The More You Know: Energy Labelling Enables More Sustainable Cryptocurrency Investments

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***Abstract*—The energy consumption of popular cryptocurrencies varies greatly: cryptocurrencies based on proof-of-work (e.g. Bitcoin) consume much more electricity than their counterparts that use alternative consensus mechanisms, such as proof-of-stake (e.g. Ethereum). Nevertheless, proof-of-work cryptocurrencies dominate the market. We investigate whether energy labelling, i.e., displaying electricity consumption information on centralized exchanges, influences consumers' product preferences. We conduct a control/treatment study: during this study, participants with an interest in cryptocurrencies ($N = 200$) are presented with a fictitious cryptocurrency exchange user interface. The treatment group is shown a user interface that displays energy labels, while the control group receives no information related to electricity consumption. Participants then declare how likely they are to acquire particular cryptocurrencies. We measure the treatment effect and find a significant negative correlation ($p = 0.002$) between being exposed to energy labels and expressing a strong preference for energy-inefficient cryptocurrencies. Based on this finding, we reflect on the sustainability issues of cryptocurrencies and discuss how energy labelling on centralized exchanges can be applied to nudge investors away from energy-inefficient cryptocurrencies. This indicates that regulators would be well advised to consider energy labelling to address the adverse climate impacts of cryptoassets.**

***Index Terms*—User Experience, Sustainable Finance, ESG Investing, Electricity Consumption, Energy Labels, Sustainability Indicators**

I. Introduction

Cryptocurrencies are positioned as technologies to transact without state intervention [1] and out of reach of sovereign monetary policy [2]. They are adopted as speculative forms of investment [3], [4] and as means of payment [5] throughout the world [6]. While BITCOIN remains dominant [7], numerous alternative products or 'altcoins' have emerged [8], turning the cryptocurrency landscape into a competitive market [9]. Cryptocurrencies enable users to conduct payments without central oversight and without the need for intermediaries [10]. From an end-user perspective, cryptocurrencies provide such benefits as decentralization, security, pseudonymity, convenience, and low transaction fees [11]. However, despite investors becoming more sensitive to considerations of environmental, social, and corporate governance (ESG) [12], the cryptocurrency landscape remains exposed to strong criticism for its excessive electricity consumption [13]–[21]. There is a wide range of consensus mechanisms [22] that result in Blockchain systems with an equally wide range of energy demands. Some of these systems are particularly excessive in terms of electricity consumption, while others have only modest requirements, as shown in subsection I-A.

In earlier research, Platt, Ojeka, Drăgnoiu *et al.* [23] have speculated that users' lack of awareness of electricity consumption characteristics contributes to the popularity of energy-inefficient cryptocurrencies, and that raising consumers' awareness could nudge them to adopt more sustainable cryptocurrencies. Comparative energy labels that show vital information on electricity consumption have been widely adopted for consumer education [24]. To understand the educational effect of comparative energy labels on users' cryptocurrency consumption intentions, we conduct a control/treatment test with the following hypothesis.

Hypothesis: Cryptocurrency users are less likely to acquire energy-inefficient cryptocurrencies when presented with energy labels during acquisition.

A. Background Literature

Three lines of background literature are relevant to our study: (1) cryptocurrency technology, especially those concerning the interplay between technology choices and electricity consumption; (2) human interaction with cryptocurrencies, especially technology preferences, attitudes, and expertise; (3) energy labelling schemes in other contexts.

1) Cryptocurrency Technology: An extensive body of work has investigated the electricity consumption characteristics of cryptocurrencies [16], [17], [25], showing that these differ fundamentally (see Table I). Early permissionless cryptocurrencies, building on PoW consensus (type *III* in Table I), have been criticized for their extreme electricity consumption [13]–[21]. BITCOIN, the most popular PoW cryptocurrency, was found to produce up to 65.4 Mt CO_2 annually, as of 2022, which equated to the overall emissions of Greece [21]. Despite this enormous electricity consumption, the BITCOIN network only delivers 5 to 7 tx/s [26]. Certain subsequent permissionless cryptocurrencies, such as CARDANO, SOLANA, and ETHEREUM apply alternative consensus mechanisms (type *II* in Table I) and have been found to be more energy-efficient in terms of orders of magnitude [15], [16]. Permissioned systems (type *I* in Table I) like HEDERA HASHGRAPH have undercut the electricity consumption of type *II* systems even further. This may be attributed to their smaller replication factor [16], [18].

Table I
CATEGORIES OF CRYPTOCURRENCY ELECTRICITY CONSUMPTION ACCORDING TO AGUR, DEODORO, LAVAYSSIÈRE ET AL. [17]

Type	Permissioning	Consensus	Avg. Electricity Demand (kW h/tx)
I	Permissioned	Non-PoW	0.00000145
II	Permissionless	Non-PoW	0.00202
III	Permissionless	PoW	273

2) Cryptocurrency Users: Studies from different regions support the notion that users of cryptocurrencies have a limited understanding of the underlying technology [27], [28]. This limitation extends to their knowledge of electricity consumption [23]. Some previous work investigated the pathways of acquisition of cryptocurrencies. It was found that the prevalent avenue for users to acquire cryptocurrencies is via CEXs [23], [29] such as Binance and Coinbase, which are already targeted by regulators [30]. This has motivated us to investigate energy labelling on CEXs.

3) Energy Labelling: Methods to increase consumer knowledge have a long history. A tried and tested method of consumer education, which has commonly been applied to durable goods, such as appliances [31], is energy labelling. Energy labels were found to be effective tools in helping consumers make more sustainable purchasing decisions [32] and adopt more sustainable behaviours [33]. They are recognized throughout the European Union (EU), including Romania, where this study is conducted. Energy labels are recognized by 86 % of Romanian consumers [34, p. T23] and 74 % of them refer to energy labels when buying energy-efficient products [34, p. T25]. A seven-point (A-G) scale, such as that applied in the EU since March 2021 [35], was found to result in high perceived importance of energy efficiency [36].

II. METHOD

A control/treatment test with 1/2 users in each group was conducted. Participants took part in the test via an online survey.

A. Participants

The study targeted Romanian internet users, 18 years of age and older, with an interest in holding cryptocurrencies.

B. Survey Design

To ensure a relevant group of participants, a screening question was applied. Participants were asked to indicate all financial products they considered holding in future: stocks, cryptocurrencies, indices, exchange-traded funds, commodities, and/or foreign currencies. Only participants who selected cryptocurrencies were considered. These participants were presented with the questions described in the following sections.

1) Section on Cryptocurrency Usage: The first survey section borrowed key elements from the 'Consumer Insights Survey on Cryptoassets' [37] of the Organisation for Economic Co-operation and Development. Specifically, participants were asked to declare how well they understood cryptocurrencies and whether they had experience of holding them.

2) Section on Environmental Attitude: A question regarding the participants' attitude towards environmental regulation was adopted from the sustainability consciousness questionnaire of Gericke, Pauw, Berglund *et al.* [38] to allow for the categorization of participants in terms of their sustainability attitudes.

3) Acquisition Scenario: Finally, subjects were presented with the control/treatment test: this revolved around an imaginary scenario in which they had received a gift card[1] that could only be redeemed at a fictitious CEX. Subjects in both groups were shown a UI that mimicked standard CEXs (see Figures 1 and 2 for translations of the UIs that were originally shown to the participants in the Romanian language). Both UIs offered a choice between four different cryptocurrencies. These represented a selection of highly capitalized cryptocurrencies, covering the entire spectrum of energy consumption characteristics shown in Table I: BITCOIN, ETHEREUM, DOGECOIN, and HEDERA HASHGRAPH[2]. However, there were slight variations in the quantity of information that was displayed in the respective UIs: the UI presented to the *control group* (see Figure 1) showed the name of the cryptocurrency (e.g., Bitcoin), its ticker symbol (e.g., BTC), and how many currency units were redeemable for the gift card balance (e.g., 0.0052). In addition, the UI presented to the *treatment group* (see Figure 2) showed an 'Energy Score', a fictitious energy label intended to express how much electricity a cryptocurrency transaction on a given blockchain consumes. Most participants were likely to be familiar with energy labels, due to their popularity in the EU. Nevertheless, a brief description of the concept was provided to this group in the UI (see Figure 2).

To determine whether energy labels have a significant effect on the acquisition decision, cryptocurrencies of vastly different sustainability characteristics were selected. We show energy labels which follow the 2021 EU energy label scale that allows for values ranging from *A* (most energy-efficient) to *G* (least energy-efficient). We consider type *I* and type *II* systems to be energy-efficient in the sense of the hypothesis (see section I) and consider type *III* systems to be energy-inefficient. To provide polarizing choices, we presented two energy-efficient cryptocurrencies (ETHEREUM and HEDERA HASHGRAPH) and two energy-inefficient contenders (BITCOIN and DOGECOIN). Using established estimates (see Table I), we identified a range of 1.45 mW h/tx to 273.14 kW h/tx to be broad enough to capture all popular products on the cryptocurrency market at the time. While an actual labelling scheme would likely be more complex, we assumed a linear relationship between electricity consumption and energy label: here, types *I*

[1]The gift card amount was set at 500 Romanian lei, an amount roughly equivalent to 100 US Dollars at the time of conducting the survey.

[2]We use the name of the HEDERA HASHGRAPH distributed ledger technology synonymously with the HBAR cryptocurrency throughout this paper.

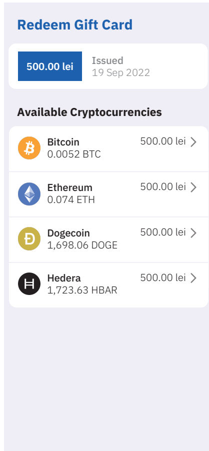

Figure 1. The UI of the *control group* showed of basic parameters without energy information.

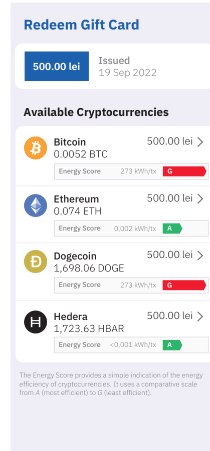

Figure 2. The UI of the *treatment group* displayed basic parameters and an energy score label.

(1.45 mW h/tx) and *II* (2.02 W h/tx) represented the least electricity-consumptive currency types. Thus, label *A* was assigned to the HEDERA HASHGRAPH and ETHEREUM cryptocurrencies. Consequently, type *III* (273.14 kW h/tx) currencies (BITCOIN and DOGECOIN) were allocated the energy label *G*.

C. Measures

The key observation to gauge the effect of energy labelling on cryptocurrency purchase intention is the self-declared likelihood of a participant acquiring a given cryptocurrency. We measure this using a Likert scale: after being presented with the scenario details (see subsubsection II-B3), users are asked to select how likely they are to redeem their gift card for a given cryptocurrency. The indicated likelihood is measured using a four-point scale ('very unlikely' to 'very likely'). We assume that a strong likelihood of acquiring a given cryptocurrency (i.e., option 'very likely') can be interpreted as an indication of an acquisition intention. Applying this interpretation, we measure the number of energy-*inefficient* cryptocurrencies participants intend to acquire. We equally measure the number of energy-*efficient* cryptocurrencies participants intend to acquire. These two measures are central to the result presented later (see section III).

D. Procedure

The study was conducted using the 'Pollfish' survey platform: participants were selected via organic random device engagement (RDE) sampling, a voluntary response sampling method that relies on advertising networks in which participants receive minor, non-monetary rewards, such as benefits in mobile games [39]. The method was found to produce accurate results [40] despite the known shortcomings of non-probability sampling [41]. Participants were initially presented with the terms of the survey platform and informed consent was obtained. Participants were then presented with a screening question to ensure that only those who considered holding cryptocurrencies for investment purposes were selected. If qualified, they were presented with the questions described earlier (see subsection II-B) in sequence. After answering the relevant questions, an attention check was administered. On completion of the survey, the participants were thanked for their participation and were dismissed.

III. RESULTS

A. Demographic Information

Two hundred valid responses were collected in November 2022. The mean time to completion was 2 min 15 s with participants accessing the survey from mobile devices and web browsers. Of the participants, 59.5 % identified as male, with the remainder identifying as female. The average age of participants was 32.7 years ($\sigma = 12.97$). Apart from demographic characteristics, experience with and attitude towards cryptocurrencies were assessed: we classify most participants (76 %) as novice users, based on their self-declared understanding of cryptocurrencies, as shown in Figure 3.

B. Preferences for Energy-Inefficient/Efficient Cryptocurrencies.

Figure 4 shows the distribution of participants' acquisition intention across different cryptocurrencies in the treatment

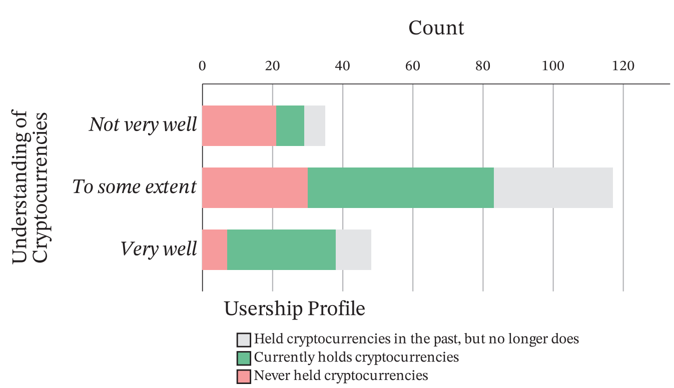

Figure 3. Participant knowledge and user profile.

Table II
KEY DIMENSIONS OF THE CRYPTOCURRENCIES USED IN THE CONTROL/TREATMENT TEST

Name ^{c,t}	Symbol ^{c,t}	Type	Units acquirable ^{c,t}	Electricity consumption ^{t} (kW h/tx)	Label ^{t}
Bitcoin	**BTC**	III	0.0052	273	G
Ethereum	**ETH**	II	0.074	0.002	A
Dogecoin	**DOGE**	III	1,698.06	273	G
Hedera Hashgraph	**HBAR**	I	1,723.63	<0.001	A

The dimensions marked with ^{c} are displayed to subjects in the control group.
The dimensions marked with ^{t} are displayed to subjects in the treatment group.
Electricity consumption data were estimated by calculating the mean of values aggregated by Agur, Deodoro, Lavayssière *et al.* [17].
Price as per https://coinmarketcap.com on 19 September 2022.

and control groups. For energy-inefficient cryptocurrencies, we noticed that participants were more likely to express an acquisition intention for BITCOIN when in the control group ($N = 48$ vs. $N = 33$ in the treatment group). The same effect applied to DOGECOIN ($N = 16$ in the control group vs. $N = 10$ in the treatment group). As we can see, with energy labelling, fewer participants expressed an acquisition intention towards energy-inefficient cryptocurrencies.

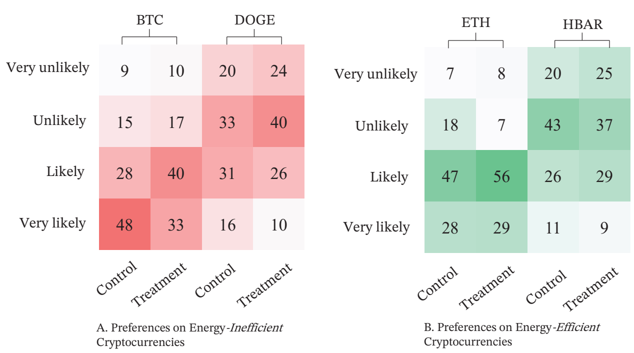

Figure 4. Preferences for energy-inefficient and energy-efficient cryptocurrencies in the control and treatment groups

C. Treatment Effect on Preferences for Energy-Inefficient Cryptocurrencies

We ran Spearman's correlation test on our measurements in relation to the number of energy-inefficient and energy-efficient cryptocurrencies participants intended to acquire. We found that there was a significant negative correlation between being exposed to energy labels and expressing a strong preference for energy-*inefficient* cryptocurrencies ($r = -0.220$, $p = 0.002$). In other words, energy labelling nudged users away from buying energy-*inefficient* cryptocurrencies. However, surprisingly, there was no significant correlation between being exposed to energy labels and expressing a strong preference for energy-*efficient* cryptocurrencies ($r = -0.010$, $p = 0.888$).

To further determine the extent of the treatment effect, an inferential statistics method, such as an independent sample t-test can be applied. We perform a Shapiro-Wilk test to investigate the normality of the number of energy-*inefficient* and energy-*efficient* cryptocurrencies with the result that neither of the two variables are normally distributed ($p < 0.001$). Therefore, we fitted a Mann-Whitney U test, which can be considered equivalent to the t-test without assumptions regarding the normal distribution of the data, instead of the t-test to determine the treatment effect. As shown in Table III, there is a significant treatment effect ($Z = -3.097$, $p = 0.002$) for the number of energy-*inefficient* cryptocurrencies and no significant treatment effect ($Z = -0.142$, $p = 0.887$) for the number of energy-*efficient* cryptocurrencies. To be specific: in the treatment group, the number of energy-*inefficient* cryptocurrencies ($M = 0.43$, $\sigma = 0.62$) is smaller than in the control group ($M = 0.64$, $\sigma = 0.52$), confirming our hypothesis.

IV. DISCUSSION

Users presented with energy labels are found to be less likely to acquire energy-inefficient cryptocurrencies according to this study. Our work, therefore, confirms the hypothesis and produces a result that is congruent with the wider literature that establishes a positive relationship between energy labelling and sustainability [32], [42]. Although a significant correlation between energy labelling and users' intention to acquire energy-efficient cryptocurrencies is not seen, the results suggest the potential of energy labelling in nudging users away from purchasing unsustainable cryptocurrencies.

Table III
MANN-WHITNEY U TEST FOR TREATMENT EFFECT

Group	N	μ	σ	M	MR	U	Z
Control	100	0.64	0.52	1.00	111.69	3,881	-3.097**
Treatment	100	0.43	0.62	0.00	89.31		

μ: mean, σ: standard deviation, M: median, MR: mean rank
** significant at the $p = 0.01$ level.

This result has potential practical implications: regulatory bodies with a remit of sustainability and consumer education may contemplate the introduction of energy labelling standards for cryptocurrencies. Additionally, operators of CEXs may preempt the potential introduction of mandatory energy labels by exposing electricity consumption information to their customers voluntarily. The findings suggest that both courses of action may lead to more sustainable consumer behaviour.

A. Conclusion

The results demonstrated in this work provide a new perspective on reducing the environmental impact of cryptocurrency market activities. Many previous regulatory initiatives in pursuit of sustainability have focused on *operators of mining hardware*. These, however, have rarely been successful, due to the supranational nature of cryptocurrencies. While some limitations remain, this work has confirmed that displaying energy labels on centralized exchange websites, thereby targeting the *buyers of cryptocurrencies*, influences consumer choice.

Energy labelling was shown to be a viable method to deter users from acquiring highly electricity-consumptive cryptocurrencies, thus offering assistance to ESG-conscious investors. Energy labelling should, therefore, be considered by regulators when establishing cryptoasset sustainability standards.

B. Limitations and Future Work

This study has several limitations. Firstly, the group of participants was limited to residents of Romania, thus our results may not be generalized to other regions, especially those outside of the EU where people may be less familiar with or mindful of energy labelling. A broader population might cause the effects of labelling across different regions to surface.

Secondly, product decisions were made in a mock environment: participants might be more conscious of their acquisition decision if money were at stake. To counteract this effect, an A/B test should be conducted in collaboration with a commercial CEX to understand how energy labelling impacts purchasing decisions in a real-stakes environment.

Finally, the RDE sampling method might have influenced the results: most participants declared to have at least a basic understanding of cryptocurrencies. To improve the generalizability of the results across all experience levels, a probability sampling method should be applied in future work.

Author Contribution

A.-E. D. and M. P. contributed equally to this work. Conceptualisation: A.-E. D. and M. P.; Data curation: A.-E. D.; Formal analysis: A.-E. D., M. P., Z. W., and Z. Z.; Investigation: A.-E. D. and M. P.; Methodology: A.-E. D. and M. P.; Project administration: A.-E. D.; Supervision: M. P.; Validation: A.-E. D., M. P., Z. W., and Z. Z.; Visualisation: A.-E. D., M. P., Z. W., and Z. Z.; Writing: A.-E. D., M. P., Z. W., and Z. Z.

Ethical Clearance

This study was approved by the ethics committee of the University of Bucharest (decision number 84/10.11.2022).

Data Availability

The data that support the findings of this study are openly available in Mendeley Data [43].

Conflicts of Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: A.-E. D. reports a relationship with certSign SA that includes employment. M. P. reports a relationship with Google Germany GmbH that includes employment and equity or stocks.

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