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Research article

Comparative analysis: CapEx in diamond mining versus diamond growing, based on open data sources and experimental results

Vladislav Zhdanov [a], Lukasz Andrzejewski [b], Julia Bondareva [c,*], Stanislav Evlashin [c]

[a] Higher School of Economics, 20 Myasnitskaya st., Moscow, 101000, Russia
[b] Adam Mickiewicz University, 1 H. Wieniawskiego st., Poznan, 61-712, Poland
[c] Skolkovo Institute of Science and Technology, 30, Bolshoy Blvd, Moscow, 121205, Russia

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ABSTRACT

The diamond industry has long been associated with environmental and social problems, ranging from mining practices to ethical concerns related to diamond sourcing. In recent years, there has been a growing interest in lab-grown diamonds as a sustainable alternative for diamond consumers. However, the production of lab-grown diamonds has own challenges. This article examines the capital expenditures per annualized carat of rough diamonds obtained through mining and two fabrication methods: high-pressure high-temperature (HPHT) and microwave plasma-assisted chemical vapour deposition (MP CVD). Lab-grown diamonds produced using HPHT and MP CVD methods require significantly higher capital expenditures per annualized carat compare to mined diamonds. HPHT diamonds require on-time CapEx of 500–833 US$ per carat annually, while MP CVD diamonds demand 549–1648 US$ per carat annually. Finding ways to reduce production cost and increase efficiency will be crucial in realizing the potential of lab-grown diamonds as a sustainable alternative to mined diamonds.

1. Introduction

Diamond mining by various methods has been ongoing for several thousand years, influencing the political, economic and social situation in the world. Throughout history, there have been controversial events associated with diamond mining, such as the colonial wars led by Sir Cecil Rhodes (the founder of De Beers) in southern Africa [1], the persecution of Larisa Popugaeva (who discovered the first diamond deposit in Eastern Siberia [2]) and many other dramatic and remarkable historical events leading to new political and socio-economic changes in society. The traditional diamond industry was disrupted by the launch of diamond synthesis by General Electric in 1954 [3]. The production of synthetic diamonds with the possibility of quality control was driven by global problems and modern trends in applied physics, opening new opportunities for entrepreneurs and researchers. After several decades of research by scientists from around the world, laboratory-created diamonds exceeding natural diamonds in size, color, and clarity have been successfully produced [4]. It would seem that diamond mining should have been on the brink of extinction under the influence of political, economic changes and the development of lab-grown diamond technologies, but it is still “alive and kicking”. Various factors continue to impact the demand for both natural and synthetic diamonds [5].

Firstly, global diamond production is heavily dependent on the economy and has declined since the economic downturn of 2008; and figures have not yet returned to pre-crisis level. Recently, the new pandemic reality has resulted in diamond’s buyers putting their

* Corresponding author.
E-mail address: j.bondareva@skoltech.ru (J. Bondareva).

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activity on hold, which is a new challenge for the diamond industry we can currently observe. Secondly, the nature of the diamond market can be described as contradictory; it is an example of purchasing anomalies in terms of behavioral economics [6]. Some buyers are willing to pay a lot to emphasize the seriousness of their intentions (in the case of engagement) or social status, both of which are intangible, marketing-driven values. Consequently, the demand for natural gem-quality diamonds is unlikely to diminish. The introduction of lab-grown diamonds has made its own adjustments: the properties of such diamonds are often as good as natural ones, and sometimes even better, their cost 20–30 percent cheaper than mined diamonds [7]. Moreover, a significant share of diamonds is used in microelectronics and other industrial sectors, where diamonds grown under certain conditions are needed. In addition, the active development of the diamond synthesis industry is confirmed by the growing interest in lab-grown diamonds as compared to mined diamonds, as illustrated in Fig. 1 a according to Google trends and the number of page views presented in Fig. 1 b according to PageViews Analysis.

This popularity is justified by the many advantages [8,9] that lab-grown diamonds have over their mined counterparts. Briefly, it is the conscientious technological control that ensures purity. In contrast, mined diamonds are randomly distributed in terms of chemical purity due to their natural origin. Therefore, mined diamonds are characterized by their uniqueness and are mainly used as gemstones, with the wors of them being used to make abrasive powder. The lab-grown, chemically pure diamonds are not limited to jewelry market only; their incredible physical characteristics make them valuable material for many industrial applications [10,11]. An excellent example to illustrate the uniqueness of lab-grown diamonds is that they are able to reflect [12,13] and focus X-rays [14], which is essential in medicine to reduce the negative effects of X-ray-based procedures for patients. It should also be taken into account that the cost of laboratory diamond is lower than mined diamond, and synthesis of 1 carat, depending on the process, takes several hours. On the other hand, there is a technology to easily replicate Malevich's Black Square [15] (everyone can do it – please see Fig. 2), however the price of original Malevich's painting has been rising for years.

Allegorically, the new diamond market represents a confluence of two diamond "rivers" of varying origins – mined and lab-grown. The stakeholders in mining focus on creating a marketing-based "dam" between these two flows to save their profit. However, this marketing dam is not axiomatic [16]. We all know that diamond mining has a negative impact on the environment. Mining removes large amounts of sand and rock, disrupting natural landscapes and ecosystems [17,18]. In addition, the water consumption per 1 carat of mined diamonds may exceed the synthetic diamond by 5–6 times, and proper water purification and reclamation of spent deposits are not always performed effectively [9]. The diamond industry will overcome all challenges by using a wide range of product advantages from an emotionally driven to physically based strategies.

Our previous studies [19,20] focused on the operating costs (OpEx) associated with the mining and production of synthetic diamonds. In this paper, we consider the capital cost per carat of rough diamonds obtained by mining and two production methods: high pressure high temperature (HPHT) and microwave plasma-assisted chemical vapour deposition (MP CVD). Unfortunately, the topic of comparing the costs of diamond mining and production has received little attention in the literature, although the proper allocation of resources and production capacities can change the trend towards sustainable development of diamond fabrication and reduce the negative impact on the environment. Accordingly, it is interesting to analyze capital expenditures for mining and to predict new trends, since the diamond market is an example of supply-side economics [21]. If it were more profitable to grow diamonds rather than to mine them, the markers could rapidly shift to this new consumer paradigm. It is also necessary to consider the limited natural resources and the difficulties associated with finding new, profitable deposits, as well as the proper disposal of old ones. All these factors make mankind think about more sustainable approaches and inspire researchers to look for optimal technical solutions.

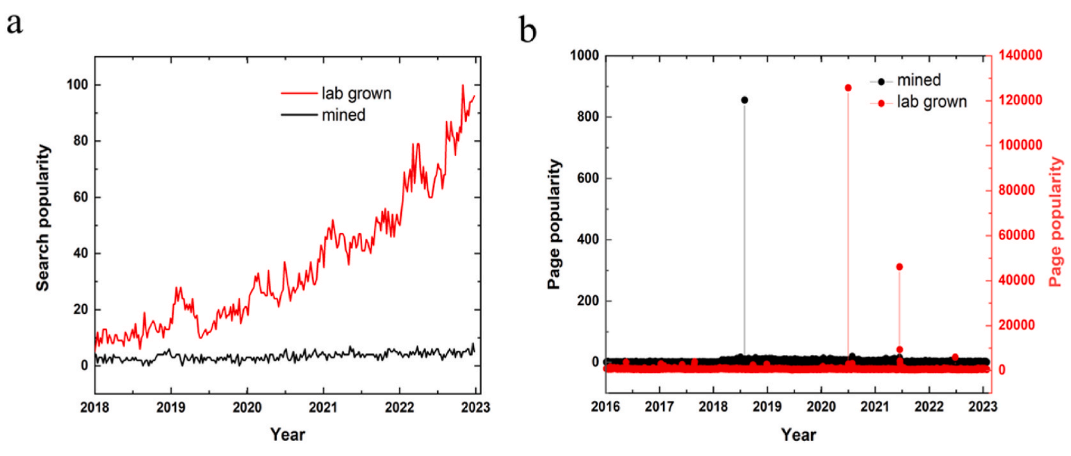

Fig. 1. a) Search popularity of lab-grown diamond versus mined. Source: Google Trend. b) Page popularity of lab-grown diamond versus mined, English Wikipedia. Source: Pageviews Analysis.

Fig. 2. The authors' replica of Malevich's "Black Square".

2. Materials & methods

2.1. Analyzed sample scale and estimation factor

In this study, we focused on the roots of the diamond industry – the manufacturing of diamonds mined and lab-grown. The three main methods of diamond fabrication such as mining, HPHT [22] and CVD [22], were analyzed to answer the main question – how much? We will describe these technologies in the next section, while here we merely wish to mention that there are more approaches for synthesis including cavitation [23] and detonation [24]. However, recently, these methods have been used only to produce abrasive powder, not gem-quality or optical-grade diamonds, which is why we will omit cavitation and detonation from the scope of our interests.

There are three recognized stages in diamond management, all coming from the oil industry [25] – upstream, middle stream and downstream. De Beers Group actively uses this terminology in their reports [26], and identifies mining as the beginning of the business cycle –upstream. This framework can be applied to each diamond manufacturer from a research laboratory with a couple of CVD reactors through those holding an array of hundreds HPHT presses, to global mining leaders, like De Beers. The diamond synthesis or mining is the first stage – the upstream phase. In this article we focused on this stage, as well as the middle stream and downstream stages – cutting, polishing, promotion, etc. are out of scope of this study, despite of their importance to adding value. For instance, while a company might have dozens of HPHT presses, high-tech laser worth close to one million dollars (the authors' dream) and 30 polishing robots, we will focus on CapEx for dozens of HPHT presses only, despite the importance of investment into the middle stream process, which significantly increases value and liquidity (it is commercially reasonable to sell polishing diamonds, not rough ones). However, this study is focused on the beginning of a diamond pipeline – the production of rough diamonds.

As an estimation factor, we used CapEx per annual productivity in carats to compare different approaches for fabricating diamonds. Our aim is to provide a simple indicator for everyone and present methodologically appropriate results to map the diamond industry's future development.

CapEx per annual carat was calculated using the following equations:

For lab-grown diamonds

$$CapEx_{total} = \frac{Cost_{phisical\ asset} + Cost_{support}}{P} \tag{1}$$

where $Cost_{phusical\ asset}$ is a cost of CVD reactor or HPHT press, $Cost_{support} = Cost_{transportation} + Cost_{installation} + Cost_{supplementally\ furniture}$ and P is productivity of physical assets per year in carats.

For mining

$$CapEx_{total} = \frac{Cost_{on-time\ investment}}{P} \tag{2}$$

where P is productivity of mine per year in carats.

2.2. Data sources

We used public reports of DeBeers Group to get the relevant data for CapEx estimation for mining, particularly data of Canadian Gahcho Kué project - the world's largest new diamond mine opened in 2016 [27]. This project serves as an excellent illustration for understanding initial CapEx and can be considered a reliable indicator for upstream investment in diamond mining. Located near the Arctic circle, the Gahcho Kué project initially lacked essential infrastructure such as roads or an electrical grid, which were subsequently developed from scratch. Therefore, the Gahcho Kué is methodologically perfectly suitable to be used as a benchmark for all new diamond mining projects, at least in terms of upstream CapEx. Open data sources were also used to estimate CapEx for HPHT method – from the Russia-based New Diamond Technology HPHT project. The mutual communication was used as well to obtain more relevant HPHT-related data from others familiar to authors growers around the world. The data for MP CVD method are based on authors' experiments with 2.45-GHz MP CVD reactors.

3. Results

3.1. CapEx for HPHT

The HPHT method was launched in the 1960's, and since then, it has been the most common way of diamond synthesis. It is based on the hydraulic system which supports the pressure up to 4–6 GPa and an inner chamber heated up to 1500 °C. Inside the chamber where diamonds are grown is an iron-based melt. The HPHT process imitates the conditions under which diamonds grow in nature. The most popular modern presses are cubic ones; they use six hydraulic cylinders with stroke diameters up to 950 mm (the 750 and 850 are more common) as shown in Fig. 3. The CapEx for them will consist of a cubic press as a base (about $250k), essential furniture (about $150k), transportation all of the machines (850 mm press is weighted 68 ton), installation in the appropriate industrial unit with all infrastructure including energy supply (the peak power of each press is more than 30 kW), water-cooling circuit, and the launch.

It is challenging to provide an exact CapEx for a HPHT manufacturing unit due to the numerous variables involved, such as the model, furniture, location of installation, and the cost of electro- and water supply. The cost of an HPHT unit can vary significantly depending on the location of production. For instance, a new state-of-the-art high-performance cube press produced in China, a leading manufacturer, would cost significantly less than in Europe. New Diamond Technologies, a Russian company and a technological leader in HPHT production, has stated that the total cost of a new high-performance cube press is up to $1 million [28], including all expenses such as transportation, installation, and supplementary furniture. However, it is important to note that the authors of this study do not have any practical experience in HPHT manufacturing, and all observations are based on privately-owned factories that shared their real investment and capabilities voluntarily.

According to the data from these factories, about $600,000 must be invested to buy and transport a modern HPHT press to Europe, including all the furniture. However, the installation cost is significant and difficult to predict, as each press weighs about 70 tons, and energy and water-based cooling will contribute to the overall cost. Therefore, we will use published numbers of New Diamond Technologies [28], one of the global technological leaders in HPHT synthesis: the HPHT CapEx per one modern press is up to $1 million. Other HPHT manufacturers, who shared their data with us, are also close to this number in terms of the total CapEx per each press.

However, this up-to-one-million-per-one-press's estimation is more relevant to other countries than the country where most presses are manufactured. The estimated cost would be lower for China, where the vast majority of lab-grown diamonds are fabricated. In other words, there are no economic reasons to install these presses outside of China, where all the necessary competences to run this business are already in place. In 2008, Christian Hultner, the CEO of Element Six (part of the De Beers Group), made an eloquent comment to the Financial Times [29]: "*[In the Suzhou plant] we used Chinese management, Chinese workers and Chinese machines. We put into this plant not an iota of technology [from outside China]. But we succeeded in finding out a lot about the Chinese way of organizing*

Fig. 3. A HPHT cubic press.

manufacturing in this field, which has been highly useful in the rest of our worldwide production operations." We have to clarify that Element Six opened its China-based manufacturing unit in 2006, which is predominately focused on HPHT methods, according to an FT-cited article [29]: "*In 2006 it set up a plant in Suzhou, near Shanghai, expressly to copy the techniques of Chinese rivals in making artificial diamonds, produced through compressing graphite under high pressures*. In the case of De Beers' expansion into China, we can see an example of the best practice, to be close to factors relevant to value creation – you mine diamond in Africa, and you grow it in China (where HPHT presses are more affordable) – the De Beers is an axiomatic example of business survival.

Taking all the above into consideration (China dominance in HPHT technology), we will use a range rather than a single number to estimate CapEx for HPHT factoring – from \$0.6 to \$1 million for each HPHT press, which is able to produce 1200–2400 carats of jewelry-market-demanded (near-) colorless (D-J color by Gemological Institute of America classification [30]) middle-sized rough diamonds per year. Press productivity depends on two factors – color and size of diamonds, which are methodologically important. Nitrogen (N) can significantly enforce the speed of growth [31] by self-replacing vacancies in the diamond cell, though the liquidity of such nitrogen-full diamond would be very limited primarily due to its color (yellowish to brown). The size is important factor in press productivity – in brief, the smaller the size, the faster the cycles. One can grow small-sized diamonds every day, while other manufacturers will grow middle-sized ones for weeks; still, the mass of diamonds in the chamber in each cycle is almost similar – X carats always, as it is limited not by the number of diamonds but the presence of carbon in iron-based melt.

As a result, the CapEx to an HPHT presses facility is in the range from \$0.6 to \$1.0 million for each press on average. The productivity of such a press is about 1200–2400 carats per year, if it produces nitrogen-less market-demanded middle-sized diamonds and nitrogen – full diamonds, respectively. Thus, according to Eq (1), we have **\$500** to **\$833** on-time CapEx is needed per one nitrogen-less annualized carat (annu. ct) but these costs can be halved for coloured diamonds with high nitrogen content.

3.2. CapEx for 2.45 GHz MP CVD

MP CVD is the second most common method of diamond synthesis, based on chemical vapour deposition [32], which is fundamentally different to the way diamonds are made naturally – there is no pressure, hydrogen-based plasma is used instead of iron-based melt, and other technical innovations are applied too. For instance, De Beers, as the global leader in both mining and lab-growing sectors, has chosen CVD technology [32] to produce lab-grown gem-diamonds under the Lightbox trademark [33], which proves that this technology is able to enter the mainstream.

There are a few sub-methods in the CVD approach, the difference between them is plasma support, which is essential to the synthesis. There are:

- Hot Filament (HF) CVD [34]: a high temperature is based on electrically heated electrode (usually, a tungsten wire);

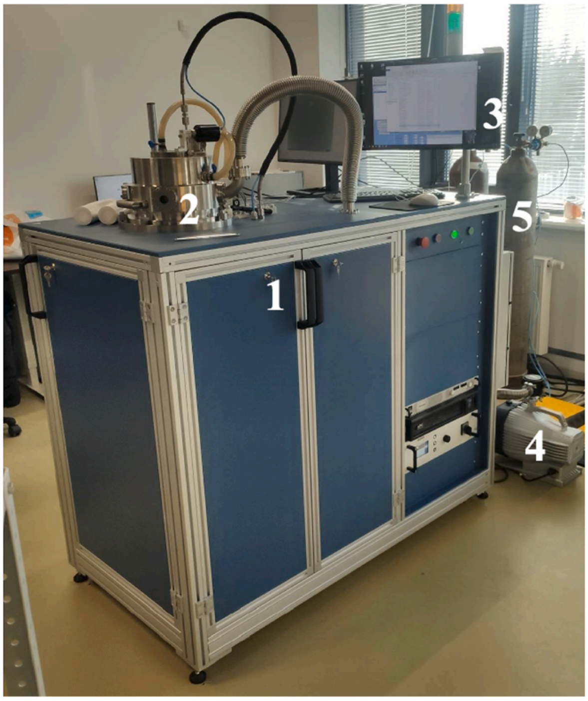

Fig. 4. A diagram of a 2.45 GHz MP CVD reactor with a magnetron (1), a chamber (where diamonds grow, 2), control panel (3), pumps (4), electric, gas and refringent supply cables (5). Photo courtesy of OptoSystems LLC.

- Direct Current (DC) CVD [35]: plasma is situated in electrical discharge between two massive round-like electrodes (usually, molybdenum discs);
- Microwave Plasma (MP) CVD [32]: plasma is supported by microwave radiation.

We have experience in DC- and MP CVD. Both synthesis are widely used for academic purposes [36], which are not limited to diamonds only. However, for our analysis, we will separate MP CVD from others CVD methods due to its ability to synthesize diamonds with the minimal level of impurity; the HF- and DC CVD methods are not suitable to synthesize electronic-grade diamonds, which is why we will omit these sub-methods from our scope, despite their advantage, such as productivity. To make it clear, DC CVD is able to be very productive thanks to the significant zone of diamond growing which is limited mainly by the power of electrical discharge. However, the purity of DC CVD diamonds is significantly lower than MP CVD, due to parasitic metallic impurities in the diamond cell.

There is a limitation of our analysis that should be mentioned in advance– we have experience in using MP CVD reactors where plasma is supported by 2.45-GHz magnetron, shown in Fig. 4; that is the only frequency we are familiar, although there is another widely-used "diamond" frequency of magnetron −915 MHz. Therefore, we need to distinguish between two sub-MP CVD methods to evaluate the CapEx per annualized productivity of reactors. All our experiment-based results for reactor productivity are applicable for 2.45-GHz MP CVD reactors only, not for all types of MP CVD's devices.

Our 2.45-GHz 6-kW MP CVD reactor is able to synthesize about 7 carats per week, which has been empirically validated through numerous experiments. The productivity of the CVD reactor can be much higher depending on the configuration of the device and synthesis conditions, although we use the results obtained under our experimental conditions. Thus, in the 24/7 regime, the annualized productivity of this reactor is about 364 carats. The same should be mentioned about nitrogen and size in case of HPHT method above – (near-) colourless middle-sized jewelry-market demanded product as a benchmark. However, there is a different correlation between productivity and size – the smaller the diamond size is, the bigger the productivity of an HPHT press, while the bigger the diamond size, the bigger productivity of a CVD reactor. To make it clear, the big-sized initial seeds are welcomed by CVD growers, as they are able to increase productivity dramatically. All our observations (as depicted in the graphical abstract) are based on different initial seeds' usage, from 3.0 × 3.0 mm to 9.8 × 9.8 mm; the "right tail" of this seed-distribution is more promising in terms of productivity.

The most sophisticated aspect of this study is an answer to a simple question – how much a MP CVD reactor costs? As there are no publicly available price lists from reactor developers, inquiries to developers typically result in confidential offers being provided. Thus, even if we have adjusted offers from leading CVD developers around the world, we would not be able to publish the figures in order to avoid conflict of interest. Moreover, the price depends on the kind of customer, some developers encourage academic-focused buyers (we are) by providing a substantial discount. Hence, despite the fact that we are sure in our productivity-related numbers, the price of MP CVD devices should be given as a range, similar to the HPHT case, based on our statement.

The CapEx for one 2.45-GHz MP CVD reactor starts from $200 thousand and can go up to $600 thousand, according to our many-year correspondence with particular CVD developers around the world. If the first figure ($200k) is closer to South-East Asia developers or laboratory-assembled devices, the right frontier ($600k) reflects approved devices from well-known developers, with years of expectation due to a long customers' queue.

Hence, the on-time CapEx for one 2.45-GHz MP CVD reactor to support 364 carat of productivity per year is $200–600 thousands. It is **$549** to **$1648** on-time CapEx per annualized carat (annu. ct) according to Eq (1).

3.3. *Mined diamonds*

This part of the study was made possible by De Beers Group's openness – the data of the new Canada-based mining project Gahcho Kué is open to everyone [27] – the on-time investment is around $500 million for 51 % stake of diamond entity with 4.5 million carat per year productivity. According to professional media (The Northern Miner, May 2014 [37]), the Gahcho Kué projects was initially valued at $858.5 million (including, citation "*a $76-million contingency*"), therefore we cannot say that De Beers bought the control with a discount – price paid was relevant. In addition, the Gahcho Kué is not the richest diamond field – there are about 1.54 carat per one ton of ore only [27] – for instance, the De Beers global competitor ALROSA best diamond pipe (The "Inter" [38]) has about 8 carat per ton of ore. Although according to the latest data, ALROSA has started construction of a new mine Mir-Gluboky with an investment of $1.26 billion [39]. The production volume of the new mine is estimated at 3 million carats of diamonds per year, respectively capital expenditures according to Eq (2) will amount to **$420/annu. ct**. In other words, the Gahcho Kué is an appropriate benchmark to analyze – the reasonable CapEx was invested into an average diamond field. Other factors, such as its localization near the Arctic Circle and the lack of any initial infrastructure (electrical greed, roads, etc.), are methodologically relevant as well.

Table 1
The on-time CapEx per annualized carat for analyzed methods.

Origin of diamonds	On-time CapEx per annualized carat of productivity, $/annu. ct	Notes
HPHT	**[500−833]**	750- and 850-mm China-made presses, about 1200 ct. per year (near-) colourless middle-sized diamonds
2.45-GHz MP CVD	**[549–1648]**	2.45-GHz, (near-) colourless, single crystal, reactor capacity is about 364 ct. per year
Gahcho Kué mining project	**217**	Gahcho Kué, DeBeers Group, mix size of diamonds

Hence, according to Eq (2), a $500 million on-time investment for 51 % of 4,5 million-carat-per-year-project is **$217/annu.**

One should also take into account the limited resources of each deposit and the duration of their operation. For example, despite the fact that production at Gakhcho Kué showed growth until 2022 and reached 6.9 thousand carats, further forecast suggests some fluctuations between 7.1 and 3.3 thousand carats [40], which is due to the limited lifetime of the deposit. In general, the world production of rough diamonds is declining slightly, so according to data [41] from 2005, the global output was about 177 million carats, and in 2021, the production fell to 116 million carats.

4. Discussion

The HPHT, 2.45-GHz MP CVD and Gahcho Kué mining project are analyzed and the findings are presented in Table 1:

Table 1 shows how many US dollars should be invested on-time into a diamond's manufacturing facilities for one annualized carat. As one can see, mining is superior in terms of on-time CapEx per annualized carat; it is lower than the smallest estimation for both analyzed lab-growing methods – HPHT and 2.45-GHz MP CVD. Moreover, the Gahcho Kué could serve as a benchmark for all the diamond mining industry. In fact, it was a greenfield [42] diamond project – all its financial history is open for analysis. The serious gap between the lowest and highest CapEx per annu. ct is in 2.45-GHz MP CVD – the difference of three times from 549 to 1648 $/annu. ct – these results cannot be averaged as there are significant variations in technology and consequently in additional equipment. The HPHT estimation is more balanced, with a difference of 333 $/annu. ct between the two figures, depending on where the presses are installed - the left number (500 $/annu. ct) is for a location close to "home-territory" in China, and the right one (833 $/annu. ct) is for elsewhere. There is not a dramatic divergence between the two HPHT figures.

To shed additional light on the CapEx in diamond projects, we have to discuss some methodological uncertainties associated with this study, as well as technological trends which can significantly raise the productivity of lab-grown methods. It is also important to note that the jewelry diamond market is not unlimited.

First of all, there are limited diamonds on each diamond field. For instance, the investigated by us *Gahcho Kué* is estimated to eventually produce 54 million carats total; the lab-growing facilities do not have any such limitation – "Diamonds are forever", from Bond's movie suggests. Moreover, synthetic diamonds have the same physical properties as natural diamonds, but they take weeks to grow rather than billions of years. Lab-grown diamonds are taking a larger share of the global diamond market each year, and their production volume is growing along with it. As of 2019, the production of lab-grown diamonds was estimated at about 14.6 billion carats [43]. The lab-grown diamond market is expected to grow at an average annual rate of more than 7 % from 2022 to 2025 [44]. Meanwhile, market revenues from CVD diamonds are much higher than those from high-pressure diamonds due to the lower economic value of the latter [45]. Clearly, these facts should be taken into consideration when one considers diamond manufacturing. However, the mechanisms used in lab-growing, such as the hydraulic presses, magnetrons, pumps, also have their own limited lifetime.

Secondly, the diamond prices, which depend on numerous parameters, are generally more attractive for lab-growers who are focused on colourless, market-demanded stones, rather than mined all-grades stones. For instance, in January 2018, before the pandemic, according to Rapaport News (citation [46]): "*The company sold a total of 351,000 carats from its Gahcho Kué mine for $27.3 million during the month, at an average of $78* per *carat. The increase from $53* per *carat in December was due in part to an improvement in the size distribution, as well as the quality of fancies and special-size stones, the company explained*". As can be seen, the Gahcho Kué diamonds cost dozens of *US$* per *carat, all depending* on "size distribution". To make it clear, if two gem-stones, a natural and lab-grown one, have equal parameters – including color, size, shape and purity – the lab-grown would be priced significantly lower due to customer stereotypes. However, the lab-growers who are focused on synthesis of high-quality gem-stones would sell their products at a better price on average than mined diamonds, as these are randomly distributed by parameters.

Thirdly, the lab-growing methods have greater potential for development than mining, despite promising advancements in the latter – people-less technology, for instance. However, mining is less affected by ultimate achievements in applied physics than lab-growing, which is based on such breakthroughs. The rise of power or/and changing frequency/pressure/methane's proportion into MP CVD reactors would change the productivity dramatically, as well as the rise of volume of the inner chamber into HPHT hydraulic base.

Lastly, the rough diamond jewelry market is tiny, valued at around $12 billion [47] per year. There just is not enough space to grow there. The global electrical and optical segment is more promising in terms of revenue, although the mined diamonds are not suitable for it, due to the uniqueness of each stone. Therefore, despite the sensitive divergences between CapEx per annualized carat of mined (Gahcho Kué) and lab-grown projects, all other parameters should be carefully considered before making an investment.

5. Conclusion

Three modern approaches to fabricating rough diamonds have been investigated in terms of capital expenditures per one annualized carat (CapEx, US$/annu. ct) using open sources and authors' experimental data. It was found that high-pressure, high-temperature (HPHT) method demands from 500 to 833 US$/annu. ct, figures that are very sensitive to the place of installation, with China being the most suitable due to its manufacturing of HPHT presses and offering other competences to exploit in HPHT-based diamond facilities. The microwave plasma chemical vapor deposition (MP CVD) method was analyzed separately. Only 2.45-GHz MP CVD reactors' experimental data were used to show that CapEx per annualized carat would be between 549 and 1648 US$/annu. ct, which mainly depends on reactor's manufacturers. The South-Eastern Asia CVD developers and laboratory-based teams offer significantly more affordable prices on CVD systems, but there are higher risks in post-production service. The growing demand for man-made diamonds is due to technological advances that can significantly reduce capital costs, increase production volume, reduce price and enable special uses of diamonds in the optical and electronic industries. The De Beers Group mining project Gahcho Kué was found significantly more attractive among the three in terms of CapEx per annualized carat – 217 US$/annu. ct; however, other parameters such as project lifetime, investments, average product price and global jewelry market limitation should also be taken into consideration. The impact of diamond mining and synthesis on the environment remains a controversial issue. In general, the manufacture of diamonds in the laboratory compares favorably with the methods used for natural diamond mining. Synthesis does not cause as much damage to the environment as mining, which requires the removal of land, disturbance of ecosystems over a huge area, consumption of fresh water and fossil fuels. However, it's not so easy with lab-grown diamonds either. Diamond growing requires a lot of energy, which does not always come from renewable sources and leads to greenhouse gas emissions.

Data availability statement

All data required to support this study is already mentioned in the manuscript.

CRediT authorship contribution statement

Vladislav Zhdanov: Writing – original draft, Visualization, Supervision, Methodology, Conceptualization. **Lukasz Andrzejewski:** Writing – original draft, Visualization, Validation, Investigation, Data curation. **Julia Bondareva:** Writing – review & editing, Writing – original draft, Visualization, Methodology, Data curation. **Stanislav Evlashin:** Writing – original draft, Visualization, Validation, Supervision, Methodology, Conceptualization.

Declaration of competing interest

The author declare that he has no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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