD_Reactors_for_Growing_Diamond_in_the_Laboratory
17 Coal gangue is one of the largest industrial residues in China https://www.intechopen.com/books/contributions-to-mineralization/trace-elements-in-coal-gangue-a-review
18 Drill cuttings are the pieces of rock that come out of a well when a well is drilled
19 https://www.bgr.bund.de/DE/Themen/Zusammenarbeit/TechnZusammenarbeit/Downloads/human_rights_risks_in_mining.pdf
20 https://www.nationaljeweler.com/diamonds-gems/social-issues/4336-agta-aims-to-combat-rise-of-silicosis

Table 2: Residual risks						
		Coal	Natural Gas / LNG[21]	Hydrogen	CVD process	Cutting & polishing
Environmental	Air pollutants and climate change[22]	Dust collection system; buffer zones, methane recovery	Identify methane leaks and reduce[23]	CO_2 using carbon capture and storage (CCS)[24]	Capturing CH_4 emissions	Not known
		Low	*Low-medium*	*Low*	*Low*	
	Water	Mine water management [25] water quality standards [26]	Water management certification API[27]	Wastewater Treatment[15]	Cooling water recirculated	Not known
		Low	*Low-medium*	*Low*	*Low*	
	Waste rock / tailings	Waste rock and tailings management[28]	Not applicable	Not applicable	Not applicable	Not applicable
		Low				
	Waste	Waste management	OSPAR legislation [29]	Not known	Not known	Not known
		Low	*Low-medium*			
Social	Human rights	ILO[30] code of practice	ILO code of practice[30]	Not known	ILO code of practice	ILO code of practice & Responsible Jewellery council (RJC)[35]
		Low-medium	*Low-medium*		*Low*	*Low-medium*
	Health & Safety	ILO code of practice[30]	API[31] standards, many association working on health & safety guidelines[32]	Production according to ISO 16110-1:2007[33] and Handling according to ISO/TR 15916:2015	Handling of hydrogen according to ISO/TR 15916:2015	Standard guidance (COP 21) Health & Safety[34] Responsible Jewellery council (RJC)[35]
		Low-medium	*Low-medium*	*Low-medium*	*Low-medium*	*Low-medium*

21 It is assumed that the synthesis of LNG carries the upstream risk from the extraction of natural gas, since compression is the next step to produce LNG
22 Considers only direct emissions in the value chain
23 https://www.iea.org/news/oil-and-gas-industry-needs-to-step-up-climate-efforts-now
24 https://www.nap.edu/read/10922/chapter/9#85
25 https://www.worldcoal.org/coal-facts/coal-mining/#minimising-the-impact
26 https://iopscience.iop.org/article/10.1088/1755-1315/252/5/052149/pdf
27 https://www.api.org/products-and-services/individual-certification-programs
28 https://www.icmm.com/en-gb/environmental-stewardship/tailings/global-industry-standard-on-tailings-management
29 https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM%3Al28061
30 ILO - International Labour Organisation https://www.ilo.org/global/topics/safety-and-health-at-work/normative-instruments/code-of-practice/lang--en/index.htm
31 API – American Petroleum Institute https://www.api.org/oil-and-natural-gas/health-and-safety
32 https://www.americangeosciences.org/sites/default/files/AGI_PE_HealthSafety_web_final.pdf
33 https://www.iso.org/committee/54560/x/catalogue/
34 https://www.responsiblejewellery.com/files/Health-and-Safety-RJC-Guidance-draftv1.docx
35 https://www.responsiblejewellery.com/standards/code-of-practices-2019/

Carbon Emissions Along the Value Chain

Carbon emissions is a significant inherent impact in the synthesis of the diamond within the value chain including raw material acquisition (extraction and processing of raw materials), synthesis of the rough diamond, and the cutting and polishing to the finished diamond. However, opportunities exist in each phase for mitigating carbon emissions - predominantly by use of renewable electricity sources (e.g. producing hydrogen via the electrolysis of water, but with renewable electricity).

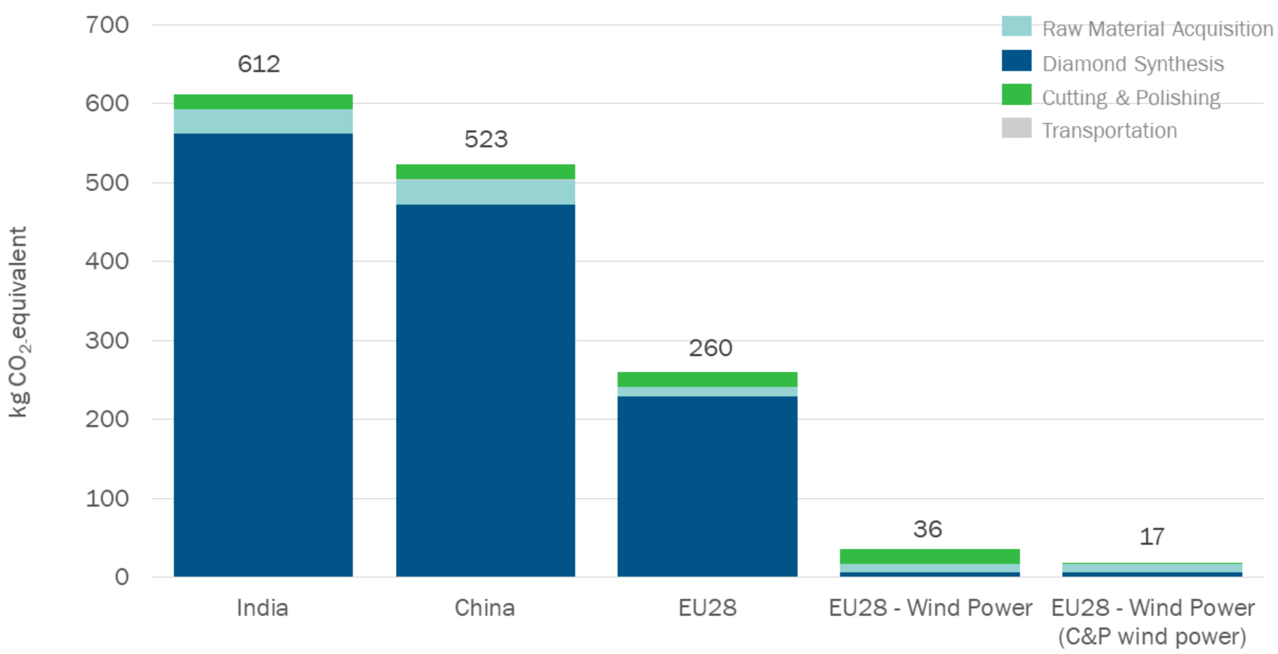
Overall, the carbon footprint of the lab-grown diamond from Chemical Vapor Deposition (CVD) is driven by electricity consumption within the synthesis process. In most scenarios, the diamond synthesis process account for more than 90% of total carbon emissions.

In Figure 3, four scenarios that are based on a common set of production assumptions resulting in an average of 620KWh per carat cut & polished diamond are presented; see Text Box 2. The Diamond Producer Association (DPA) reports an average of 591 kWh per cut & polished diamond[36]. The assumptions used to calculate the carbon emissions shown in Figure 3 are, are therefore, conservative.

> *Text Box 2:* Assumptions
>
> Yield: 25% from rough to cut & polished diamond, i.e. it takes 4 carats rough diamond to produce 1 carat finished diamond.
>
> Growth time: 100 hrs per rough carat
>
> Microwave capacity: 1.5KW

[36] The Diamond Producer Association (DPA) reports an average of 591 kWh per cut & polished carat of lab grow diamonds (https://www.spglobal.com/marketintelligence/en/documents/the-socioeconomic-and-environmental-impact-of-large-scale-diamond-mining_dpa_02-may-2019.pdf)

Figure 3: Carbon footprint for a one carat cut and polished diamond



The differences in the scenarios are due to the underlying electricity mix representing the grid mixes in the different countries which are based on GaBi LCA database 2020.

Text Box 3: **Mined diamonds**

Based on 2016 data, in 2019 the Diamond Producer Association (DPA)[36] has estimated 160kg CO_2-equivalent per carat cut and polished mined diamond

The scenarios show that the synthesis in China, India and Europe[37] accounts for the far greatest share of carbon emissions across the value chain with raw materials acquisition, transportation and cutting & polishing constituting around 10% of total emissions. Figure 3 also shows that in the scenario where 100% renewable energy is used in synthesis and cutting & polishing, some emissions remain from raw materials processing (mainly through production of hydrogen, from natural gas and coal depending on country). In addition, emissions from the windfarm manufacturing is also accounted for. Such emissions cannot be completely eliminated but can be off-set through investments in quality carbon off-setting schemes.

The carbon footprint for producing one carat lab-grown diamond made with 100% renewable energy in diamond synthesis and cutting & polishing phases corresponds to 17 kg CO_2-equivalent per carat cut and polished.

[37] The carbon footprint data for the power grids in China, India and EU 28 are from the GaBi database 2020.