Operation Nifty Carbon Emissions (O.N.C.E.)

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Abstract

In every serious conversation about blockchains, in particular NFTs, there are always detractors who talk about how harmful the NFTs are for the environment. One of the rebuttals to this argument is the renewable energy sources used by miners across the world. Still, we do not have the actual numbers to prove our point and show how “green” the NFTs are. In this project, we assess the actual environmental impact of the NFTs by going drilled down all the way to the transaction level. Several projects showcase the environmental impact of a blockchain network as a whole. This project attempts to go further, by segregating the NFT transactions independently.

We have used a sample Smart Contract for an NFT on the Ethereum blockchain and look at various types of transactions such as “deploy”, “mint”, and “transfer”. Each transaction will have a different gas cost associated with that, hence varying carbon emission impact. We also consider other factors like the energy mix used for mining these transactions and try to make it palatable and easy to understand by comparing these values against trees felled or miles travelled in a typical car.

Introduction

Energy consumption by blockchains

Blockchains consume a lot of energy for mining, mainly because of their use of PoW (Proof of Work) algorithms. Blockchain networks are decentralised peer-to-peer networks, which maintain an append-only ledger of transactions. Consensus on what transactions can be added to this ledger must be achieved using a distributed and Sybil-resistant consensus algorithm. Proof of work, adapted from Hashcash [1], is a key component of the main, and most common, of such consensus algorithms known as Nakamoto consensus, named after the pseudonymous creator of Bitcoin. Proof of work employs a technique in which the computers on the blockchain network (miners) perform a lot of computations (hashing), most of the results of which are expected to be discarded. This expends a large amount of energy in the process. Miners are compensated in an amortised manner for their energy expenditure of the discarded hashes when they are the first to find the one hash that allows them to add a block (collection containing multiple transactions) to the ledger. Several news outlets usually like to compare the energy consumption of the whole Bitcoin network [2] with countries like Argentina or Norway. In contrast, the energy consumption of the Ethereum blockchain [3] is compared to that of countries like Panama!

Energy consumption associated with a carbon cost

Here, we establish the terms that we use to describe and measure energy and carbon and will use these throughout the rest of the paper.

Energy consumption

Blockchain networks consume energy in the form of electricity. Thus we will use the kilowatt-hour, which is the billing unit for energy most commonly used by electric utilities.

Carbon Cost

As a result of consuming electricity, blockchain networks are responsible for the carbon cost of producing that electricity. Carbon dioxide emissions are responsible for approximately 81% of all greenhouse gas emissions [4] and thus other greenhouses gases (including methane, nitrous oxide, and fluorinated gases) are levelled to their carbon dioxide equivalent. “Carbon dioxide equivalent or CO_2e means the number of metric tons of CO2 emissions with the same global warming potential as one metric ton of another greenhouse gas” [5]. The carbon cost of a blockchain network is thus measured in kilograms of carbon dioxide equivalent. Note that we only consider the scope 1 (direct usage) carbon cost of electricity; scope 2 and scope 3 are not considered in this paper.

Carbon-energy intensity

Carbon energy is taken as the carbon cost divided by the energy consumption and is, therefore, a measure of the amount of carbon per unit of energy consumed. This term is sometimes also known as “GHG emission factor”. This value is highest when the source of electricity is fossil fuels, and lowest when it is renewable energy. Within fossil fuels, there is also a range of different carbon-energy intensities, with coal having the highest values (879 gCO2e/kWh), petrol and diesel at (713 gCO2e/kWh), and natural gas the lowest (391 gCO2e/kWh) [6]. The world average carbon-intensity value is 475 gCO2e/kWh [11]. Different countries/cities/locations use a mix of different energy sources, and have varying efficiencies, resulting in a range of carbon-energy intensity.

Summary of Units used

Term	**Unit**
Energy Consumption	kWh
Carbon Cost	gCO2e
Carbon-energy intensity	gCO2e/kWh

Network footprint and transaction footprint

Existing literature calculates the total energy (and consequently carbon cost) of an entire blockchain network. This is an attempt to calculate the per-transaction energy (and consequently carbon cost) of individual transactions on a blockchain network. There are speculations in various articles and news outlets that the energy consumption for deploying one NFT is equivalent to the entire year’s consumption of a British household! [7] We aim to challenge and prove some of these speculations by using scientific methods and actual data from reputed sources.

Hypothesis

When we began working on this project, we hypothesised that the energy consumption for deploying the NFT Smart Contract and the minting of NFTs through that contract would be significantly higher than the transfer or trading of the NFTs.

Methodology

Transaction costs

In the original blockchain, Bitcoin, virtually all transactions were about transferring an amount of currency from one account to another. Thus, the energy used and the carbon cost per Bitcoin transaction would be approximately equal across all transactions during a given time (ceteris paribus, especially hashing difficulty). In the Ethereum blockchain, Smart Contract capability was added. Thus transactions were not only for transferring amounts of currency between one account to another but also about interacting with programs stored on the blockchain (Smart Contracts), which involves additional computational power (processor, memory, and disk) over the “baseline” transactions. The energy used, and thus the carbon cost, per Ethereum transaction would vary significantly across all transactions within the same period, even within the same block. Thankfully Ethereum tallies the computational power needed per transaction using a mechanism called gas [8], and this gives us a good proxy for the proportion of energy consumed in processing each transaction. We acknowledge the accuracy of using gas to estimate energy consumption within the limitations section.

Computing per transaction carbon cost

Using input values for carbon-energy intensity, total network energy consumption, and a baseline constant representing equivalent gas overhead per transaction, and the amount of gas used for a particular transaction, we are able to work out the carbon cost associated with that particular transaction using the following arithmetic:

```
networkCarbonCost = carbonEnergyIntensity * networkEnergyConsumption

transactionResponsibleFraction = (transactionGasUsed +
baselineConstantGas) / networkGasUsed

transactionCarbonCost = transactionResponsibleFraction *
networkCarbonCost
```

Note that in this paper we are using a zero value for the baseline constant representing equivalent gas overhead per transaction. This choice will be discussed in the limitations section.

Implementation

Smart Contract

We have deployed a Smart Contract with a standard implementation of an ERC721 token interface to represent the NFTs. This was deployed on a test network of the Ethereum blockchain and can be found here - https://kovan.etherscan.io/address/0xb78615d79cf590588c055319f96617c842040db9. Through this contract, we can find out the exact carbon cost for the three main categories of NFT transactions:

1. **Deploy -** This is the cost for deploying the Smart Contract itself on the Ethereum blockchain.
2. **Mint -** This is the cost for creating a new unit of the NFT on the Ethereum blockchain.
3. **Transfer -** This is the cost of transferring or trading an existing unit of the NFT from one address to another on the Ethereum blockchain.

The gas used by each of these types of transactions varies considerably. Also, the frequency of the transactions for each of these types is considerably different. Like any other Smart Contract, deployment is permanent and immutable, and thus there will only ever be one deploy transaction per NFT. Mint transactions are only performed by creators of new units of the NFT; whereas transfer transactions are performed by any user interacting with the blockchain network or even other Smart Contracts deployed on the blockchain network. Both mint and transfer transactions are expected to occur multiple times, with transfers typically occurring in larger numbers.

For example, if one takes an example of a project like Hashmasks [9], the number of NFTs will always remain constant going forward, but these NFTs can be traded amongst the users forever. Hence, although the carbon impact of this project was relatively high during the inception, it is going to be relatively much lower during its lifetime.

Calculations

Prior work existed in the form of a script, whose original purpose of this script was to calculate the per-transaction dollar cost on both the Ethereum and RSK transactions. The RSK component is ignored for the purposes of this paper.

In order to be able to install and run the script, you will need to have Git and NodeJS installed on your system.

```
git clone git@github.com:bguiz/gas-fee-comparison.git
cd gas-fee-comparison
cp sample.env .env
# edit .env
cp energy-data.sample.json energy-data.json
# edit energy-data.json
node ./gas-fee-comparison.js
```

This script has been extended to include calculations described in the methodology presented in this paper to calculate the per-transaction carbon cost. You should edit energy-data.json to update the configuration data used in the calculations.

Interactive Data Visualization

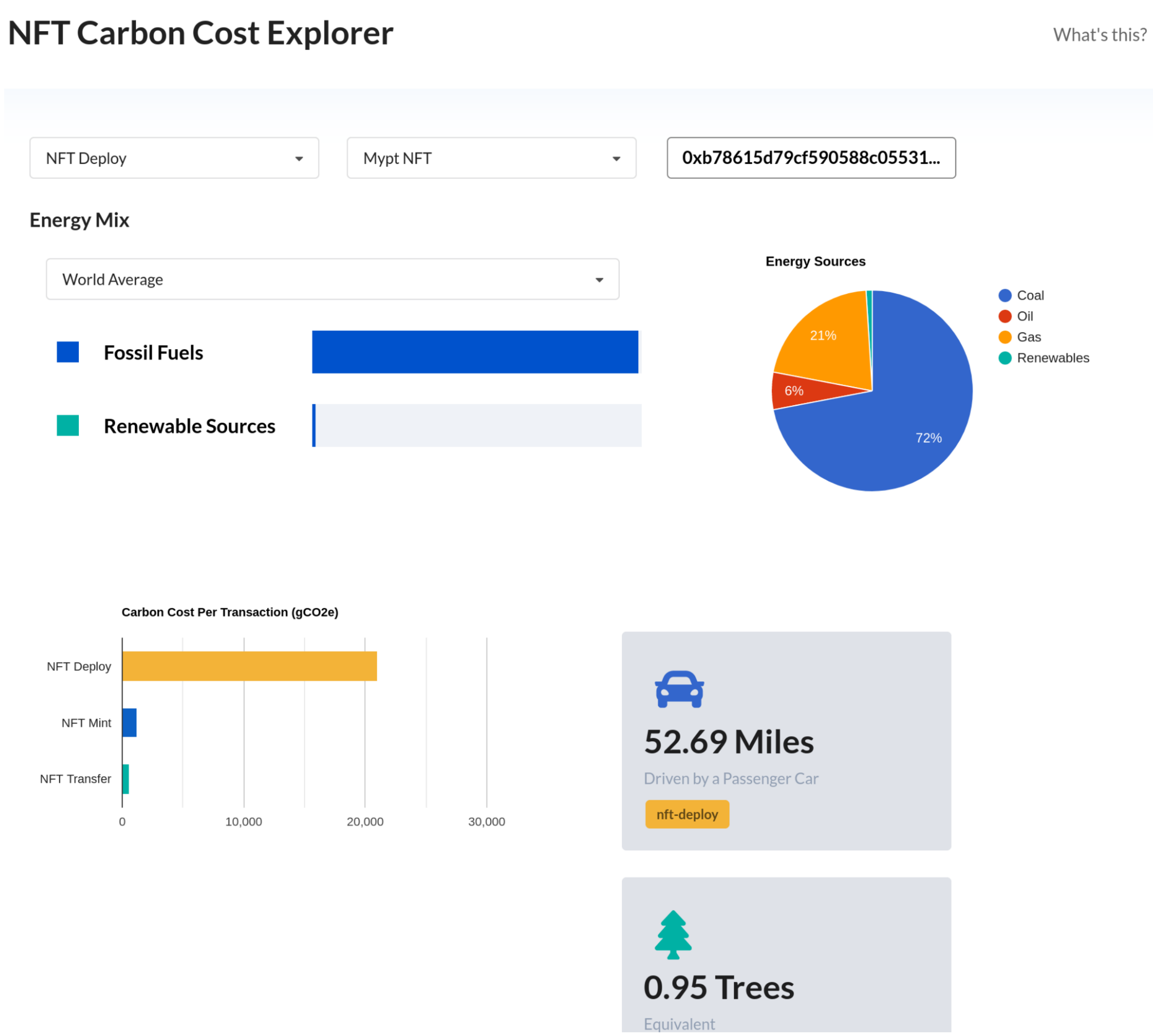
We have created an interactive visualisation of the calculations which can be found here: https://blockchain-carbon-cost-visualizer.vercel.app/

On this app, you can do the following:

- Select the type of NFT transaction - deploy, mint or transfer. You can choose from a selected list of transactions in this particular Smart Contract.
- Select from a preset mix of energy intensity values from these options
  - World average
  - 80% fossil - 20% renewable
  - 50% fossil - 50% renewable
  - 20% fossil - 80% renewable
- View a chart comparing the estimated carbon cost (gCO2e) resulting from the transactions

In this visualization, we have also included reference equivalents for them - number of trees and miles travelled in a passenger car. These apply simple linear conversions of 394 gCO2e per mile [12] and 22000 gC02e per tree [13].

The overall objective of this is to provide an easy to use and easy to understand way for non-technical users or those new to the blockchain world to understand and compare the carbon cost of their interactions with NFTs on blockchain networks.



Conclusions

As seen in the interactive visualisation, we can conclude that the different categories of typical NFT transactions have different carbon costs. We can also see the absolute values are significant and hope that users of NFTs consider this when interacting with NFTs.

The following table shows, for a selected NFT (MyptNFT), the carbon cost results, as well as the equivalent number of trees or passenger car travel this equates to.

Interaction	Carbon Cost	Equivalent Passenger Car Emissions' Distance	Equivalent Trees' Sequestration

	(gCO2e)	(miles)	(unit)
NFT Deploy	20,919	52.69	0.95
NFT Mint	1,186	2.99	0.05
NFT Transfer	530	1.34	0.02

Results for other selected NFTs are available via the interactive visualization.

Limitations

This methodology has attributed all of the energy consumption, and therefore also carbon costs to transactions. These only occur when a network request is sent to the blockchain network that alters the state of the blockchain. This involves appending a new block per set of transactions and is where energy costs are significant, as consensus requires the energy-intensive proof of work computations to occur. However that does not mean that the blockchain network does not expend energy in other areas too, these include servicing network requests that do not result in any alteration to the state of the blockchain, block synchronisation, among others. For this reason, the methodology proposes that future work that extends upon this paper should also include a non-zero value for the baseline constant representing equivalent gas overhead per transaction to take this into account.

Additionally, this methodology also assumes that the gas consumed for these transactions is proportional to the energy consumption. While this assumption is generally true, extensive EVM bytecode instrumentation and analysis has shown that this is not uniformly the case as the computational cost is disproportionate to gas price for some particular EVM op-codes [10].

Please note that this research is still at a very high level, and we have had to make many assumptions. As such, these findings should be used with caution, and the numbers cannot be relied upon for any other scientific research.

Future work

In this project, we looked at only one blockchain - Ethereum. In the future, we want to work on comparing the energy consumption of comparable transactions against various blockchain networks. We will work on integrating blockchain networks like RSK, Binance and also some layer 2 solutions like Matic (Polygon).

We also want to work on an analysis to separate read transactions from write transactions, and consequently, separate values accruing from the former instead of including their amortised values in the latter.

Another potential avenue is to work on an analysis to account for, and consequently level off, the proportions between gas and energy consumed per transaction.

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