NFT EMISSIONS REPORT

Monstercat

NFT Carbon Offset Program

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Date: September 10, 2021

R&G
THE SUSTAINABILITY AGENCY

Introduction

Monstercat is entering a new journey in its efforts to better support the livelihoods of its artists and engage its customers in new ways. With the increasing popularity of blockchain-based transactions and digital art, selling unique editions of the label's music as NFTs (non-fungible tokens) presents an opportunity to access a new platform for music sales which can also improve the bottom line for artists.[1] However, as blockchain-based platforms gained in popularity, their overall greenhouse gas (GHG) emissions increased as well. In fact, Bitcoin, the highest emitter on the Blockchain, has an annualized carbon footprint similar to that of the entire country of Colombia.[2] Ethereum, the platform that will be used by Monstercat to sell NFTs, has an annualized carbon footprint similar to Azerbaijan's.[3]

In an effort to ensure they are meeting the highest standards of sustainability and to minimize their contribution to climate change, Monstercat is looking to account for the emissions associated with their NFT drops on Ethereum so they can offset those emissions. To do this, Monstercat enlisted the help of R&G Strategic to complete a scan of existing research on blockchain emissions and validate a methodology for calculating those emissions for each drop, and each NFT sold.

Before reading further, a note about the basis of our calculations: For the purposes of gathering data, we used a hypothetical number of 1,500 NFTs (50 unique RELIC songs with 30 editions each) to gain an understanding of what emissions would look like for each of Monstercat's drops. This number was based on a best-guess of what an average drop might be, but at the time of writing, no set number of NFTs has been selected for the first drop.

An Overview of NFTs

How does blockchain work?

Blockchain is intended to be a low-cost, secure, decentralized ledger system used to make digital transactions, whether transferring cryptocurrency, uploading programs, or selling digital art.[4] All transactions on the Ethereum network are enabled and verified using a consensus protocol called Proof of Work.[5] When a transaction is entered into a blockchain, it is sent out to groups of other computers, or nodes, in that same block, which then solve equations to confirm the validity of the

[1] Ethereum. 2021. Non-fungible token (NFT). https://ethereum.org/en/nft/
[2] Digiconomist. 2021. Bitcoin Energy Consumption Index. https://digiconomist.net/bitcoin-energy-consumption
[3] Digiconomist. 2021. Ethereum Energy Consumption Index. https://digiconomist.net/ethereum-energy-consumption
[4] Ethereum. 2021. Transactions. https://ethereum.org/en/developers/docs/transactions/
[5] Ethereum. 2021. Proof of Work. https://ethereum.org/en/developers/docs/consensus-mechanisms/pow/

transaction. Using the computational power required to solve these equations can require a significant amount of electricity, which can emit GHGs.

How do you sell an NFT?

Selling a single NFT, or doing a full drop, on a blockchain can require several transactions:

- First, a smart contract is uploaded for each drop. Smart contracts are programs stored on a blockchain that allows a seller to automatically execute a sale with their terms and conditions already built in.[6] Most collectible series only require one smart contract deployment per drop.
- Collectible updates must also be deployed. This stage ensures there can only be one authentic, verified version of each NFT uploaded (in the same way that there can only be one real Mona Lisa, but there can be many replicas). This update can be done for multiple NFTs at a time. In Monstercat's case, there is one transaction required per five unique NFTs uploaded (multiple editions of the same NFT would not count).
- The NFTs are sold for Ethereum. In one 'transaction' the NFT is minted (created), sold, and transferred to its new owner. Each NFT edition has its own transaction. For example, an NFT with 30 editions that sell would require 30 separate transactions on the blockchain.
- The last step is any metadata updates that are applied to the NFTs after they have been minted. The smart contract Monstercat uses allows for one property on the NFT to be updated, which can occur for each unique NFT uploaded at a to-be-determined time period after the drop. This update is not impacted by the number of NFT editions.

After an NFT goes through this process and is sold to a buyer, it 'lives' in the buyer's digital wallet, which requires very little computational power. During that time, they can stream the song, hold onto it hoping it increases in value, or they can sell it on secondary sales platforms like OpenSea. The re-sale of the NFT on secondary platforms requires additional transactions on the blockchain.

How do we measure power use?

Each one of these transactions on Ethereum has a digital cost or fee associated with it called gas. The amount of gas a transaction costs is directly tied to the amount of computational power (and therefore energy) that is required to upload and verify that transaction using the Proof of Work protocol.[7] For example, uploading Monstercat's smart contract will cost roughly 8 million gas per drop, and NFTs can range in cost but are estimated to be around 200,000 gas per Monstercat NFT.

Because the amount of gas required for a given transaction on Ethereum is directly tied to the amount of computational effort required to initiate and implement that transaction, we are able to

[6] Ethereum. 2021. Introduction to Smart Contracts. https://ethereum.org/en/developers/docs/smart-contracts/
[7] Ethereum. 2021. Gas and Fess. https://ethereum.org/en/developers/docs/gas/

determine the amount of corresponding electricity required for that transaction.[8] For example, across the Ethereum network, a transaction is estimated to require about 158 kilowatt hours of electricity, on average.[9] However, the gas fees for a given transaction can change from day to day with the amount of network activity and the number of miners (computers dedicated to proof of work calculations) available on the block.

GHG Accounting

What is GHG accounting?

Similar to the process of using financial accounting to track the money spent by a business, GHG accounting is used to track the GHGs emitted by a business following similarly designed global reporting standards, the most common being the Greenhouse Gas Protocol corporate accounting and reporting standard.[10] These internationally recognized standards are used for consistent reporting, whether voluntary or required by law, so that unified data can be drawn from organizations across industries and across countries. For the purpose of calculating the emissions of Monstercat's NFTs, we are following three basic accounting steps:

- **Setting boundaries:** Setting realistic limitations to the scope of analysis
- **Establishing an inventory base:** Determining a metric that emissions will be evaluated against, which can be applied to any drop or NFT in the future to create consistent analysis and reporting
- **Calculating GHGs:** Using the selected boundaries, inventory base, and data collected on NFT activity to calculate the GHG emissions associated with Monstercat's next drop

Setting Boundaries

Even though each NFT is unique and not interchangeable, their intangibility and inter-reliance on complex hardware and software structures makes the question of where to start or stop the GHG accounting process important. The GHG Protocol divides greenhouse gases into three scopes as they relate to a business and its operations:

- **Scope 1:** GHGs emitted directly from the business and its operations, like pollution from manufacturing processes or from driving vehicles owned by the business
- **Scope 2:** The emissions associated with the business's purchased energy, like its electricity purchased from the local power grid

[8] ibid.
[9] Digiconomist. 2021. Ethereum Energy Consumption Index. https://digiconomist.net/ethereum-energy-consumption
[10] Greenhouse Gas Protocol. (n.d.) A Corporate Accounting and Reporting Standard. *World Resources Institute, World Business Council for Sustainable Development.* https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf

- **Scope 3:** Other emissions that are a result of the business's activities but not controlled by the business, like its suppliers' emissions generated from serving that business. These emissions are not typically compared because they are too far removed from operational or organizational boundaries.[11]

All energy emitted from the use of blockchain technology for NFT sales could be considered a Scope 3 emission for Monstercat. This means where the boundaries are set within this scope is not dictated by international standards and is dependent on the appropriateness for our evaluation. Because the scope of our analysis is specifically focused on the emissions associated with the sale of Monstercat's NFTs on a blockchain platform, the boundaries will be set to include the preparation, upload and sale of NFTs on the blockchain, and will exclude pre-sale and post-sale activity. See Figure 1 below for the basic steps in the NFT's life cycle and where we have defined the boundaries of analysis.

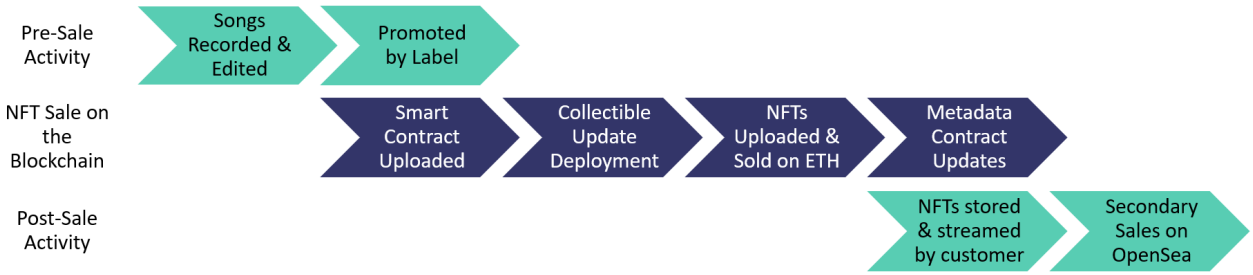

Figure 1. Monstercat NFT Life Cycle Boundaries

Only the operational steps included in the "NFT Sale on the Blockchain" section have been included in the analysis.

Inventory Base

Setting an inventory base allows us to create a consistent datapoint for a meaningful and consistent comparison of emissions, and it gives Monstercat a performance metric to report on over time. In examining the inconsistency across drops depending on the number of songs and editions involved and the varying gas fees from day to day, the most appropriate metric for tracking Monstercat's GHG emissions on Ethereum is using NFTs as its inventory base.

Though whole drops can be used to quickly calculate the total amount of GHGs emitted that require offsetting, calculating emissions on a per NFT basis allows the company to more accurately and personally communicate environmental impact with its customers. This will allow Monstercat to raise awareness while also establishing a consistent inventory base across its NFT sales, regardless of the number in each drop. Emissions will vary slightly depending on the NFT

[11] Greenhouse Gas Protocol. (n.d.) A Corporate Accounting and Reporting Standard. *World Resources Institute, World Business Council for Sustainable Development.* https://ghgprotocol.org/sites/default/files/standards/ghg-protocol-revised.pdf.

and when it is dropped as the size, the country block, and the gas requirements on a given day may change, but emissions for each NFT can still be tracked and reported on consistently over time and compared to the GHGs offset.

GHG Calculations

Calculating the GHG emissions from uploading and selling each NFT is best done by using the amount of gas required for the sale. Because the amount of gas required for a given transaction on Ethereum is directly tied to the amount of computational effort required to initiate and implement that transaction,[12] it directly corresponds to the amount of electricity required (and, therefore, its associated emissions) for that transaction.

Once we have an understanding of the average gas required for Monstercat NFTs, we can determine an estimate for the average number of emissions per transaction by calculating the energy requirements per gas. More specific calculations can also factor in country-specific emissions factors based on the country blocks on which the transactions take place, but because Monstercat's transactions on Ethereum occur across various blocks, using a global average can ensure we are accounting for possible activities in higher-emitting countries more reliant on fossil fuels for electricity consumption.

Calculating Monstercat's NFT emissions was based on Carbon.FYI, created by the environmental science and carbon offset company Offsetra,[13] which determined the number of kilograms of GHG emissions (CO_2e) per gas on Ethereum based on a global average.[14] They did this by determining the maximum energy requirements per network on Ethereum using hash rates, then determined the total resulting GHG emissions per country using internationally recognized emissions factors. They were then able to use historic Ethereum transaction data to calculate the average amount of emissions per transaction and their corresponding gas requirements.[15] Further explanation of their methodology can be found in **Appendix A**.

The estimated GHG emissions per gas on Ethereum was calculated using an upper, lower, and average scenario based on available studies on Ethereum and Bitcoin energy consumption. In 2020, global average CO_2e emissions per unit of gas were:

- **Upper scenario:** 0.0003895583921 kg
- **Average scenario:** 0.0001809589427 kg
- **Lower scenario:** 0.0001132972855 kg

[12] Ethereum. 2021. Gas and Fess. https://ethereum.org/en/developers/docs/gas/
[13] Offsetra. 2021. https://offsetra.com/
[14] Offsetra. 2021. Carbon.FYI Methodology. https://www.notion.so/Carbon-FYI-Methodology-51e2d8c41d1c4963970a143b8629f5f9 This methodology write-up discusses the overall global average of emissions per transaction as a broad example, but in further reading their process you can see that the theory used directly ties emissions to as used.
[15] Offsetra. 2021. Carbon Data. https://docs.google.com/spreadsheets/d/1Uedk9n44m8anKc9gdF430HJ0-BBd-E8kYfmi0eacz0M/view#gid=1116617753

These estimates were used to calculate the total anticipated GHGs that would be emitted for a hypothetical drop of 1,500 NFTs, which was then broken down to a per-NFT estimate by multiplying the kg of CO_2e per gas estimate by the expected gas costs of the drop, divided by the number of NFTs (**Appendix B**).

Based on the anticipated gas costs of 379 million for a 1,500 NFT drop, Monstercat's expected **GHG emissions would be 68,222 kg CO_2e for the entire drop, or 45 kg per NFT, not including the GHGs associated with metadata updates.** Because metadata updates can reoccur an indeterminate number of times for a given drop, the emissions associated with that phase cannot be properly estimated until it is decided how many times the update would occur, whether that happens once or ten times for each song. If Monstercat chose to apply a metadata update for this drop, it would emit an additional 362 kg of CO_2e per update. These emissions would have to be multiplied each time a new update is completed. Note, these estimates are using the global average scenario emissions per gas to account for possible network activity in higher-emitting countries, as Monstercat's customer base has international reach. They are also using 2020 emissions per gas calculations, which could be revised if or when 2021 numbers are released.

This estimate only includes emissions associated with the primary sale of the NFTs; if Monstercat chooses to account for emissions covering the broader life cycle of their NFTs on the blockchain, secondary sales and any metadata updates would also need to be taken into account. This could be offset in one transaction per drop or as individual offset amounts as each NFT purchase is made.

Future Considerations

Although calculations were presented for the average scenario for GHGs per gas as that is expected to be most accurate, Monstercat could re-evaluate whether it wants to further over-estimate its possible emissions from NFT sales by using the upper bound scenario when purchasing offsets to be certain all possible emissions from the sales are covered.

GHG estimates per NFT presented are lower than estimates presented by other researchers because the boundaries set in the analysis were limited to the primary sale. To better account for the full life cycle of an NFT on the blockchain, other research accounts for one or two secondary sales, indicating that ongoing best practice in NFT carbon accounting does include considerations for secondary sales. Monstercat could consider including one or two sales on OpenSea in its accounting to ensure it is better covering the lifespan of an NFT and to follow the standards set by a growing body of research.

When it comes to climate change mitigation, the first and most important step is to reduce or eliminate GHG emissions. Then, where eliminating them is not possible, an organization can look to offset the rest. An offset program for Monstercat's blockchain use is an important first step in managing the company's impact on climate change, but it also has an

opportunity to establish itself as a leader in the music industry by also reducing emissions wherever possible, offsetting more emissions from other aspects of the business, and by examining opportunities to further improve social equity and resilience in music.

Appendix A: Research Summary

Methodology Summary

The most appropriate methodology for estimating emissions is likely basing them on the amount of gas used to upload and sell each NFT. The amount of gas required for a given transaction on Ethereum is directly tied to the amount of computational effort required to initiate and implement that transaction.[16] This in turn directly corresponds to the amount of electricity required (and, therefore, its associated emissions) for that transaction.

If we have an understanding of the gas required for Monstercat NFTs and the blockchain pools that will be hosting these transactions, we can determine an estimate for the average number of emissions per transaction by calculating the energy requirements per gas.[17]

This method does factor in overall Ethereum network functions that would be operating outside of any specific transaction, but are factored in proportionally to the transaction as basic operational functions are still required to maintain the platforms needed to complete these transactions, and as the number of transactions on the network increase, so does the demand for more energy from the network.

Emission Calculations

Carbon.FYI, created by the environmental science and carbon offset company Offsetra is our preferred resource for calculating NFT emissions for the following reasons:

- Transparency: They reference their sources, acknowledge their assumptions and limitations, and they provide access to their full collection of data with a thorough explanation of their methodology.
- Specificity: They use country-specific emissions factors to distinguish between the environmental impact of blockchain transactions across different country pools, and their calculator pulls from specific contract addresses to get the exact amount of gas used.
- Validation: Other research has validated their methodology by arriving at similar results using different modelling techniques and calculations. The sources they use are widely

[16] https://ethereum.org/en/developers/docs/gas/

[17] https://www.notion.so/Carbon-FYI-Methodology-51e2d8c41d1c4963970a143b8629f5f9 This methodology write-up discusses the overall global average of emissions per transaction as a broad example, but in further reading their process you can see that the theory used directly ties emissions to as used.

cited by others in the space, and their own methodology has also been cited and repeated.

Data

Carbon.FYI's carbon data can be broken down by key sheet to further explain their methodology:

- Hash rates per pool: Hash rates refer to the computational power of the mining network or a specific block on Ethereum; essentially, it tells us the maximum capacity that it is able to process in a given second.[18] By segregating the hashing data by country, we can calculate maximum possible energy requirements to operate the network, and we can ensure the rates for each pool are tied to the appropriate countries where the transactions are taking place.
- Country emissions factors: Based on the hash rates for each pool and its corresponding energy requirements, we can calculate the total GHG emissions of Ethereum for each country by using internationally recognized emissions factors.[19] You can also see on this page that Carbon.FYI creates estimates using lower and upper scenarios of possible emissions to find a reasonable average.
- Ethereum transaction data: Once we have the overall energy use of the network in each country, we can find the average amount of every used per transaction and per gas for that country using daily network data. Finding the total gas used and translating that to energy use allows us to find a more precise number of emissions per average transaction, because the amount of gas required for a transaction is directly tied to the amount of computational effort (AKA energy use) required to process that transaction. By basing calculations on gas rather than a transaction, we can reach a more accurate understanding of energy use because the energy consumption of different transactions can vary widely.
    - As an example, if you notice off to the side, they provide the average amount of gas used per NFT (259911.3012) on ZORA. We can multiply this by their calculated kgs of emissions per gas (0.0002895399681) to find the global average for emissions of a single NFT on ZORA, which in 2019 was 75.25kg. However, that is based on the global average scenario. Someone in the Chinese pool, for example, will likely generate more emissions than someone in the Canadian pool, and different NFTs can have different gas requirements. If we look at the upper scenario for emissions per gas in 2019, the estimate is 162kg per NFT using the same average amount of gas per NFT.
- BTC and ETC energy consumption comparisons: This sheet outlines their key sources for information on energy use for both Bitcoin and Ethereum, which gave them a range of lower and upper scenarios for their research. This also acted as a second source of

[18] https://2miners.com/eth-network-hashrate
[19] https://www.carbonfootprint.com/docs/2019_06_emissions_factors_sources_for_2019_electricity.pdf

validation for Ethereum numbers, as they were able to calculate Ethereum's overall energy use as a proportion of Bitcoin's energy use. The primary sources used were:

- University of Cambridge's Bitcoin Electricity Consumption Index
- Digiconomist's Bitcoin Energy Consumption Index (they also have the same index for Ethereum[20])
- Technical University of Munich study on the energy consumption of cryptocurrencies
- These sources use a combination of energy use relative to hash rates and energy use relative to mining revenues to determine their energy use estimates.

Additional Resources

Rebuttal article on blockchain energy consumption and carbon footprint calculation methodologies to date - valuable for understanding the full picture and approaching the project with a critical eye

Memo Akten's research on NFT-specific emission data - Akten uses the same methodology basing emissions on gas used per transaction. His research analyzed about 8,000 NFT purchases on SuperRare.[21]

Other hash rate calculation methodologies across Ethereum platforms

Efficiency of equipment used by blockchain miners

Blockchain for Climate - a non-profit organization working to put the Paris Agreement on the Blockchain.

Additional code used to calculate Ethereum energy consumption and carbon footprint

Article on Bitcoin's energy consumption - used as a reference point for Carbon.FYI's methodology

[20] https://digiconomist.net/ethereum-energy-consumption

[21] https://docs.google.com/spreadsheets/d/1xrUHPG4oJimMcYuTGuxFYgtS9AO7bjKSqumb7EbOFo8/edit#gid=500649266

Appendix B: Gas & Emissions Data

Gas for a 1,500 NFT Drop* on Ethereum, by Transaction[22]					
Transaction	**Gas per Transaction**	**Quantity**	**Transactions per Drop**	**Total Gas per Drop**	**Gas per NFT**
Smart Contract Deployment	8,000,000	Does not matter how many NFTs are sold (1 or 1 million) this is fixed per drop	1	8,000,000	5,333
Collectible Update Deployment	6,900,000	1 transaction per 5 unique RELIC songs (not editions). A song with 100 editions is still only one RELIC song	10	69,000,000	46,000
Primary Sale (Mint)	200,000	1 per NFT sold. 1500 NFTs sold on primary market would be 1500 transactions	1,500	300,000,000	200,000
Smart Contract Update (per update)	40,000	1 transaction per unique RELIC song, per update. Can be updated multiple times but listed here as only 1 update	50	2,000,000	1,333
Total	**15,140,000**		**1,561**	**379,000,000**	**252,667**

*1,500 NFTs (50 unique RELIC songs with 30 editions each) was used for this report, but the number of NFTs will likely vary in actual Monstercat drops. It will be important to review the amount of gas with each drop to ensure accurate emissions calculations.

[22] A more detailed spreadsheet can be found here: https://docs.google.com/spreadsheets/d/1MGJ-7J-lIFnhpBH9aRrXJ8ZJOZaaggcY8DIBXzNB6Mo/edit?usp=sharing

GHG Emissions for a 1,500 NFT Drop* on Ethereum, by Transaction[23]						
Transaction	**Upper Scenario**		**Average Scenario**		**Lower Scenario**	
	Emissions (kg) per NFT	**Total Emissions (kg) for Drop**	**Emissions (kg) per NFT**	**Total Emissions (kg) for Drop**	**Emissions (kg) per NFT**	**Total Emissions (kg) for Drop**
Smart Contract Deployment	2.08	3,116.47	0.97	1,447.67	0.60	906.38
Collectible Update Deployment	17.92	26,879.53	8.32	12,486.17	5.21	7,817.51
Primary Sale (Mint)	77.91	116,867.52	36.19	54,287.68	22.66	33,989.19
Smart Contract Update (per update)	0.52	779.12	0.24	361.92	0.15	226.59
Total	**98.43**	**147,642.64**	**45.72**	**68,583.44**	**28.62**	**42,939.67**

*1,500 NFTs (50 unique RELIC songs with 30 editions each) was used for this report, but the number of NFTs will likely vary in actual Monstercat drops. It will be important to review the amount of gas with each drop to ensure accurate emissions calculations.

Emission Comparisons (for a 1,500 NFT drop)		
Upper Scenario	**Average Scenario**	**Lower Scenario**
99 homes' electricity for a year	46 homes' electricity for a year	29 homes' electricity for a year
Roundtrip flight from Toronto to Cairo (total aircraft)	Roundtrip flight from Houston to Lima (total aircraft)	Roundtrip flight from LA to Miami (total aircraft)

[23] A more detailed spreadsheet can be found here: https://docs.google.com/spreadsheets/d/1MGJ-7J-lIFnhpBH9aRrXJ8ZJOZaaggcY8DIBXzNB6Mo/edit?usp=sharing