Investment opportunities

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Published in:
International Journal of Hydrogen Energy

DOI (link to publication from Publisher):
10.1016/j.ijhydene.2021.11.206

Publication date:
2022

Document Version
Accepted author manuscript, peer reviewed version

Citation for published version (APA):
Ghaebipanah, P., Bornapour, M., Cui, X., & Guerrero, J. M. (2022). Investment opportunities: Hydrogen production or BTC mining? *International Journal of Hydrogen Energy*, *47*(9), 5733-5744. Advance online publication. https://doi.org/10.1016/j.ijhydene.2021.11.206

Investment Opportunities: Hydrogen Production or BTC Mining?

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Abstract: Green hydrogen production investment is encouraged for GHG reduction while cryptocurrency mining might be more lucrative. GHG emission reduction may visibly happen in areas of attention while other dirty businesses can grow in the shadow due to inconsistent carbon policies. This paper sheds light on the importance of integrated regulatory policies among cross markets to nail a tangible global impact on GHG emissions. The levelized cost of hydrogen production via grid-connected electrolysis is calculated at around 4 €/kgH2 in Europe. The scenario-based analyses on the current markets indicate that investments in the water-splitting industries can be as attractive as BTC mining if the products are fully purchased at prices above 20 €/kgH2. Such a deep economic chasm can be moderated by policymakers. Crypto Tax is introduced to interconnect the purchased price of hydrogen with the BTC market by tagging the coins regarding the mining origins. Cryptocurrency miners are obliged to provide dynamic subsidies for electrolyzers depending on their emission coefficients and the coin prices. Simulations confirm that the crypto tax leaves insignificant impacts when BTC falls below 10000$; however, cryptocurrency rushes, like in 2020-2021, can be harnessed in favor of green hydrogen production. The efficacy of crypto tax is also showcased by Net Present Value (NPV) trajectories for BTC soaring up to 100000$.

Keywords: Bitcoin, Crypto Tax, GHG Emission, LCOH, Net Present Value, Profitability Analysis.

1. Introduction

Today, sustainability is the main keyword in plenty of scientific subjects. A global energy dream is to find economically feasible replacements for fossil fuels with zero emissions. Several alternatives are in the race to develop from lab to market in commercial scales such as hydrogen, ethanol, methanol, etc. where none of them is the definite prevailing solution yet [1]. The cheapest hydrogen referred to as “grey” is produced via natural gas with large amounts of carbon waste. A cleaner version is called “blue” when the carbon is recaptured and/or reused. The “green hydrogen” denotes RES-based electrolysis with ideally zero emissions [2]. Among all, steam methane reforming (SMR) is currently the dominant hydrogen production way on commercial scales

[3]. However, environmental restrictive policies are pushing industries towards GHG reduction. Human being has been also aware of water electrolysis for decades but never became an economically viable alternative. Electrolysis has garnered more attention after public awareness about global warming and emission reduction policies. Nowadays, the aim is to reduce electrolysis costs down to competitive levels compared to other alternatives. Depending on the country, hydrogen market prices in 2020 are 1.18-2.03 €/kg for blue hydrogen and 0.85-1.52 €/kg for high-carbon grey hydrogen [4]. If the electricity and gas prices remain unchanged, the projected prices for 2030 are 1.1-2.4 €/kg and 2-2.5 €/kg for the green and grey hydrogen respectively €1.1-2.4/kg [5]. Today, many countries are still at the strategy and policy stages but some others have set explicit capacity targets. Australia and Chile aim for reaching 1.27 €/kg by 2030 to become the cheapest in the world [6].

There are various parameters besides capital expenditure (CAPEX) and operating expenditure (OPEX) influencing the green hydrogen production costs. For instance, taxation rate, costs of civil works, grid connection, and permits [7][8]. However, the cost of electricity is believed a substantial parameter that can barricade the price reduction [9]. The suggested configurations for scalable electrolysis via cheap electricity sources can be categorized as follows:

- Curtailed electricity: Power systems with a high share of renewables may experience periods when the generation exceeds the demand. This can be interpreted as negative prices in the electricity markets and considered an opportunity to store energy under the Power-to-Gas (P2G) concept in competitive prices. Technologies such as PEM electrolyzers are flexible enough to coordinate their operation regime with cheap electricity periods [9]. However, this strategy needs a meaningful probability of occurrence for low price hours to make it economically viable. Currently, there are not many power systems with the abovementioned attributes [10]. It is expected, from the investor's viewpoint, to have an intensive use of the plant to compensate for the relatively high electrolyzer's CAPEX.
- Off-grid RES: There might be plenty of geographic locations with ample RES capacity where electrolyzers can benefit from extremely cheap electricity. For example, it is potentially available as PV, WT, and hybrid systems in Saudi Arabia, Brazil, and Chile respectively [11]. Although this can remarkably reduce OPEX due to electricity, the necessity of extra equipment and infrastructures such as storage and transportation may grow.

Water electrolyzer's profitability in the grid-connected mode is investigated in different European markets. The business model simulations on several scenarios show that the hydrogen price is the most critical parameter. Moreover, cross-commodity arbitrage trading is more capable of profit compared to the transportation sector and industries [12]. A similar case study in Denmark finds investments in electrolyzer/fuel cell in the transportation sector more gainful than grid-service provision [13]. Multipurpose hydrogen production systems such as Power-to-Industry, Power-to-Mobility, and Power-to-Power can be more prolific than single usage plants due to the higher number of operation hours [14]. Furthermore, large-scale storage systems can provide flexibility and elevate economic feasibility [7]. A case study in Spain denotes the contribution of grid services to the hydrogen fuel fascination for the transportation section if a certain demand for FCEV is provided [15]. A purely RES-based hydrogen production case for very heavy vehicles in New Zealand verifies that the electricity price is the most significant parameter [16]. Meanwhile, an off-shore hydrogen analysis signifies capital costs and discount rates as the most sensitive parameters from the investors' perspective [14]. Another study in the North Sea finds electrolyzers capacity and offshore-onshore distance as the most influential factors in the economic analysis [17].

Innovative ideas like dedicated off-shore [18], stand-alone PV [19], or sailing wind turbines [20] are also suggested to produce green hydrogen using remote RES farms in long-term perspectives. A study on the current European market conditions confirms that P2G plants are not profitable even though there are low electricity prices in power systems with higher shares of RES [21]. The cost of green hydrogen production markedly varies with several uncertain factors such as the energy source, electrolysis technology, hydrogen usage, storage and transportation, market frames, etc. [22][23][24]. Table I summarizes the extracted marginal prices through different configurations/operations in the recent publications. The noticeable variance in the levelized cost of hydrogen verifies the uncertainty of analysis and immaturity of the green hydrogen section. It is frequently mentioned that hydrogen is at the beginning of a revolutionary road. The current market conditions may not allow for the constantly economical operations of P2G even though several extreme optimistic analyses are reported. Profitable business cases are imaginable in the future with a combination of CAPEX reduction and hydrogen revenue enhancement [25]. The abovementioned profitability analyses sometimes provide economic viabilities; however, private investors normally seek the most lucrative opportunities with the lowest risks. For instance, a frequent inaccuracy in flexible electrolyzers is to be overoptimistic about the excess RES and free electricity in power grids or to ignore the expectation of private investors.

Table I. Green hydrogen marginal price reports by 2020.

Configuration/Operation	Region	H2 Price (€/kg)	Source
Grid-connected	USA	7.4	[26]
	USA	5.2	[27]
	Europe	11	[26]
	Germany	5	[12]
	Germany	5.9	[7]
	Belgium	8.1	[7]
	The Netherlands	5	[12]
	Spain	5	[12]
	Iceland	8.5	[7]
	Denmark	2.5	[9]
	Denmark	4.8	[13]
	China	4.6	[27]
	Japan	8.4	[9]
	New Zealand	4	[16]
Grid-connected/off-peak	USA	3.4	[27]
	China	2.3	[27]
Curtailed Electricity	USA	9.3	[26]
	USA	4.6	[27]
	Europe	9.1	[26]
	China	1	[27]
Offshore WT	Global	4-8	[20]
	Denmark	5	[28]
	Norway	5.2	[29]
	Ireland	5	[18]
WT	USA	3.6	[30]
PV	USA	3.1	[19]
	Spain	3.4	[19]
	Saudi Arabia	3.3	[9]
	Australia	3.1-3.6	[9]
	Australia	3.3	[19]
	Japan	4	[19]
	Chile	3	[19]

1.1. Contributions and Novelties

Whereas most studies compare green hydrogen production costs with other fossil-fuel-based methods, this paper conducts a wider analysis from the private investors' viewpoint. This is perhaps a more realistic strategy for green hydrogen expansion to rely also on private sectors. However, this can be accelerated through incentive packages supported by policymakers. The fundamental motivation of this research is to highlight the possible consequences of cryptocurrency booming markets on green energy developments. It seems necessary to reconsider the current taxing systems on international scales to avoid deceleration of investment in green hydrogen production. Similar to the CO2 tax, designed to push car owners toward electric vehicles, the crypto tax tries to maintain green energy production attractive enough compared to cryptocurrency mining. The following bullet points are worthy of attention in this research:

- The profitability of grid-connected electrolysis is compared with bitcoin mining to quantify the attraction of cryptocurrency investments. The huge gap from 2020 onwards may impede the expansion of private investments in green hydrogen production.
- The levelized cost of grid-connected electrolysis in Europe is approximated around 4€/kgH_2 which is not competitive with fossil-based alternatives yet. Moreover, the attractive purchased price of hydrogen for electrolysis is estimated above 20€/kgH_2 in comparison to BTC mining.
- Crypto Tax is introduced to restrict GHG emitting cryptocurrency mining by tracing the carbon footprint in BTC originations. The miners' profit is tied with their GHG emission via dynamic subsidies depending on the BTC price. The self-tuning crypto tax redirects private investments in favor of either RES-based mining or other eco-friendly opportunities such as water electrolysis. The intersection of NPV planes for BTC mining and green hydrogen production indicates alarming consequences if BTC price flies up. However, the crypto tax is unnecessary as long as BTC stays below 10000$.

2. Green Hydrogen Market

Hydrogen has already found its own way to be noticed as a capable alternative among sustainable energy solutions. Today, there is no doubt for governments and companies that the hydrogen market has remarkable potentials beyond borders. For instance, Australia and Norway, regarding their massive RES potentials, aim for the rapidly growing markets in Asia [9]. However, investments in such projects directly depend on the revenue of selling hydrogen to customers. Indeed, the hydrogen price has a pivotal role in driving the electrolyzers' deployment rate. Today, the hydrogen pathway is still unclear in terms of policy statements, certain demand, and low-cost RES. However, the European Commission already considered hydrogen as a key vector across energy sectors and highlights hydrogen as an investment priority. For instance, €9 billion is suggested for hydrogen as part of the economic recovery package in Germany due to the COVID-19 crisis with €2 billion exclusively assigned to international partnerships [6].

At the moment, not only investors but also customers have hesitancy in the money willing to pay. The end-users can be divided into three different sectors of transportation, industry, and natural gas systems. The marginal prices may noticeably depend on the customer type and location since hydrogen cannot be easily transported through the already existing infrastructures (i.e., gas pipelines). Part of these added costs can be alleviated when the hydrogen technology matures but a meaningful cost reduction comes with large-scale investments. Besides, futuristic scenarios are erroneous due to uncertain policies such as GHG emission certificates. Hence, the hydrogen price can be estimated with a broad variance in different sectors. The marginal prices for the transportation can be 4-10.4 €/kg while it might be 3.3-9.4 €/kg for light industries like glass production and fat hydrogenation and even cheaper for larger industries such as refineries, steel manufacturing, and ammonia or methanol production facilities (1.1-4.5 €/kg). The lowest achievable prices may happen in the natural gas systems where it is directly coupled to the NG spot market price. If the biomethane injection tariffs also apply for green hydrogen, the marginal price might range between 1.3 to 2.6 €/kg [12].

Although the acceptable price for urban Fuel Cell Buses (FCB) is 4-5 €/kg [20], vast investments in this section are questionable in the presence of Battery Electric Buses (BES) [25]. Probably one of the most advanced markets in terms of hydrogen fuel is fuel cell forklifts where the acceptable price is 6-7 €/kg [20]. They have been commercially in use for years due to the intrinsic advantages of zero-emission and quick refueling. Hydrogen-driven aircraft is also grabbing attention because of the environmental measures; however, the hydrogen fuel only in the range of 2-3 €/kg could be comparable with the jet fuel [20].

Several studies show that cost reductions in electrolyzers cannot compensate for high electricity prices. Only massive deployment of electrolyzer followed by supportive policies can make green hydrogen cheaper than other low-carbon alternatives over time. If so, green hydrogen might be competitive, depending on the country, with blue hydrogen by 2030 [6]. Remunerative actions that may boost the green hydrogen sector can be tax breaks for the domestic production of electrolyzers, direct grants, conditional and convertible loans, feed-in tariffs, etc. [6].

3. Cryptocurrency Mining

Bitcoin mining is known as a dirty business since its carbon footprint is not easily tracible. Countries with low-cost electricity and ineffective GHG emission regulations are popular with cryptocurrency mining camps. It is estimated that half of the total coins are mined in areas where the electricity is cheap, poorly taxed, and mainly powered by fossil fuels. The Cambridge Center for Alternative Finance estimates coal accounts for 38% of miner power. The recent actions by China in restricting cryptocurrency mining does not necessarily help GHG emission reduction. In practice, mining camps may grow more in other apt countries such as

Kazakhstan, Venezuela, and Iran where the inspection system is unclear. Although some studies show RES-based cryptocurrency mining can be economically viable under circumstances [31], the share of such "clean coins" is ignorable. Since BTC is the dominant currency in the crypto market, this paper considers BTC mining costs/benefits in the calculations (Table II). The daily mined bitcoin varies with the share of the total network hashrate carried out by the miner. The higher percentage of hashrate allocated to the miner, the bigger bonus rewarded as follows:

$$BTC_{M1}^{Day} = BTC_{Total}^{Day} \times \left(\frac{Hr_{M1}^{Day}}{Hr_{Total}^{Day}}\right) \tag{1}$$

where BTC_{M1}^{Day} is the daily reward of the miner, BTC_{Total}^{Day} is the total bitcoins mined per day, Hr_{M1}^{Day} is the hashrate share of the miner, and Hr_{Total}^{Day} is the network hashrate.

There is high competition among different brands to introduce miners with higher efficiencies. The mining capacity and energy consumption have remarkably improved in recent years. Considering three miner models listed in Table III and assuming BTC price 50000$, different scenarios are generated with 5% variations in electricity prices from 2020 to 2021 in Denmark. The accumulative yearly profits for 128 mining machines before tax are depicted in Fig. 1. It can be concluded that state-of-the-art miners are more profitable due to improved efficiencies.

Table II. The involved parameters in BTC mining calculations.

Parameter	Value	Source
BTC Network Hashrate (6-month avg.) [TH/s]	150 E+6	[32]
Block Time [s]	600	[32]
Block Reward [Coins/Block]	15.5	[32]

Table III. The parameters of mining machines.

Model	Miner Consumption [kW/h]	Miner Hashrate [TH/s]	Miner Price [USD/piece]
Antminer S19 Pro	3.25	110	15000
Canaan Avalon 1246	3.15	83	10000
WhatsMiner M20S	3.12	68	5000

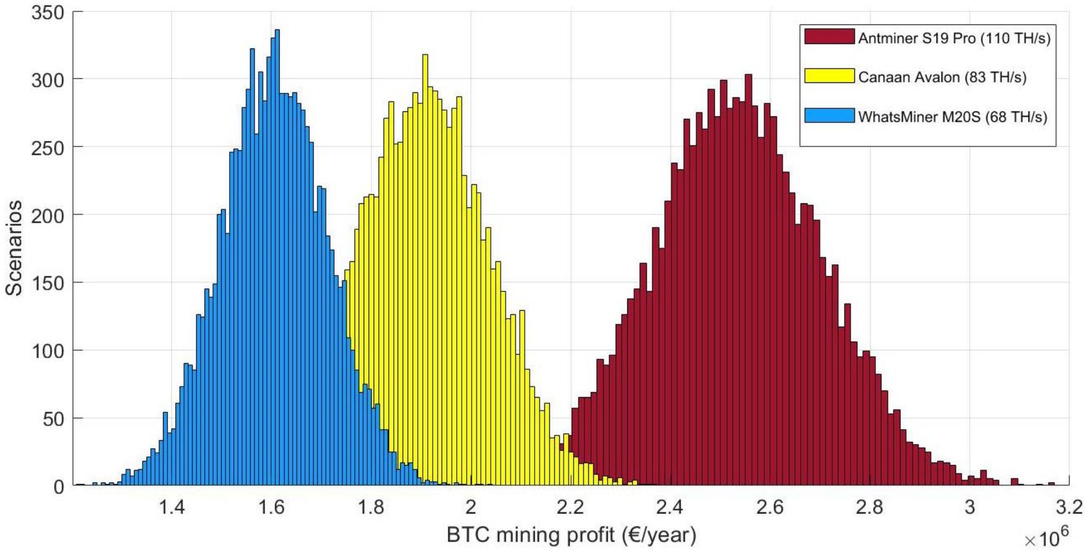

Fig. 1. Yearly profit of mining camps using different miners.

4. Economic Assessments

The profitability of both water electrolysis and BTC mining may result in diverse outcomes depending on the involved parameters such as technology, configurations, lifetime, maintenance, energy price, taxes, etc. A scenario-based methodology is developed to consider the uncertainty effects on the profitability analyses. The problem is seen through the current market uncertainties such as BTC and electricity prices along with the future trends.

Both Alkaline and PEM electrolyzers are already advanced and mature technologies in commercial scales with slight differences. PEM electrolyzers are privileged in flexible operating conditions, i.e., the curtailed electricity, while alkaline ones have the lowest CAPEX. Larger production capacities can reduce the costs; hence, electrolyzers are typically installed in series of modular units. Solid Oxide Electrolysis Cells (SOEC) have also garnered attention due to high efficiency even though they are not fully commercialized yet. Table IV summarizes the status quo and pros/cons of alkaline, PEM, and SOEC [33]. The CAPEX of Alkaline electrolyzers may range from 400 to 900 €/kW while it is slightly higher for PEM (600 to 1200 €/kW). The CAPEX of SOEC is estimated above 2000 €/kW as it is not fully commercialized yet. However, these values are expected to drop below 250 €/kW for all three technologies by 2050 [6]. Several studies verify that electrolysis in the scale of MW can markedly cut down LCOH [34][7][6]. Since CAPEX is a substantial element in investment decisions, this paper considers a 418kW alkaline electrolyzer, the largest commercial single unit at the moment, powered by the national grid of East Denmark [35]. Note that the mining camp included 128 miners (Antminer S19 Pro) for the sake of equal power consumption to the hydrogen electrolyzer

(HyProvide A90). Aside from the electrolyzer, compression and on-site storage systems are also necessary to provide flexibility but the technology and capacity leave a meaningful impact on the CAPEX. The levelized cost of hydrogen production can be calculated as follows [14].

$$LCOH = \left(\sum_{i=1}^{N} \frac{total\ costs\ in\ year\ i}{(1+discount\ rate)^i}\right) / \left(\sum_{i=1}^{N} \frac{produced\ hydrogen\ in\ year\ i}{(1+discount\ rate)^i}\right) \qquad (2)$$

where N is the number of years.

Table IV. The pros and cons of dominant electrolysis technologies.

Type	Advantages	Disadvantages
Alkaline	Proven performance MW stack size Durability Low CAPEX Non-noble materials	Low current density Corrosive electrolyte Slow dynamics Gas permeation
PEM	High current density Simple and compact structure high-pressure hydrogen production Flexible operation	Expensive membrane Noble materials Acidic environment Degradation
Solid Oxide	High efficiency Non-noble materials Co-electrolysis (syngas) Reversible operation (fuel cell)	Bulky design High CAPEX Degradation Brittle ceramics Sealing issues

The number of active hours in a year (load factor) has significant impacts on LCOH. Electrolyzers are meant to keep running all year round to alleviate operation costs such as start-up/shut-down; however, electricity price peaks, technical faults, periodic services, etc. are inevitable. The dependency of LCOH on the operating regime using the given data in Table V is plotted in Fig. 2. It can be seen that higher load factors running under low-cost electricity remarkably drop the LCOH. Assuming normal distribution uncertainties in electricity price, the LCOH with 100% load factor is plotted in Fig. 3 for 10000 scenarios in Denmark. It should be noted that regional tax and levies are ignored in this analysis. Similar assessments are applied on some other European day-ahead electricity markets to illustrate the difference. Fig. 4 gives a rough idea of LCOH in Europe where the lowest costs are more likely achievable in Norway. As mentioned earlier, several parameters can influence LCOH; hence, a sensitivity analysis with 25% variations is developed in Fig. 5. The significant alterations result from both CAPEX and the electricity price while OPEX and the discount rate leave minor impacts. Similarly, the net profit sensitivity analyses for both electrolysis and BTC mining are respectively provided in Figs. 6 and 7. Hydrogen production is substantially affected by the market price; hence, it is naive to solely put hope on the technology development and CAPEX reduction. The striking difference between the efficacy of hydrogen market price and other factors implies that accelerating subsidies should primarily target the H2 price promotion.

In spite of the welcoming atmosphere for hydrogen production, BTC mining is restricted in many countries. Rules and regulations on cryptocurrency are still immature; therefore, it is hard to develop a comprehensive study among countries. Using the given data [31] and the BTC average daily prices in 2020-2021, the mining profitabilities are plotted in Fig. 8. It is worthy of note that cryptocurrency mining has legal restrictions in China, Iran, and Russia. Also, the taxing systems might not be as transparent as in Canada and the USA.

Despite the water electrolysis, BTC mining profitability is not merely shaped by the final product value. BTC mining is a competitive group activity where individuals are relatively awarded. Fig. 7 verifies that the profitability of a mining camp depends also on the network difficulty. This is a self-regulating mechanism of BTC to maintain the balance on the network. It should be noted that among all parameters, BTC price has shown the most volatile one. Despite the network difficulty and hashrate, the BTC price is not mathematically modeled. In practice, BTC price is still absolutely unpredictable even in the short term.

Fig. 9 shows the day-ahead electricity price in the national grid of Denmark (DK2). The price history of BTC is also depicted in Fig. 10. Note that 10000 scenarios are generated with the assumption of 5% and 20% deviations in day-ahead and BTC markets due to the relatively high volatility of crypto markets. The distribution of profitability balance can be calculated with the floating hydrogen price as follows:

$$Price_{floating}^{H2} = \frac{Profit_{Mining}(Price_{BTC}, Price_{Elec}, \dots) + Cost_{Electrolysis}(Price_{Elec}, \dots)}{Production_{H2}} \qquad (3)$$

where $Price_{BTC}$ and $Price_{Elec}$ are monthly average values.

Fig. 11 illustrates the equal profitability distribution of BTC mining and the grid-connected electrolysis if all the produced hydrogen is purchased by 20.91 €/kgH2. This means that typical private investors are readily attracted to BTC mining due to the phenomenal profit regardless of subsidies. The distinct gap between the hydrogen balancing price and the market acceptability puts a significant warning on the green hydrogen production investments.

Table V. The involved parameters in green hydrogen production calculations.

Parameter	value	source
Electrolyzer CAPEX [€/kW]	826	[16]
Compressor CAPEX [€]	125000	[13]
Tank CAPEX [€/kgH_2]	300	[13]
Nominal Power [kW]	418	[35]
System Efficiency [%]	76.2	[35]
H_2 Production Rate [kg/h]	8.1	[35]

Energy Consumption [kWh/kgH_2]	51.7	[35]
Installation & design [% of CAPEX]	30	[21]
OPEX per Year [% of CAPEX]	6.2	[12][26]
H_2 Discount Rate [%]	6	[14]

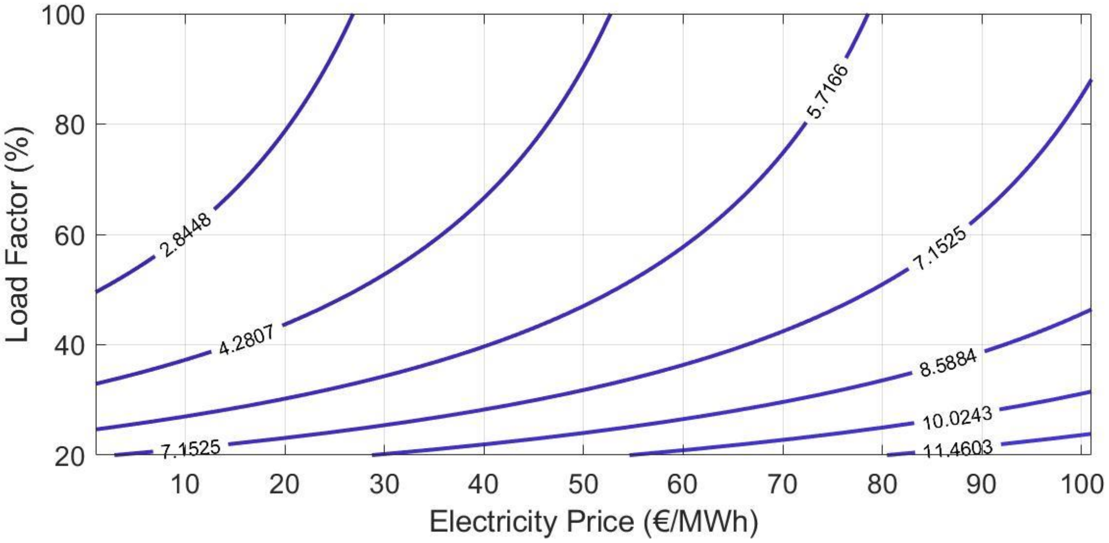

Fig. 2. LCOH (€/kgH_2) contours for different operating regimes and electricity prices.

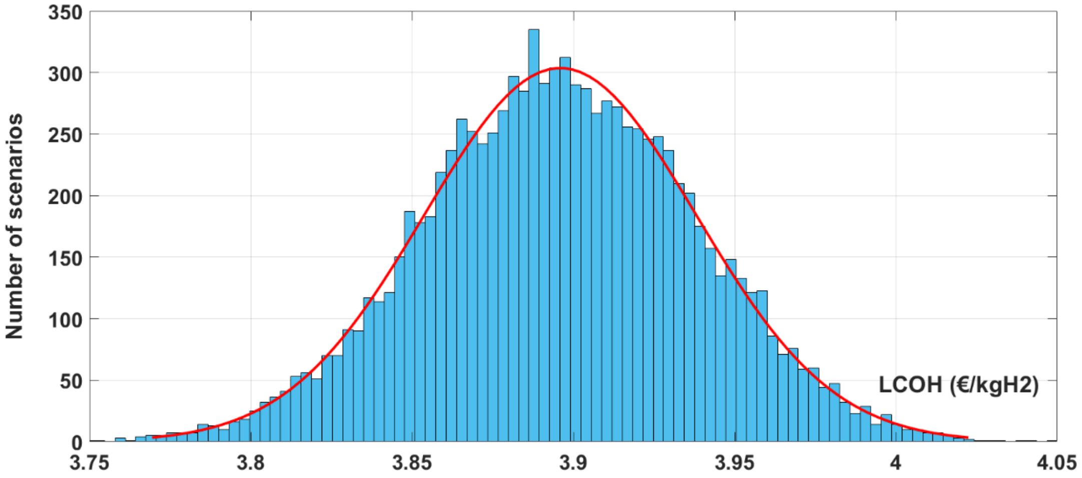

Fig. 3. Levelized cost of grid-connected electrolysis in Denmark (electricity price: monthly average 2018 to 2020).

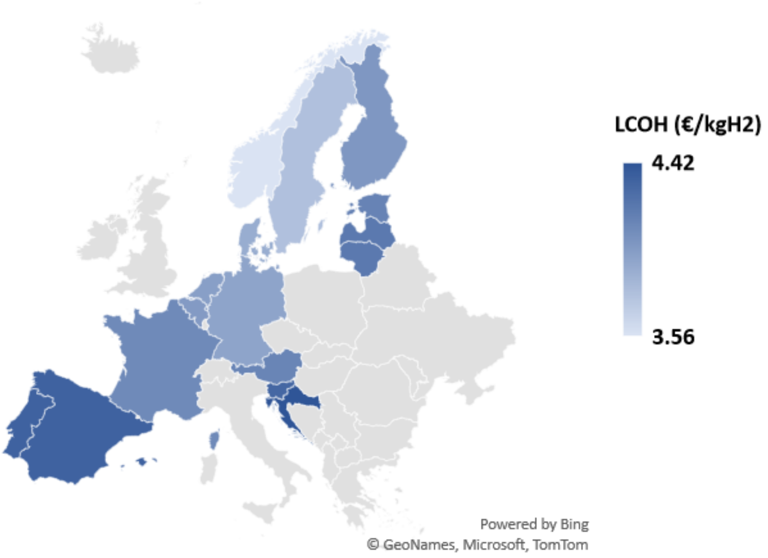

Fig. 4. Levelized cost of grid-connected electrolysis in Europe.

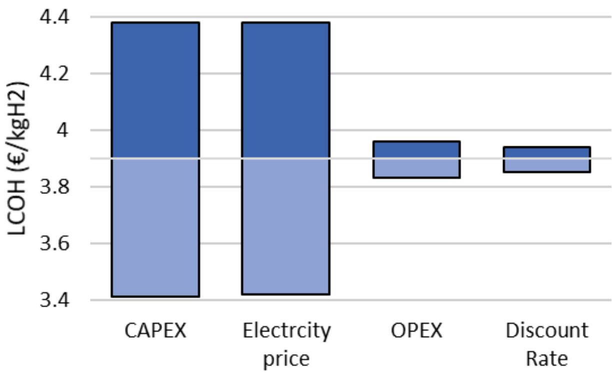

Fig. 5. Sensitivity analysis of the grid-connected electrolysis (25% variations).

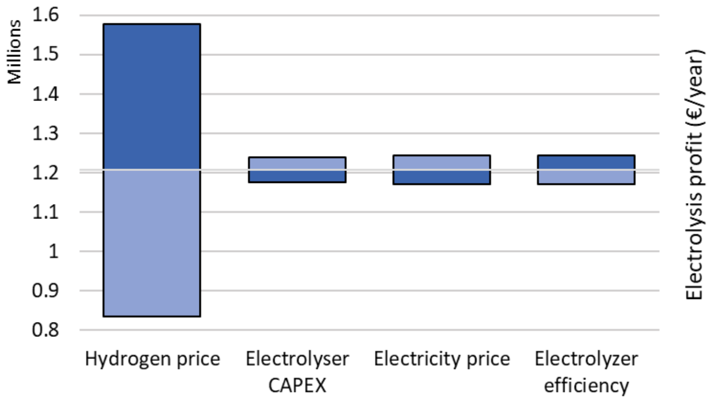

Fig. 6. Sensitivity analysis of the grid-connected electrolysis profitability (25% variations).

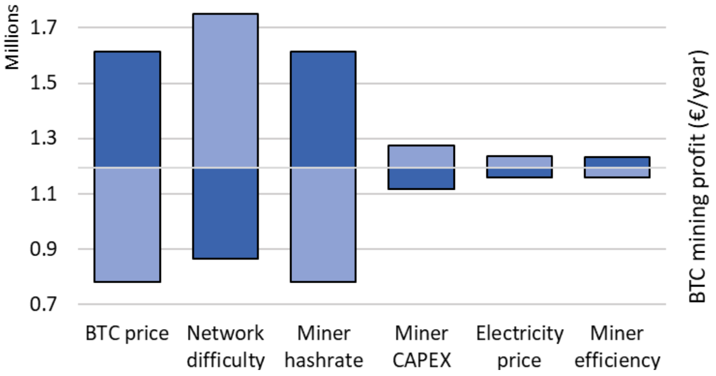

Fig. 7. Sensitivity analysis of BTC mining in Denmark (25% variations).

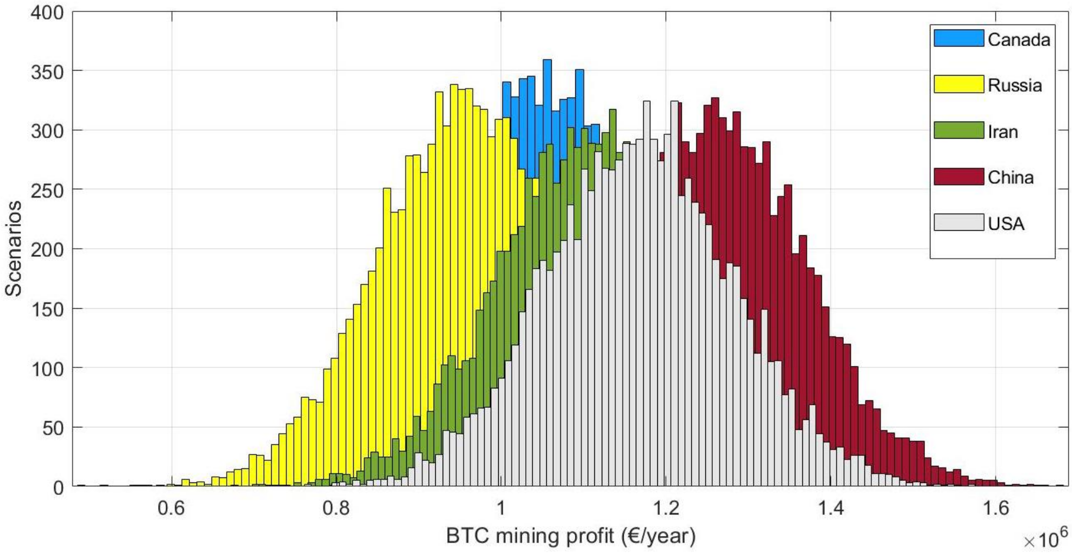

Fig. 8. BTC mining profits using the estimated electricity prices in different countries.

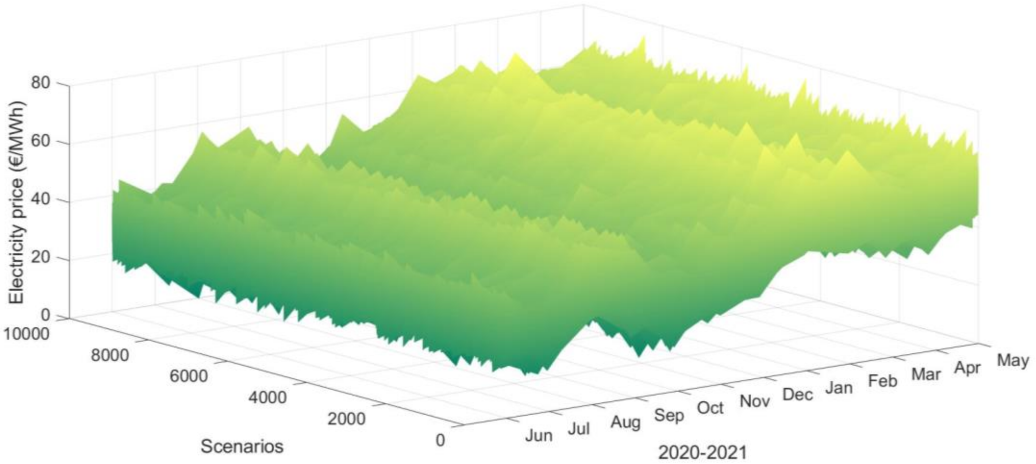

Fig. 9. The price of electricity in the Danish day-ahead market (DK2).

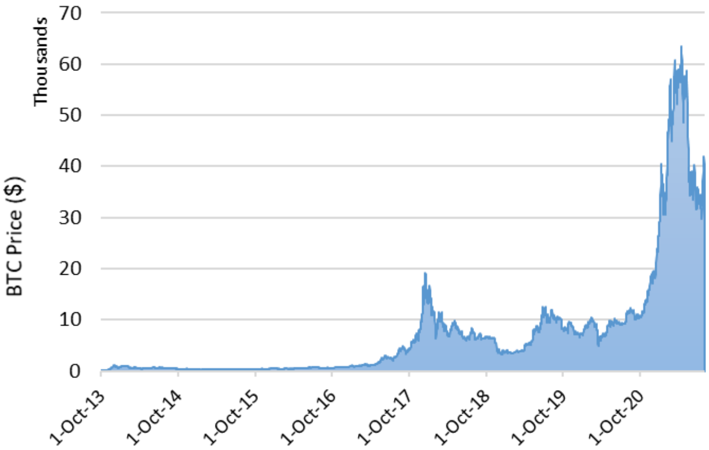

Fig. 10. The BTC price history.

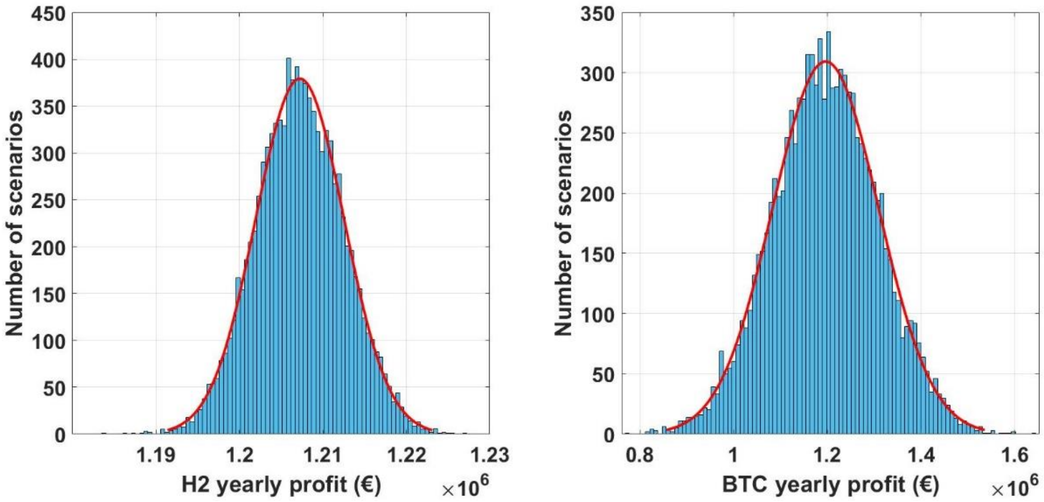

Fig. 11. Profitability comparison between BTC mining and electrolysis (Electricity price: 2020-2021, BTC price: 2020-2021, H2 price: 20.91 €/kgH2).

4.1. Future Horizons

The wide acceptance of hydrogen as a fuel is imaginable in the future but a realistic timeline is disputable since several uncertain parameters are concerned. The main unanimously agreed trends in technologies and markets are listed below:

- BTC price: cryptocurrencies in general, and BTC in particular, have proven potentials to skyrocket like in 2017 and 2020. Any sharp ascent in parallel markets may negatively affect sustainable energy investments.
- H2 price: there might be more customers, mostly in developed countries, willing to pay extra money for clean fuels. However, the global dream of hydrogen comes true when the price falls down to the fossil-based alternatives.

- Electricity price: the general trend of RES deployment aims for sustainable and low-cost energy; in addition, their inherent intermittency provides more opportunities for curtailment periods when electrolyzers can reap the benefits of cheap electricity.
- Crypto mining efficiency: mining camps are greedy profit maximizers; therefore, the energy consumption rate is expected to constantly improve in the new generations of miners. In addition to efficiency enhancements, mass production and price competence can reduce the total mining costs.
- CAPEX reduction: aside from alkaline and PEM, there are several methods in the lab scale with huge potential for commercialization. The dominancy of a single low-cost water splitting method is obscure since many options are still embryonic; however, the CAPEX anticipates a continual drop regardless of the technology type.

4.2. Crypto Tax

Although customers may be willing to pay an extra price in compensation for GHG emission in some sectors, the lack of transparent GHG tax chains in cross markets may result in floods of investments in particular pollutant industries [36]. Subsequently, emission reduction may visibly happen in areas of attention while other dirty businesses can grow in the shadow. Such incomprehensive policies may end up in GHG immigration instead of reduction. This paper suggests dynamic subsidies called “Crypto Tax” as balancing leverage to conduct investment streams toward green energy. The crypto tax, illustrated in Fig. 12, can help fledgling technologies keep the race with already commercialized market-dominant products through a self-tuning mechanism. Liberal markets will naturally settle in equilibrium points and hydrogen cannot be an exception. However, dynamic subsidies can inaugurate parallel alternatives to avoid monopolistic markets. Besides, a gradual phase-out of such nurturing plans is necessary for sustainable economies.

Crypto Tax values can be calculated via several parameters such as the cryptocurrency price, transaction fees, mining energy efficiency & carbon footprint, etc. even though controversies can be placed. Assuming mining camps with transparency and carbon footprint certificates, the following relations can be defined.

$$R_i^{H2} = Price_{Base}^{H2} + (1 - C_i^{H2}) \times (H2_i / H2_{Total}) \times CryptoTax_{BTC} \tag{4}$$

where R_i^{H2} is the promoted hydrogen price for the producer i, $Price_{Base}^{H2}$ is the hydrogen price without subsidies, C_i^{H2} is the carbon footprint coefficient of the producer i, $H2_i$ is the amount of daily delivered hydrogen by the producer i, $H2_{Total}$ is the total delivered hydrogen by all producers in the day, and $CryptoTax_{BTC}$ is the total collected crypto tax on the same day as follows

$$CryptoTax_{BTC} = P_{BTC} \times \sum_{j=1}^{m} (C_{BTC,j} \times Coin_j) \tag{5}$$

where $C_{BTC,j}$ and $Coin_j$ are respectively the carbon footprint coefficient and the daily number of mined coins in the miner j, P_{BTC} is the average daily BTC price, and m is the number of miners.

Crypto tax is indeed a reward/punishment mechanism that plays a confining role in GHG emitting miners to encourage environment-friendly cryptocurrencies. Some believe that cryptocurrency mining will be more distributed in the future; if so, taxing and supervisory mechanisms can barely monitor numerous miners in small businesses and residential spaces the same way they inspect mining camps in the scales of MW. Assuming that we are at the beginning of the cryptocurrency era, politicians and authorities are needed to consider proper measures to facilitate the wide integration of crypto trades rather than conservative prohibitions. In the first step, large companies which allow for legal crypto payments should be obliged to track and report the cryptocurrency carbon footprints for inclusion in the crypto tax. Discussions around the underground mining camps and money laundry transactions stay beyond the scope of this paper.

As mentioned earlier in equation (4), a variable purchased price for hydrogen can keep the balance of profitability between the electrolysis and BTC mining. However, the promoted prices should be mostly provided by the mining camps with higher carbon footprints. A simple solution is to bind cryptocurrency camps with electrolyzers through internal contracts where the carbon footprint coefficient ($C_{BTC,j}$) defines the subsidy rate. In other words, miners are committed to remunerating green hydrogen in proportion to their own GHG emission rate. On the one hand, this strategy pushes cryptocurrency miners toward low emission profiles. On the other hand, the water-splitting business can be more lucrative for private investors. Fig. 13 shows the impacts of subsidies as a function of BTC price to promote the hydrogen purchased price. Considering the current market price ranges and the estimated LCOH above, applying the crypto tax leaves remarkable impacts on the green hydrogen profit.

In addition to LCOH, the Net Present Value (NPV) is an assessment index to compare different investment opportunities and can be calculated as below [14].

$$NPV = \sum_{i=1}^{N} \frac{Net\ cash\ flow\ in\ year\ i}{(1+discount\ rate)^{i}} \tag{6}$$

where N is the number of years.

Major uncertainties in cash flows stem from the price of products in the upcoming years. The hydrogen price is expected to gradually fall with an arguable ramp while BTC is totally unpredictable. Fig. 14 depicts the variations of NPV with hydrogen and BTC prices under different subsidy rates. The net present value of BTC with today's price is unbeatable by hydrogen projects. If the BTC price stably soars, cryptocurrency mining may devour notable amounts of investments. However, if the dynamic subsidy proportion to BTC price is applied, the NPV gap can be reduced to keep the green hydrogen generation in the race. If the BTC price falls below 10 k$, the efficacy of the crypto tax will be negligible; but soaring BTC periods can be harnessed in favor of hydrogen due to their interwoven structures. Regarding the BTC price history, the necessity of crypto tax has never been so obvious before the fly-up in 2020. Some crypto market experts believe that BTC can escalate up to 100k$ by 2022. The lack of regulated frameworks for crypto mining may cause unprecedented consequences and irreversible impacts. However, the ambitious prices (i.e., under 2 €/kgH_2) seem achievable if remunerative plans such as GHG restrictive policies and carbon taxes are properly implemented [9]. The succeeding possibilities are conceivable in this context:

- Investment risk supportive packages can pump up the emission-free sectors to accelerate the market growth and to enhance the price competency. In other words, policymakers can indirectly create markets for green hydrogen. For instance, long-haul transportation, where the availability of low-cost hydrogen is a critical factor, seems already at the brink of economic feasibility [9]. A similar transition to ammonia in the industry sector is imaginable followed by rail, shipping, and aviation sectors.
- Coordination and harmonization of codes, standards, and regulations can pave the way for new investments. Lack of clear policies and stable pathways in many countries may repel investors. Historically, countries with stable rules and policies host larger groups of international funds. Governments with clear long-term signals can relieve the volatility risks of projects [37]. Some studies say that hydrogen policy revisions are urgent now before turning to midterm barriers [9]
- Tax incentives can also be effective in many ways such as exemptions on capital cost, income, or sales. Recently in the US, the authorities are considering the production tax credit of USD 0.42/kg for clean hydrogen and hydrogen carriers – based on emissions intensity – and a manufacturers production tax credit of USD 500/kW. Another example is to let investments in transitions from fossil fuels to renewable alternatives be tax-deductible (i.e., up to 41.5% in the Netherlands) [6].

The main contribution of this paper, crypto tax, falls into this category by establishing a self-tuning economic framework between electrolysis and BTC mining.

Fig. 12. The fundamental concept of the crypto tax in favor of green energy.

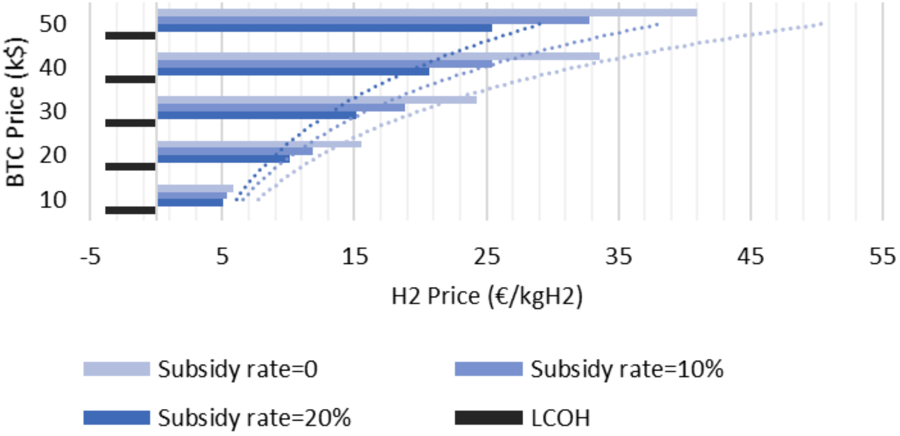

Fig. 13. The promoted hydrogen price to keep the profitability balance of electrolysis and BTC mining.

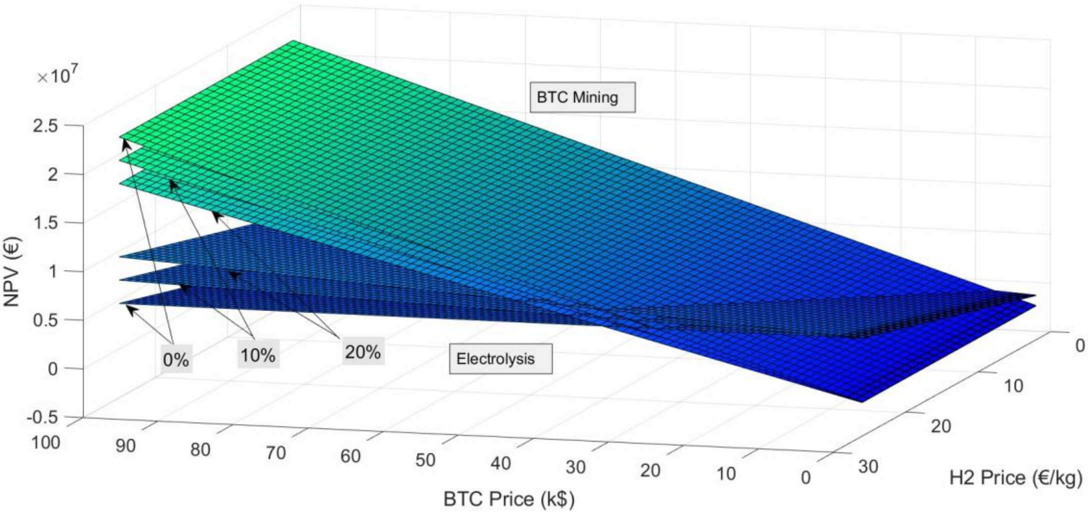

Fig. 14. Net present value comparisons for BTC mining versus electrolysis (10% and 20% subsidies).

5. Conclusions

Cryptocurrency mining has recently become one of the most profitable businesses in the world. If BTC miners are driven by 100% renewable energy, they are warmly welcome; but today they are mainly categorized among pollutant industries. From the second half of 2020 onward, the investment in cryptocurrency mining has been immense. This trend is not in line with GHG emission reduction and sustainable development goals. This paper tries to alert the policymakers to revise the taxing systems to avoid financial drains from green industries like electrolysis by parallel markets.

The numerical analysis provided in this research calculates the levelized cost of hydrogen production through grid-connected electricity around 4 €/kg in Europe. It also verifies that BTC mining is privileged by private investors in comparison to electrolysis. The profitability chasm is worsened if the BTC price soars with the economic status quota. It is calculated that the minimum attractive hydrogen price in 2020-2021 is 20.91 €/kgH2 which is far beyond any competence with fossil fuels. Dynamic subsidies are proposed under the frame of crypto tax to interconnect BTC and hydrogen markets. The coins are tagged with the carbon footprints for proportional taxing to the mining origins. The efficacy of crypto tax is showcased by the intersection of NPV trajectories for BTC mining and water electrolysis. The comparative profitability analyses reveal that BTC prices below 10000$ leave no necessity for intervention. However, escalations of BTC price will multifold the profitability to unparalleled levels. The green hydrogen can also benefit from the BTC market boom under the suggested crypto tax frame.

This paper analyzed a case study in Denmark where BTC mining is legal and noticeable shares of electricity come from wind energy. Further investigations can be considered for other countries with different energy resources, governmental restrictions on cryptocurrency, regional tax and levies, etc.

Funding Sources

This research did not receive any specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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