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The carbon footprint of the Target Instant Payment Settlement (TIPS) system: a comparative analysis with Bitcoin and other infrastructures

by Pietro Tiberi*

Abstract

Reducing the environmental impact of human activities has become a strategic objective of governments, institutions, companies and individuals. In this paper, we estimate the CO2 equivalent emissions of the TARGET Instant Payment Settlement (TIPS) system and compare it with that of Bitcoin and other infrastructures.

The TIPS carbon footprint in 2019 was almost 40,000 times smaller than that of Bitcoin; the difference is only partially accounted for by the lower overall volume of TIPS transactions, as the marginal increase in emissions per additional transaction is very small: the difference would therefore persist even if TIPS worked at full steam. The huge discrepancy in the carbon footprints of TIPS and Bitcoin stems from the fact that the latter uses a large amount of energy to generate trust and consensus among Bitcoin network participants, whereas in the case of TIPS this trust is provided by the Eurosystem.

The comparison is then extended, using publicly available data, to other infrastructures. The over-performance of TIPS, while less marked than in the case of Bitcoin, remains nevertheless considerable.

Keywords: TIPS, Carbon footprint, Bitcoin.

Sintesi

La riduzione dell'impatto ambientale delle attività umane è oggi un obiettivo strategico di governi, istituzioni, aziende e individui. In questo articolo viene presentata una stima delle emissioni di CO2 equivalente del sistema TARGET Instant Payment Settlement (TIPS), che viene poi confrontata con quella di Bitcoin e altre infrastrutture.

L'impronta di carbonio di TIPS nel 2019 è stata quasi 40.000 volte inferiore a quella di Bitcoin; la differenza è solo in piccola parte spiegata dal minor volume complessivo di transazioni di TIPS, in quanto l'incremento marginale delle emissioni per transazione aggiuntiva è molto contenuto: pertanto, anche se TIPS lavorasse a pieno ritmo, questa differenza rimarrebbe pressoché invariata. L'enorme discrepanza nell'impronta di carbonio di TIPS e Bitcoin deriva dal fatto che quest'ultimo utilizza una notevole quantità di energia al fine di generare fiducia e consenso tra i partecipanti alla rete, mentre nel caso di TIPS questa fiducia è fornita dall'Eurosistema.

Il confronto viene poi esteso, utilizzando le fonti pubbliche disponibili, anche ad altre infrastrutture. Le prestazioni di TIPS, per quanto meno pronunciate che nel caso del confronto con Bitcoin, rimangono purtuttavia sensibilmente più elevate.

* Bank of Italy, ITC Operations Directorate.

CONTENTS

1 Introduction[1]

The term carbon footprint (Thomas and Jan 2007) is a well-established concept commonly understood as the carbon equivalent emissions and effects related to a product or service during its whole life cycle.[2] The carbon footprint, its magnitude and the development trends are important matters to investigate for any sector due to the growing concern of global warming (Malmodin and Lundén 2018).

To calculate the impact of ICT (Information and Communication Technology) services on CO_2e emissions, there are several approaches that, in a first approximation, can be divided into two categories: bottom-up and top-down (Intellect 2012).

The bottom-up approach tends to work at a granular level, examining individual characteristics of a product or service in detail, often using life cycle assessment (LCA).[3] When applied to ICT, the assumption is that the results of these individual LCAs can theoretically be multiplied or aggregated to give a meaningful idea of the cumulative impact of lots of devices, networks or services, and that this in turn can provide an estimation of the impact of ICT sector as a whole.

A top-down approach starts with the collected data at a corporate, industry or network level and then applies assumptions and modelling techniques to extrapolate the total energy usage and estimates the embodied carbon.

In this study a bottom-up approach is used to calculate the carbon footprint of TIPS system (Renzetti *et al.* 2021, Arcese, Di Giulio and Lasorella 2018) in terms of CO_2e[4] emissions by referring to the GHG (Greenhouse gases)[5] protocol framework published by GeSI.[6] The ICT Sector Guidance (The Carbon Trust 2017) provides guidance and accounting methods for the calculation of GHG emissions for ICT products with a focus on ICT services .

The carbon footprint thus calculated is then compared with the one of the payment system based on the use of the Bitcoin cryptocurrency (Nakamoto 2018). The energy consumption values (kWh) and the amount of CO_2 emissions ($kgCO_2e$) of the Bitcoin system used in this paper are published in various scientific studies (Stoll, KlaBeen and Gallersdörfer 2018, Köhler and Pizzol 2019, Stoll, KlaBeen and Gallersdörfer 2019) and by the University of Cambridge that provides online data on the annual electricity consumption by the Bitcoin system (University of Cambridge 2020).

1. I would like to thank Silvio Orsini, Giampiero Longobardi, Alessio Manzo, Alessandra Rollo , Giuseppe Zingrillo and Stefano Siviero for revising the article and for their useful comments. Special thanks to Fabrizio Lucarini for the technical support and data collection. *The views expressed in the paper are solely those of the author and do not necessarily represent those of the Bank of Italy.*

2. The carbon footprint is a parameter that is used to estimate the greenhouse gas emissions caused by a product, a service, an organization, an event or an individual, generally expressed in tons of CO_2e equivalent (Ministero della Transizione Ecologica 2020) taking as reference for all greenhouse gases the effect associated with CO2.

3. LCA, or Life Cycle Assessment, (sometimes called life cycle analysis) looks at the environmental impacts made by, say, a product over its whole life, usually broken into different stages, such as raw material extraction, manufacture, distribution, use and end-of-life (Intellect 2012, Guinée *et al.* 2011).

4. Carbon dioxide equivalent (CO_2e) is used to provide a common figure for measuring the impact of different greenhouse gases. It is determined by multiplying the mass of a given greenhouse gas by its global warming potential (GWP). GWP is a factor describing the radiative forcing impact of 1 kilogram of a given greenhouse gas relative to a kilogram of carbon dioxide over a given period of time.

5. Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wave-lengths within the spectrum of thermal infrared radiation emitted by the Earth's surface, the atmosphere itself, and by clouds. This property causes the greenhouse effect.

6. The Global Enabling Sustainability Initiative (GeSI) is a leading source of impartial information, resources and best practices for achieving integrated social and environmental sustainability through ICT. In GeSI there is a collaboration with members from major Information and Communication Technology companies and organisations around the globe, (GeSI 2020).

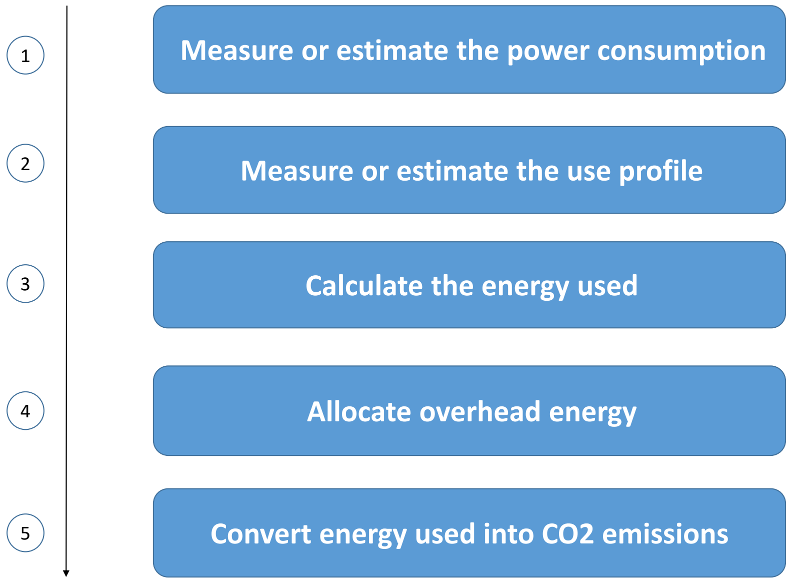

Figure 1. The carbon footprint calculation steps for an ICT system (The Carbon Trust 2017)

2 Methods

The LCA method requires the calculation of emission impact for the entire life cycle of the individual components used to create the ICT system, whose value has to be considered. For what concerns TIPS, the energy used for the production of servers, for its transportation and installation, for its usage and disposal at the end of its useful life should therefore be considered (Guinée *et al.* 2011, The Carbon Trust 2017).

However for many ICT goods and services like TIPS, the use stage dominates the total emissions(The Carbon Trust 2017). Usage stage emissions are primarily caused by the ICT hardware's use of electricity (The Carbon Trust 2017). As shown in the Figure 1, 5 steps are necessary in order to calculate the amount of emissions in terms of $kgCO_2$. The first step is to measure the amount of electricity E_1 used by all the systems needed to provide the TIPS service for one year. The ICT devices used by TIPS are hosted in datacenters operated by Banca d'Italia and all devices are installed in racks located inside modular islands for which the measurement of the instantaneous power $P(t)$ absorbed by the single rack is available.

$$E_1 = \sum_{i=1}^{N} \left(\int_{oneyear} P_i(t)dt \right) \tag{1}$$

The total amount of energy used by TIPS over a year E_1 is given by (1) where $P_i(t)$ is the instantaneous power absorbed by the single rack i and N is the number of racks where TIPS equipment are installed.

Considering that the power absorbed by the single rack, in the observation period, is not very variable around its average value, it can be approximated with the average $\overline{P_i}$ (see Figure 3); the equation (1), expressed in kWh, becomes:

$$E_1 \simeq \left(\sum_{i=1}^{N} \overline{P_i} \right) \times 365 \times 24 \; kWh \tag{2}$$

The second step of the methodology involves the usage profile calculation of the service over

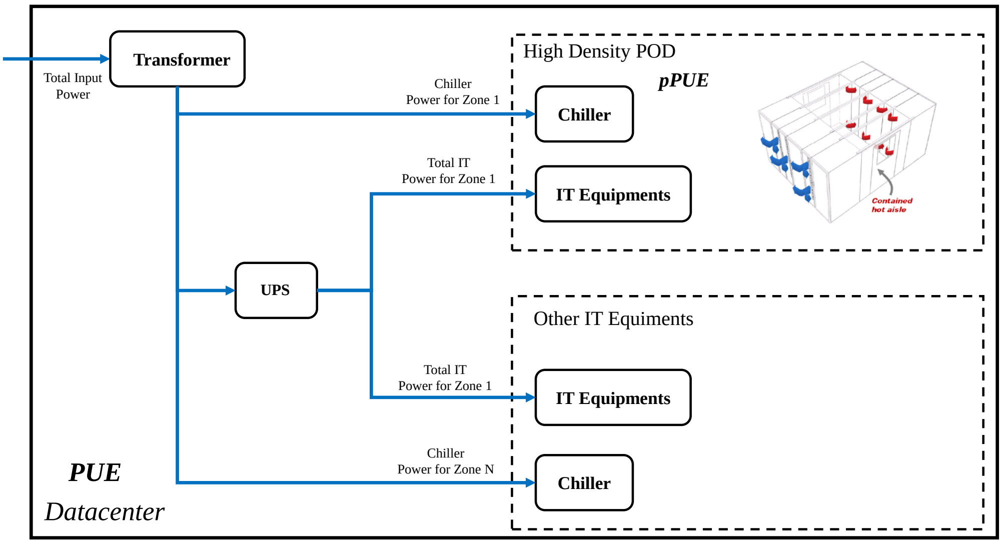

Figure 2. PUE calculation reference environment (The Green Grid 2012)

time $U(t)$ [7] by users. Since TIPS service is available to users over a 24-hour period for the whole year without scheduled maintenance windows, it can be considered always on and therefore:

$$U(t) = 1 \tag{3}$$

Considering the use profile (3) step 3 of the methodology can be completed by calculating the energy used by TIPS which is:

$$E_2 = E_1 U(t) = E_1 \tag{4}$$

To complete step 4 it is necessary to consider the overhead energy necessary to keep the devices in optimal operating conditions and datacenter operations. The parameter that provides this indication is the PUE[8] which is defined as (Sharma, Arunachalam and Sharma 2015, The Green Grid 2012):

$$PUE = \frac{TotalFacilityEnergy}{ITEquipmentEnergy} \tag{5}$$

Using (5) and knowing the amount of energy used by IT equipment (E_2) is possible to calculate the total energy (E_3) required in step 4 of the methodology as:

$$E_3 = E_2 \times PUE \tag{6}$$

The calculation of the PUE must be done continuously for the derivation of a significant average value. TIPS systems are installed inside high density pods (PODS) which provide continuous measurement of instantaneous electric power consumption. The PODS are closed rooms, equipped with their own conditioning and are installed in the datecenter according to the diagram reported in Figure 2.

7. The function $U(t)$ takes values in the range $[0, 1]$ in which the extreme values 0 and 1 have the following meaning: $U(t) = 0$ when the service is never used while $U(t) = 1$ holds when the service is always active.
8. Power Usage Effectiveness (PUE) is a measure of how efficient a data center is in using the electricity that powers it (The Green Grid 2012). It is a parameter that gives a figure of how much electrical power is dedicated to the power supply of IT equipment compared to auxiliary services such as air conditioning or UPS losses.

Table 1. Average,Min,Max and Std.Dev of the instantaneous power $P_i(t)$ measured in Watt absorbed by the individual racks over the observation period.

Rack Id.	$\overline{P(t)}$ **[W]**	**min** $P(t)$ **[W]**	**max** $P(t)$ **[W]**	σ **[W]**
$Rack_1$	3,375	3,236	3,565	42.9
$Rack_2$	3,885	3,776	4,033	33.8
$Rack_3$	3,925	3,834	4,081	27.3
$Rack_4$	3,463	3,332	3,742	46.9

According to The Green Grid 2012, the measured PUE value, in our case, is actually a partial PUE ($pPUE$). The average $pPUE$ in the case of TIPS is 1.46 and does not take into account the energy losses of the UPS system and the Transformer. The UPS devices available on the market typically have efficiency greater than 90%. As a precaution an overall impact of 10% of energy losses is considered and therefore a value of 1.60 for the $pPUE$ is assumed. The equation (6) becomes:

$$E_3 = E_2 \times pPUE = E_2 \times 1.6 \tag{7}$$

To complete the calculation and obtain the TIPS carbon footprint, it is necessary to convert the energy used into $kgCO_2e$ emitted. This conversion can be carried out with the *CO_2e emission by electricity generation* [9] parameter which is specific to each country and depends on the methods used to produce electricity. As TIPS systems are installed in Italy, more precisely in Banca d'Italia's datacenters, the most recent italian value of this parameter published by *Istituto Superiore per la Protezione e la Ricerca Ambientale* (ISPRA 2019) which is 316 gCO_2e/kWh is to be used.

So the formula to obtain the yearly carbon footprint of TIPS (CF_{TIPS}) is:

$$CF_{TIPS} = E_3 \times (CO_2\ Emissions\ by\ electricity\ generation)_{Italy} \tag{8}$$

where CF_{TIPS} is measured in $kgCO_2e$ emitted per year. Combining (8) and (7) the formula to evaluate the TIPS carbon footprint is obtained:

$$CF_{TIPS} = 0.316 \times E_3 \simeq 0.506 \times E_2\ kgCO_2e \tag{9}$$

3 Results

The monitoring system of the PODS in which the racks that house the TIPS devices are located detects the electricity consumption in terms of instantaneous power $P(t)$ every 5 seconds.
Figure 3 shows the measurement values for the period February 1 2020 - March 2 2020 of one rack.

It can be easily seen that $P(t)$ oscillates slightly around a constant average value. In Table 1 the minimum, maximum, average and standard deviation $\sigma(P(t))$ of the measured values for each rack are reported. The moving average, calculated using a sliding window of 120 samples, is almost constant (red curve in Figure 3) and the standard deviation (σ in Figure 3 and Table 1) is very limited and oscillates in the range 27.3 - 46.9 W (0.7 - 1.4 % of the average value).

This means that the average value $\overline{P(t)}$ can be used as a significant indicator for electricity consumption in the observation period.

Applying (2) and (4) the following value for TIPS total energy E_2 can be derived:

$$E_2 \simeq (3,375 + 3,885 + 3,925 + 3,463) \times 365 \times 24 \simeq 128,317\ MWh/year \tag{10}$$

9. The emission factors are reported in gCO_2e/kWh excluding the electricity produced from pumped storage units using water that has previously been pumped uphill, as requested by Directive 2009/28/EC of the European Parliament, based on the values published in Italy by Istituto Superiore per la Protezione e la Ricerca Ambientale (ISPRA 2019).

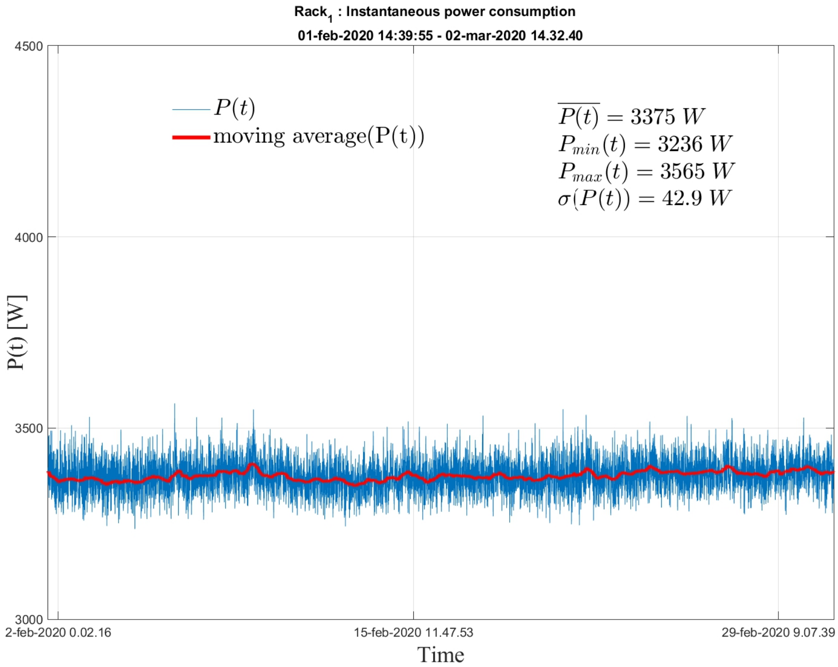

Figure 3. TIPS Instantaneous power consumption from 01 February 2020 to 02 March 2020 for $Rack_1$. The moving average (red line) is computed using a sliding 10 minutes window (120 values)

Applying (9) and (7) and using the total measured total energy E_3 the following value for the total CO_2e emissions of TIPS in the year 2019 can be obtained:

$$CF_{TIPS_{2019}} = 128,317\ kWh\ \times 0.506\ \frac{kgCO_2}{kWh} = 64,928.4\ kgCO_2 \tag{11}$$

The value $CF_{TIPS_{2019}}$ calculated in (11) indicates the absolute emissions of CO_2 caused by the set $\mathcal{U}_{TIPS}$ of all the devices necessary for the operation of TIPS. The $\mathcal{U}_{TIPS}$ set contains the network equipment, storage/SAN devices and compute servers used to create the Development, Certification and Production environments.

Defining $N_{TIPS_{2019}}$ the number of settlement transactions managed by TIPS in the year 2019 the average amount of CO_2e emissions per single transaction can be derived:

$$CF^{Trx}_{TIPS_{2019}} = \frac{CF_{TIPS_{2019}}}{N_{TIPS_{2019}}} \simeq \frac{64,928.4}{77,000}\ gCO_2 = 8.43 \cdot 10^2\ gCO_2 \tag{12}$$

The adoption of the TIPS service by the European banking community is gradual and therefore the value $N_{TIPS_{2019}}$ is much lower than the number $N_{TIPS_{Normal}}$ of annual transactions for which the system has been sized.[10]

A more accurate estimation of the environmental impact per transaction of TIPS is obtained by measuring the electricity consumption under normal load conditions ($N_{TIPS_{Normal}}$). This measure is possible because in the certification environment (CERT) , which is specular to the production (PROD) environment, is possible to inject payment orders at a variable rate of up to 2000 transactions

10. The TIPS system is currently sized to handle an average volume of 500 transactions per second which corresponds to $N_{TIPS_{Normal}} = 15.7 \times 10^9$ transactions per year. In addition, the system is currently able to absorb traffic peaks of 2000 transactions per second (European Central Bank 2018).

Table 2. Average instantaneous power $\overline{P(t)}[W]$, absolute carbon footprint $CF[kgCO_2]$, total transactions N and CO_2e emissions per transaction ($CF^{Trx}[gCO_2]$) measured for TIPS in different trx/s scenarios: (A) TIPS in 2019; (B) Bitcoin in 2018; (C) Mature instant payments market (e.g. Sweden); (D) TIPS under normal load conditions.

	trx/sec.	$\overline{P(t)}$	CF_{TIPS}	N_{TIPS}	CF^{Trx}_{TIPS}
(A) TIPS in 2019	0.0025	14,648	64,928.4	$7.70 \cdot 10^4$	$8.43 \cdot 10^2$
(B) Bitcoin in 2018	4	14,994	66,461.8	$1.26 \cdot 10^8$	0.53
(C) Mature instant payments market	100	15,078	66,834.1	$3.15 \cdot 10^9$	$21.21 \cdot 10^{-3}$
(D) TIPS under normal load conditions	500	15,201	67,379.4	$15.7 \cdot 10^9$	$4.29 \cdot 10^{-3}$

per second and therefore, for a given time interval, the load and the total energy consumption of the TIPS system under different load profiles can be reproduced.

In Table 2 the values measured in CERT environment in four different traffic scenarios are reported : (A) TIPS in 2019; (B) Bitcoin in 2018; (C) Mature instant payments market (e.g. Sweden); (D) TIPS under normal load conditions. It is useful to remember how the calculation of the absorbed power is always estimated considering the totality of the test (TEST), certification (CERT) and Production (PROD) systems therefore the power consumption measurements detected injecting payments in CERT are undoubtedly an excellent estimation of the actual consumption that would have the same production volumes.

As it can be clearly seen from the measurements in Table 2, the average values of the instantaneous power $\overline{P(t)}$ cumulated for the four Racks increases slightly with the increase of the number of transactions and the increase between the two extreme cases is of about 553 W which correspond to a growth rate of about 4% compared to an increase of a factor 2×10^5 in the number of transactions per second.

A good estimation of the CO_2e emissions per TIPS transaction is therefore given by:

$$CF^{Trx}_{TIPS_{Normal}} = \frac{CF_{TIPS_{Normal}}}{N_{TIPS_{Normal}}} \simeq \frac{67,379.4}{15.7 \cdot 10^9}\ kgCO_2 = 4.29 \cdot 10^{-3}\ gCO_2 \tag{13}$$

4 Discussion

The results obtained allow to have a clear idea on the environmental impact of TIPS both in absolute terms (CF_{TIPS}) and per single transaction (CF^{Trx}_{TIPS}). Similar data are also available for other payment systems such as those based on the Bitcoin cryptocurrency (Stoll, KlaBeen and Gallersdörfer 2019, Köhler and Pizzol 2019, University of Cambridge 2020).

The Cambridge Bitcoin Electricity Consumption Index (CBECI) provides a real-time estimate of the total electricity load and consumption of the Bitcoin network. Given that the exact electricity consumption cannot be determined, the CBECI provides a range of possibilities consisting of a lower bound (floor) and an upper bound (ceiling) estimate. Within the boundaries of this range, a best-guess estimate is calculated to provide a more realistic figure that comes closest to Bitcoin's real annual electricity consumption (University of Cambridge 2020).

The method followed to calculate the CBECI index is of the bottom up type and basically follows steps 1-4 of Figure 1 but, as it cannot have direct measurements of the electricity consumption of all the devices of the Bitcoin network, it is based on a model that estimates the energy consumption. The following equation is used:

$$E_{estimated} = \frac{\sum_1^N \theta_i}{N} \times H \times PUE \times 3.16 \cdot 10^7 \tag{14}$$

where $\frac{\sum_1^N \theta_i}{N}$ is the average energy efficiency of profitable bitcoin hardware ($\frac{J}{hash}$), H is the hashrate ($\frac{hash}{s}$) and $3.16 \cdot 10^7$ is the number of seconds in a year. The PUE value used in this formula is equal to 1.10 and is significantly lower than that typical of a normal datacenter (in our case PUE = 1.6)[11].

CEBCI index estimates an average electricity consumption value for 2018 equal to around 42 TWh. This value is in good agreement with what is estimated by Stoll, KlaBeen and Gallersdörfer 2018 which calculate, for the same year, a consumption of 48.2 TW for entire the Bitcoin network. In 2019, article Stoll, KlaBeen and Gallersdörfer 2019 reviews the values provided by Stoll, KlaBeen and Gallersdörfer 2018 and calculates the total annual electricity consumption of the bitcoin network in 45.8 TWh.

In Stoll, KlaBeen and Gallersdörfer 2019, step 5 of the method described in Figure 1 is also completed. The geographical location of all the Bitcoin servers is taken into consideration and the corresponding conversion factors between kWh and $kgCO_2e$ are applied to obtain the following value for the total CO_2e emissions in 2018:

$$22.0 \times 10^9 \ kgCO_2 \ < CF_{Bitcoin_{2019}} < \ 22.9 \times 10^9 \ kgCO_2 \tag{15}$$

By comparing (11) with (15) the ratio between the CO_2e emissions of Bitcoin (year 2018) and TIPS (year 2019)[12] can be calculated:

$$R_{CF} = \frac{CF_{Bitcoin_{2018}}}{CF_{TIPS_{2019}}} = \frac{22 \times 10^9 \ kgCO_2}{6.49 \times 10^4 \ kgCO_2} \simeq 3.39 \times 10^5 \tag{16}$$

The R_{CF} value calculated in (16) indicates how the impact, in absolute terms, on the CO_2e emissions of the TIPS system is absolutely negligible compared to the amount of CO_2e emitted by the Bitcoin network in 2018.

The number of transactions made using Bitcoins is public and is available online. Using the data provided by Blockchain.com 2020 it is possible to calculate the total number of Bitcoin transactions made in the year 2018 ($N_{Bitcoin_{2018}}$).

$N_{Bitcoin_{2018}}$ is equal to[13] 0.82×10^8 and therefore the CO_2e emissions per single transaction for the year 2018 can be calculated:

$$CF^{Trx}_{Bitcoin_{2018}} = \frac{CF_{Bitcoin_{2018}}}{N_{Bitcoin_{2018}}} \simeq \frac{22 \times 10^{12} \ gCO_2}{0.82 \times 10^8} \simeq 2.68 \times 10^5 \ gCO_2 \tag{17}$$

By comparing (12) with (17) the ratio between the CO_2e emissions of Bitcoin (year 2018) and TIPS (year 2019) can be calculated:

$$R_{CF^{Trx}} = \frac{CF^{Trx}_{Bitcoin_{2018}}}{CF^{Trx}_{TIPS_{2019}}} = \frac{2.68 \cdot 10^5 \ gCO_2}{8.43 \cdot 10^2 \ gCO_2} \simeq 3.18 \times 10^2 \tag{18}$$

To make a more reliable comparison the data in Table 2 relating to an annual TIPS traffic ($N_{TIPS_{\simeq Bitcoin}}$) of the order of 10^8 transactions (Footnote (b) of Table 2) which is comparable with the volumes of Bitcoin transactions in the year 2018 should be considered:

$$R_{CF^{Trx}} = \frac{CF^{Trx}_{Bitcoin_{2018}}}{CF^{Trx}_{TIPS_{\simeq Bitcoin}}} = \frac{2.68 \cdot 10^5 \ gCO_2}{0.53 \ gCO_2} \simeq 5.05 \times 10^5 \tag{19}$$

11. According to University of Cambridge 2020 and Stoll, KlaBeen and Gallersdörfer 2019 mining facilities generally have significantly lower PUE than traditional data centres. The Uptime Institute estimated an average PUE for 2019 equal to 1.67 for general purpose datacenters (Uptime Institute 2019).

12. TIPS has been released into production 30 November 2018 so there is not enough data for 2018.

13. This number is an estimate obtained by multiplying by 365 the average number of daily transactions which in 2018 was equal to 223,450.

Table 3. CO_2e emissions per transaction(Leopold and Englessson 2017) ($CF^{Trx}[gCO_2]$) and comparison with TIPS (R_{CF}^{Trx} calculated using $CF_{TIPS_{Normal}}^{Trx}$ derived by (13)) for Ether, USD Dollar on VISA network and Ripple (XRP)

Currency	CF^{Trx}	R_{CF}^{Trx}
Ether (ETH)	9.07×10^3	2.1×10^6
VISA (USD)	3.6	8.3×10^2
Ripple (XRP)	6.03×10^{-3}	1.40

On the basis of what has been obtained in (19), it is clear that the environmental impact of TIPS for each transaction is also negligible compared to that of a transaction carried out on the Bitcoin network.

Bitcoin is the most studied cryptocurrency and not many works have been published on the other currencies regarding environmental impact assessment. However, in Leopold and Englessson 2017 a comparison of the carbon footprint of Bitcoin (BTC), Ether (ETH),[14] Ripple (XRP) [15] and US dollar on the VISA circuit is presented.

The comparison with these systems is particularly interesting because Ethereum is the reference platform for smart contracts (Buterin 2014), Ripple is the wholesale settlement system that is establishing itself for cross-currency payments (Ripple 2020b) and Visa is one of the world's leaders in digital payments (VISA 2020).

In table 3 the values of CO_2e emissions per single transaction (CF^{Trx}) of Ether, Ripple and US Dollar on the Visa circuit (Leopold and Englessson 2017) are reported and the comparison with TIPS using $CF_{TIPS_{Normal}}^{Trx}$ is inserted using (13). The obtained value is reported in Table 3 and it is just a rough estimate of the order of magnitude of R_{CF}^{Trx} because the comparison is made between systems managing very different total amount of transactions per year.

However, it can be observed that systems such as Ether based on *permissionless* public blockchains have low energy efficiency while systems based on private blockchains (*permissioned*) and which are limited only to the validation of transactions using a reduced number of nodes such as Ripple have an environmental impact comparable to that of TIPS.

The comparison with VISA seems to indicate the greater energy efficiency of the TIPS application; it must also be taken into account that the VISA network, in addition to offering value-added services compared to the settlement service, is operational on 4 datacenters hosting thousands of servers (VISA 2018).

5 Conclusions

Analyzing the results obtained, it is evident that the environmental impact of TIPS is drastically lower than that of the Bitcoin network. This result is not surprising because of the peer to peer nature of Bitcoin and its promise to solve the so-called *double-spending problem*[16] with distributed ledger technology.

In the Bitcoin network, in the absence of a currency universally recognized and guaranteed by an entity such as the European Central Bank, there is a need to build a distributed community

14. Ether (ETH) is the cryptocurrency generated by the Ethereum protocol (Buterin 2014) is presented. Unlike Bitcoin, Ethereum operates using accounts and balances according to the so-called state transitions, which are not based on unspent transaction outputs (UTXOs), but on the current balances (called states) of all accounts, as well as to some additional data. Status information is not stored in the blockchain, but is stored in its own binary tree.

15. Ripple is a real-time gross settlement system, currency exchange and remittance network (Ripple 2020a). XRP is the native currency of the Ripple network.

16. This refers to the incidence of an individual spending a balance of that cryptocurrency more than once, effectively creating a disparity between the spending record and the amount of that cryptocurrency available, as well as the way that it is distributed.

and generate a shared consensus among all participants in the network. The construction of the consensus is based on a *Proof of Work* which is based on the use of processing power and therefore electricity.

Most of the energy is therefore dissipated to generate trust among all the Bitcoin network participants. In the case of TIPS, this trust is provided by the European Central Bank which guarantees every transaction made in euros.

Furthermore, the results of Table 2 clearly show how TIPS electricity consumption grows very slowly with the increase in the number of transactions leading to obtaining a CO_2e emission value per single transaction of 4.29×10^{-3} gCO_2e if we consider the traffic of 500 payments per second for which the current system has been sized.

The comparison with the 2.68×10^5 gCO_2e emitted by the Bitcoin network to validate a single transaction in 2018 makes the reduced environmental impact of the TIPS system even more evident.

The excellent energy efficiency of TIPS is also confirmed by the comparison with the energy consumption per single transaction of other currencies shown in Table 3.

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