



Bárbara Alexandra Gomes Félix

**MiCA AND THE FUTURE OF BLOCKCHAIN: A LEGAL
ANALYSIS OF SUSTAINABILITY IN CONSENSUS MECHANISMS**

Dissertation to obtain a Master's
Degree in Law, in the specialty of
Law and Financial Markets

Supervisor:

Professor João Vieira dos Santos, NOVA School of Law

September, 2025

Anti-plagiarism Statement

I declare on my honour that the dissertation I am submitting is original and that all citations are correctly identified. I am aware that the use of non-identified elements from others is a serious ethical and disciplinary fault.

Dedication and Acknowledgements

I dedicate my Dissertation to my Advisor, João Vieira dos Santos, whose expertise, patience, and encouragement have been crucial throughout this process, provided clarity regarding many elements, and helped me accomplish this work. In addition, I am deeply grateful for the time and energy you invested in me.

To my Boyfriend, who always supported me throughout my academic journey and encouraged me to go out on a limb and challenge myself every day. Your belief in my abilities, even during moments of doubt and fatigue, has been invaluable. Thank you for being my unwavering support, my cheerleader, and my anchor throughout this journey.

To my Grandparents, whose wisdom, warmth, and example have shaped the person I am today. They taught me the value of hard work, humility, and perseverance, showing me the importance of always striving to achieve my goals while maintaining simplicity and integrity. Their guidance and quiet strength have inspired me throughout my life and studies.

To my Father, whose unconditional support, dedication, and guidance have been my anchor. He also instilled in me the values of hard work, humility, and the relentless pursuit of my goals, always with simplicity and grace. His belief in me and his example of perseverance have been a constant source of motivation and inspiration.

Quoting Conventions

This dissertation follows the provisions of the Portuguese Norms 405-1 and 405 4 of the Portuguese Quality Institute. Each reference is indicated throughout the dissertation with the complete name of the author(s), the title of the work referenced, and the specific pages expressly cited or referenced. The second and following references are reduced to the surname of the author(s) and first letter of the name(s) followed by the number of the note corresponding to the first citation and the number(s) of the pages cited. Nevertheless, due to the specific legal and technical investigations required throughout this Dissertation, a hybrid solution was implemented in some cases, as several essays were written during Conventions and Conferences.

Acronyms and Abbreviations

AML – Anti-Money Laundering

BCBS - Basel Committee Banking Supervision

BFT - Byzantine Fault Tolerance

CASPs – Crypto-asset service providers

DeFi – Decentralised Finance

Delegated Regulation (EU) 2025/422 supplementing MiCA – Commission Delegated Regulation (EU) 2025/422 of 17 December 2024 supplementing Regulation (EU) 2023/1114 of the European Parliament and of the Council with regard to regulatory technical standards specifying the content, methodologies and presentation of information in respect of sustainability indicators in relation to adverse impacts on the climate and other environment-related adverse impacts

DLT - Distributed Ledger Technology

DPoS – Delegated Proof of Stake

ECB – European Central Bank

EIA – International Energy Agency

ESMA – European Securities Markets Authority

EU – European Union

EU Taxonomy – Regulation (EU) 2020/852 of the European Parliament and of the Council of 18 June 2020 on the establishment of a framework to facilitate sustainable investment, and amending Regulation (EU) 2019/2088

GHG – Greenhouse Gases

MAR – Regulation (EU) 596/2014 of the European Parliament and of the Council of 16 April 2014 on market abuse (market abuse regulation)

MiCA – Regulation (EU) 2023/1114 of the European Parliament and of the Council of 31 May 2023 on markets in crypto-assets

NCA – National Competent Authorities

PoA – Proof of Authority

PoS – Proof of Stake

PoW – Proof of Work

Regulation (EU) 2025/422 of 17 December 2024 amending MiCA – Commission Delegated Regulation (EU) 2025/422 of 17 December 2024 supplementing Regulation (EU) 2023/1114 of the European Parliament and of the Council with regard to regulatory technical standards specifying the content, methodologies and presentation of information in respect of sustainability indicators in relation to adverse impacts on the climate and other environment-related adverse impacts

SFDR – Regulation (EU) 2019/2088 of the European Parliament and of the Council of 27 November 2019 on sustainability-related disclosures in the financial services sector

Statement of Characters

I hereby declare that the body of the dissertation, including spaces and notes, occupies a total of 125.328 characters.

Resumo

Esta Dissertação de Mestrado propõe analisar a abordagem legislativa da União Europeia para promover a sustentabilidade no setor dos criptoativos, com foco no MiCA. A pesquisa avalia como o MiCA incentiva práticas ambientalmente responsáveis através de requisitos de transparência e divulgações sobre os mecanismos de consenso, como PoW e PoS.

Esta análise destaca os desafios legislativos impostos pela UE para promover a adoção de mecanismos menos intensivos em energia, como o PoW, e avalia se o MiCA incentiva a adoção de alternativas de baixo consumo energético, alinhando-se com os objetivos de sustentabilidade mais amplos da UE, incluindo o Green Deal, EU Taxonomy, e as Metas de Neutralidade Climática. Além disso, a pesquisa avalia o impacto do MiCA na formação de um ecossistema financeiro digital mais sustentável, transparente, confiável e resiliente, posicionando a UE como líder em inovação responsável no setor dos criptoativos. Os resultados destacam o papel duplo da regulamentação na proteção dos detentores de criptoativos, ao mesmo tempo em que fomenta a evolução tecnológica e promove os objetivos ambientais, apesar da persistente dependência de mercado em mecanismos de consenso menos sustentáveis.

Abstract

This dissertation explores the European Union's regulatory approach to fostering sustainability within the crypto-assets sector, emphasising the MiCA regulation. It analyses how MiCA promotes environmentally responsible practices, particularly through transparency requirements and disclosures on consensus mechanisms such as PoW and PoS.

This research examines the regulatory requirements posed by the EU to foster the adoption of less energy-intensive mechanisms like PoW and evaluates whether MiCA incentivises the adoption of low-energy alternatives, aligning with broader EU sustainability objectives, including the Green Deal, EU Taxonomy, and Climate Neutrality Goals. Furthermore, the research assesses the impact of MiCA in shaping a sustainable, transparent, reliable, and resilient digital financial ecosystem, positioning the EU as a leader in responsible crypto-assets innovation. The findings highlight the regulation's dual role in safeguarding crypto-assets holders, encouraging, simultaneously, technological evolution, and advancing environmental objectives, despite the continued market reliance on less sustainable consensus mechanisms.

Keywords: MiCA; Consensus Mechanisms; Sustainability; Crypto-assets; Crypto-assets providers; Crypto-assets holders; Proof of Work; Proof of Stake; Responsible Innovation.

Introduction

Context

Blockchain and DLT have driven rapid innovation in financial markets. DeFi¹, facilitating digital asset trading and fostering the development of tokenised economies, has emerged as a viable alternative to traditional financial systems. For instance, crypto-assets trading has experienced exponential growth, unlocking new investment opportunities and redefining asset ownership.

These advancements have collectively redefined the way transactions are conducted, significantly reduced the reliance on traditional finance, and, perhaps most importantly, empowered users with more control over their financial assets, enabling a greater sense of financial autonomy and inclusion.

Nevertheless, alongside these advancements, decentralisation can come at a higher cost than expected – the will to pursue short-term individualised interest (enabling potential conflict of interests), and also the potential compromising of scalability, since one unwise decision can impact multiple individuals, or the organisation itself², resulting in a continuous and inherent untrust in this system and need for proper regulation and supervision of the activity. In addition, the lack of harmonised definition of what embodies a crypto-asset among the Member States creates a “legislative void” and, as a

¹ DeFi, according to VIEIRA DOS SANTOS, João; MAIA, Guilherme, In *MiCA and DeFi - (“Proposal for a Regulation on Market in Crypto-assets” and “Decentralised Finance”)* is a collection of decentralized apps offering financial services on peer-to-peer and autonomous networks, eliminating the need for a central authority to supervise and regulate its activity. This is the pinnacle characteristic of this system. In addition, in line with ZETZSCHE, ARNER, and BUCKLEY in *Decentralized Finance* and in *Remaining Regulatory Challenges in Digital Finance and Crypto-assets after MiCA*, the decentralization we see in DeFi is an effect of disintermediation and its inherent costs, namely those associated with *centralized infrastructure*. As ZETZSCHE et al. mention, the emergence of DeFi is caused by the belief that there could exist a system that could not be dependent on sovereign regulations and supervision, without the need to comply with the *dominance centralised intermediaries and regulators*, without compromising its security, but eliminating or at least mitigating the inherent risks in a centralised system

² PERESTRELO DE OLIVEIRA, Madalena; BOURA, Marta, *MiCA e DeFi: onde fica a regulação no caminho da descentralização?*, In *MiCA: Estudos sobre a nova Regulação Europeia de Criptoativos*, pp. 289-332.

consequence, does not provide a coordinated and clear view on the subject³, creating a sense of disorientation because there are no clear directives and standardised approach among all Member States. This allows CASPs to provide their services in a Member State that is more lenient in this sense than in the other.

In addition, concerning the environment, the European Commission has risen concerns regarding the environmental impact of energy-intensive consensus mechanisms - particularly PoW -, but also an urge to regulate DeFi to protect investors (and in the particular case of this Dissertation, crypto-assets holders), from the almost anonymised transactions, increasing the probability of cybercrime occurrence (money laundering, fiscal fraud, among others)⁴. This originated debates about updating the regulatory framework, addressing sustainability concerns, and assessing the long-term viability of these technologies. That is, since the emergence of crypto-assets and their specific system flow, the regulation of such technology is crucial, namely in terms of market integrity, financial stability, investor protection, and preventing cybercrime³.

Furthermore, the substantial energy consumption associated with PoW, exemplified by Bitcoin, has raised alarms about the carbon footprint of crypto-assets operations. As growing awareness of climate change has arisen over time, crypto-assets holders and regulators are increasingly assessing the inherent tension between technological progress and environmental responsibility.

This debate underscores the fundamental importance of a careful and nuanced comparison between PoW and its energy-efficient counterparts, such as PoS, compelling a thorough examination of the trade-offs between maintaining robust decentralisation and minimising environmental impact - a critical balancing act that will ultimately determine the future trajectory of blockchain technology.

³ ZETZSCHE, Dirk; ANNUNZIATA, Filippo; ARNER, Douglas; BUCKLEY, Ross, *The Markets in Crypto-Assets Regulation(MiCA) and the EU Digital Finance Strategy*, In Law Working Paper Series Paper number 2020-018, 2020.

⁴ PERESTRELO DE OLIVEIRA, Madalena; BOURA, Marta, *MiCA e DeFi: onde fica a regulação no caminho da descentralização?*, In *MiCA: Estudos sobre a nova Regulação Europeia de Criptoativos*, pp. 289-332.

In response to these concerns, the European Union has adopted a proactive regulatory stance through the Digital Financing Package, in 2020.

In that context, to neutralise the fact that there was a legislative void in the EU regarding this field, it was pivotal that the EU policymaker was aware of this fact and built a robust legislation that enhances and incentivises innovation and the usage of such innovative digital financial instruments, but also ensures that there is an accurate and adequate usage of the crypto-assets without compromising crypto-assets holders and consumers' protection⁵ – that is, the European Commission encourages the “responsible digitalisation”, where there is an adequate balance between fostering digitalisation and innovation within the financial sector in the EU and consumers' protection to ensure there is robust supervision and potential mitigation of hazardous effects in terms of cybercrime, consumers' protection, money laundering and sustainability. In a broader sense, the existence of the Digital Financing Package, and as part of the broader Green Deal and climate neutrality goals, the EU is committed to fostering innovation in blockchain technology while simultaneously addressing environmental concerns and protecting crypto-assets holders from the potential wrongdoing of other market participants, such as issuers of crypto-assets that can act maliciously.

In that sense, MiCA is enclosed in this package, positioning the EU at the forefront of global efforts to reconcile the immense potential of technological innovation with the increasingly pressing imperatives of environmental stewardship and long-term sustainability. That is, as PERESTRELO DE OLIVEIRA and BOURA⁴ mention, the legislation in MiCA embodies the need for the legislator to design an innovative, accurate, and comprehensive regulatory framework with a broad scope and application for the crypto-assets market, thereby fostering a closer and trust-based relationship with the consumer.

This commitment is further underscored by the EU's broader Digital Finance Strategy⁶, which recognises the transformative potential of digital technologies in finance while also emphasising the need to address emerging risks and ensure consumer protection – hence,

⁵ Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions on a Digital Finance Strategy for the EU, available at eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:52020DC0591.

the EU has been showing a positive and open-minded approach regarding the environmental impact that consensus mechanisms have, ensuring that crypto-assets holders (the more vulnerable market participants) have all the important and relevant factors to make a well-informed decision.

In that sense, MiCA requires clear disclosure of the environmental footprint of different blockchain technologies so that crypto-assets holders can make informed investment and usage decisions. It also standardises rules across Member States, creating a coherent EU-wide framework for crypto-assets governance.

By combining transparency with common rules, MiCA helps shift market behaviour toward lower-energy consensus mechanisms and strengthens the EU's leadership in sustainable blockchain regulation.

One of the key questions emerging from this regulatory framework, and which will be analysed further in this Dissertation, is whether MiCA's provisions will incentivise the transition towards low-energy consensus mechanisms. PoS mechanisms is inherently more energy-efficient, as they eliminate the need for extensive computational efforts and significantly reduce electricity consumption compared to PoW systems, but without compromising significantly on decentralisation issues that may arise. This shift could represent a pivotal change in how digital assets are validated and transacted, potentially leading to broader adoption of PoS across various blockchain networks.

Conversely, while MiCA may encourage innovation in energy-efficient mechanisms, it also poses challenges for established PoW-based assets, like Bitcoin. The regulatory landscape could impose stringent requirements that may affect the marketability, accessibility, or operational viability of these assets, thereby influencing crypto-assets holders' behaviour and institutional adoption.

In summary, the intersection of blockchain technology, sustainability, and regulation highlights a critical juncture in the evolution of financial markets. As will be assessed, MiCA promotes more environmentally responsible blockchain practices, posing as an essential exercise to assess how these regulatory initiatives will reshape the landscape for

crypto-assets and decentralised applications in the years to come. The outcome of this transition not only holds implications for the crypto market but also reflects broader social aspirations for a sustainable future.

Significance of the research

The significance of this research lies in the far-reaching implications of the MiCA regulation, as it has the potential to harmonise regulatory standards across the European Union and to establish a new global benchmark for the regulation of crypto-assets and their impact in the environment.

By addressing pressing challenges such as market manipulation and crypto-assets holders' risk, it not only seeks to mitigate potential harm but also establishes a baseline of trust necessary for fostering continuous innovation and responsible growth within the sector.

Crucially, MiCA's focus on the environmental impact of crypto-assets practices marks a pivotal shift towards integrating sustainability into the very core of the digital economy. The regulatory emphasis on transparency fosters a culture of accountability, aligning the advancement of blockchain technology with the EU's overarching sustainability targets and reinforcing the commitment to a low-carbon economy.

This research explores the critical intersection of blockchain regulation, financial markets, and sustainability - an increasingly important topic for policymakers, financial institutions, and developers. By examining MiCA's impact on consensus mechanisms, the study provides insights into how regulation shapes technological adoption and investment in the crypto-assets sector, but also how the EU policymaker has adapted to this rapid shift and still can maintain interested parties (crypto-assets holders, CASPs) to still operate within the EU, ensuring that is still appealing and not to restrict for crypto-assets holders, but also for issuers of crypto-assets. Furthermore, by analysing MiCA's push towards new consensus mechanisms, it would be important to understand the economic and regulatory impacts and contributions that may lead to more regulatory frameworks.

As the EU takes a leading role in shaping global crypto regulation, this research will offer valuable insights for policymakers, industry players, and crypto-asset holders worldwide. By analysing how MiCA is implemented, the study aims to provide a clear, data-based evaluation of its success in fostering environmentally sustainable practices. It will also examine potential challenges.

Given the EU's influence on global standards, understanding MiCA's sustainability measures is crucial for assessing its wider impact on international financial markets, institutional crypto-assets holders, and blockchain governance. This research also contributes to the ongoing debate over whether regulation can strike an effective balance between technological innovation and environmental responsibility in emerging digital assets.

Research questions

The implementation of MiCA brings forth critical inquiries that warrant thorough investigation to understand the regulation's implications and effectiveness. Therefore, the following research questions will guide this Dissertation:

The Dissertation examines how the MiCA influences blockchain sustainability, particularly in relation to consensus mechanisms adopted. Given MiCA's focus on transparency environmental responsibility, this research seeks to explore whether and how the regulation encourages the adoption of energy-efficient blockchain technologies.

The primary question guiding this Dissertation is: How has MiCA's regulatory framework been adapted to increase the adoption of sustainable consensus mechanisms in blockchain and financial markets, or, at least, provide crypto-assets holders with the necessary tools to make well-informed decisions, protecting their objectives within the crypto-assets market?

To further develop this inquiry, the following secondary questions will be addressed:

First, to what extent do MiCA's sustainability provisions create regulatory challenges for energy-intensive consensus mechanisms such as PoW? Given the high energy

consumption associated with PoW, it is important to analyse whether MiCA imposes direct or indirect restrictions that could impact its long-term viability in European financial markets.

Second, does MiCA favour the adoption of low-energy consensus mechanisms such as PoS, and what are the implications for financial markets and institutional crypto-assets holders? As the EU aims to align financial regulation with its sustainability goals, this research will assess whether MiCA's requirements create an incentive structure that encourages financial institutions to prefer PoS-based assets over PoW-based ones or, if it has a more neutral-based approach, leaving that choice to the crypto-assets holders and just providing them the necessary tools and requesting information from the issuers for the crypto-assets holders to make decisions that are in accordance with their core values.

Finally, what role does MiCA play in shaping Europe's position on sustainable finance and blockchain innovation? Taking into account relevant and remarkable legislation and EU initiatives, namely by MiCA within the broader context of the EU's Green Deal and digital finance strategy, this research will assess whether the regulation fosters blockchain innovation while maintaining its commitment to sustainability.

Through these research questions, this Dissertation will critically analyse the MiCA regulation's role in promoting sustainability, enhancing crypto-assets holders protection, and aligning the development of the crypto-assets market with the EU's climate objectives. This analysis is crucial for understanding the regulation's potential to foster a responsible and sustainable financial ecosystem within the rapidly evolving blockchain domain.

Literature review

Summary of MiCA's sustainability provisions

Behind the creation of MiCA was the aim of investing more, developing, and promoting the uptake of transformative technologies in the financial sector, including the uptake of DLT, while ensuring fair competition and protection of the crypto-assets holders⁷. In that sense, the EU aims to deepen the knowledge regarding this area because it will ultimately lead to economic growth and new employment opportunities for the EU citizens⁸.

In addition, MiCA establishes uniform and harmonised rules for issuers of crypto-assets not yet regulated by other EU acts on financial services and for providers of services related to those crypto-assets (in this case, CASPs). According to articles 2.°, 6.° and 8.° of MiCA, this Regulation is applicable to *natural or legal persons that engage in the issuance, offer to the public of crypto-assets or that provide services related to crypto-assets*⁹. That is, this regime applies to individuals or organisations, as well as specific entities involved in the issuance, public offerings, and trading of crypto-assets. In that sense, this relatively broad scope is intended to ensure comprehensive oversight and regulation of all activities concerning crypto-assets, which comprise a digital

⁷ Recital (6) of MiCA: “A dedicated and harmonised framework for markets in crypto-assets is therefore necessary at Union level in order to provide specific rules for crypto-assets and related services and activities that are not yet covered by Union legislative acts on financial services. Such a framework should support innovation and fair competition, while ensuring a high level of protection of retail holders and the integrity of markets in crypto-assets (...)”.

⁸ Recital (1) of MiCA: “It is important to ensure that Union legislative acts on financial services are fit for the digital age, and contribute to a future-proof economy that works for people, including by enabling the use of innovative technologies. The Union has a policy interest in developing and promoting the uptake of transformative technologies in the financial sector, including the uptake of distributed ledger technology (DLT). It is expected that many applications of distributed ledger technology, including blockchain technology, that have not yet been fully studied will continue to result in new types of business activity and business models that, together with the crypto-asset sector itself, will lead to economic growth and new employment opportunities for Union citizens”.

⁹ Article 2.°/1 of MiCA: “This Regulation applies to natural and legal persons and certain other undertakings that are engaged in the issuance, offer to the public and admission to trading of crypto-assets or that provide services related to crypto- assets in the Union”.

representation of value of rights that are secured by cryptography using DLT¹⁰ and can be traded or transferred on various platforms.

Under article 3.º/1 (5) and 2.º/4 (a), (b), and (c) of the Regulation, MiCA is applicable to crypto-assets¹¹ that are not funds, financial instruments or deposits. Hence, the crypto-assets considered in this Regulation must not be subject to other EU financial law^{Error! Bookmark not defined.}. Nevertheless, ZETZSCHE, ANNUNZIATA, ARNER, and BUCKLEY advocate for a modification in MiCA in terms of normative clarification - *regulators should clearly identify which assets will fall within its (MiCA) scope and which fall outside the scope of MiFID and EU prospectus rules*³.

In addition, to determine which activities are regulated by MiCA in a clearer capacity, the Danish Financial Supervisory Authority also attempts to interpret the Regulation and considers crucial to include in this Regulation a clear approach for CASPs to consider whether the activities they intend to offer are regulated¹² or not by MiCA. In that sense, the Danish Supervision Authority explains the baseline assessment for whether an activity is offered in a decentralised manner:

- There shall exist a valid contractual relationship between two legal entities

Regarding this first prerequisite, it is essential in any regulation – that is, there must exist two parties involved - natural or legal person⁹. However, in this case, the two entities must form a valid contract to offer a regulated activity if they clearly express their content, that is, if they are bound to follow MiCA’s guidelines if they express declarations of intent. In that context, this prerequisite is only fulfilled if both parties are bound to MiCA

¹⁰Article 3.º n.º (5) of MiCA: “For the purposes of this Regulation, the following definitions apply: (...) (5) ‘crypto-asset’ means a digital representation of a value or of a right that is able to be transferred and stored electronically using distributed ledger technology or similar technology (...)”.

¹¹ Article 3.º/1 (5) of MiCA: “For the purposes of this Regulation, the following definitions apply: (...) ‘crypto-asset’ means a digital representation of a value or of a right that is able to be transferred and stored electronically using distributed ledger technology or similar technology”.

¹² Danish Financial Supervisory Authority, *Decentralised finance and the markets for crypto-assets: When is your offering exempt from regulation?*, pp.4.

by stating their commitment to the other counterparty to have that specific contractual relationship.

- There must exist a legal entity that is behind the issuance of crypto-assets or the provision of crypto-assets services. This is the pinnacle prerequisite for the Danish Supervisory Authority and is based on a two-step analysis:
 - Technical decentralisation: assess if the activity is provided solely through smart contract that a legal entity can't control.
 - Decentralised governance: if the activity is not technically decentralised, then it shall be determined whether a legal entity has control over how it is managed and operated.

Hence, there is a “*quantity control*” assessment that must be done to conclude if the activity offered by the CASPs is done in a decentralised way and, in that context, regulated by MiCA. Essentially, it's about examining if the smart contracts operate independently without a legal company's direct influence or control; or if the legal entity has control over the activity it is managing.

The MiCA Regulation requires that crypto-assets white papers¹³ disclose key information about the issuer or offeror, the crypto-assets project and technology, and the principal adverse environmental effects of the consensus mechanism used to issue the asset. Such disclosures must be clear and not misleading, as required by Article 6.º/2 of the Regulation, reflecting the EU legislator's explicit intent to ensure that crypto-assets holders are properly informed about what they are investing in. In particular, issuers must address how their consensus mechanism affects energy consumption, use of natural resources, waste production, and greenhouse-gas emissions, and whether the mechanism relies on renewable or non-renewable energy sources.

To implement these requirements, ESMA is mandated to develop regulatory technical standards and guidelines that govern the management and disclosure of crypto-assets

¹³ The inclusion of this provision empowers crypto-assets holders to thoroughly analyse the white paper, allowing them to assess its adequacy and quality. This process ensures that the objectives of holder's projections are successfully achieved.

within the MiCA regime. Those standards must recognise the diversity of consensus mechanisms, the different security needs, efficiency, and energy-use profiles they entail, and how network incentives influence participant behaviour and environmental impacts. ESMA is also required to keep these standards under review to ensure they remain up to date with technological and market developments¹⁴.

Complementing the disclosure and standard-setting obligations, article 8.º/1 requires offerors and trading-platform operators to submit the crypto-asset white paper to the competent authority in their home Member State. This notification obligation facilitates regulatory scrutiny and enhances transparency, accountability, and avoid market abuse¹⁵. Taken together, these provisions demonstrate that MiCA seeks to promote a harmonised, sustainable, and transparent framework for the EU crypto-assets market, both by protecting investors through improved information disclosure and by encouraging environmentally responsible practices across the industry.

Hence, MiCA not only aims to ensure a high level of crypto-assets holders' protection and market integrity but also seeks to align the growth of the crypto-asset sector with broader environmental sustainability goals (also analysed and portrayed by the EU in other regulations further discussed in *EU Green Deal and climate neutrality goals – MiCA's alignment* section).

¹⁴ Article 12.º, n.º12, 1.º and 2.º paragraphs of Delegated Regulation (EU) 2025/422 supplementing MiCA: “ESMA, in cooperation with EBA, shall develop draft regulatory technical standards on the content, methodologies and presentation of the information referred to in paragraph 1, first subparagraph, point (j), in respect of the sustain ability indicators in relation to adverse impacts on the climate and other environment-related adverse impacts. When developing the draft regulatory technical standards referred to in the first subparagraph, ESMA shall consider the various types of consensus mechanisms used to validate transactions in crypto-assets, their incentive structures and the use of energy, renewable energy and natural resources, the production of waste and greenhouse gas emissions. ESMA shall update those regulatory technical standards in the light of regulatory and technological developments”.

¹⁵ According to BARCZENTEWICZ and GÂNDARA GOMES, MiCA is filling the gap concerning the prevention of market abuse that MAR left, since it applies to crypto-assets that constitute financial instruments under MiDIF II. Hence, MiCA applies a specific regime of market abuse prevention to non-financial instruments.

EU Green Deal and climate neutrality goals – MiCA’s alignment¹⁶

The European Union's commitment to sustainability is embodied in key initiatives for sustainable activities, such as the European Green Deal, the Paris Agreement, the EU Taxonomy, and several others. These frameworks collectively aim for climate neutrality by 2050, guiding the transition toward a low-carbon economy.

The Green Deal outlines strategies to reduce greenhouse gas emissions and promote clean technologies, while the Paris Agreement fosters global cooperation in limiting global warming.

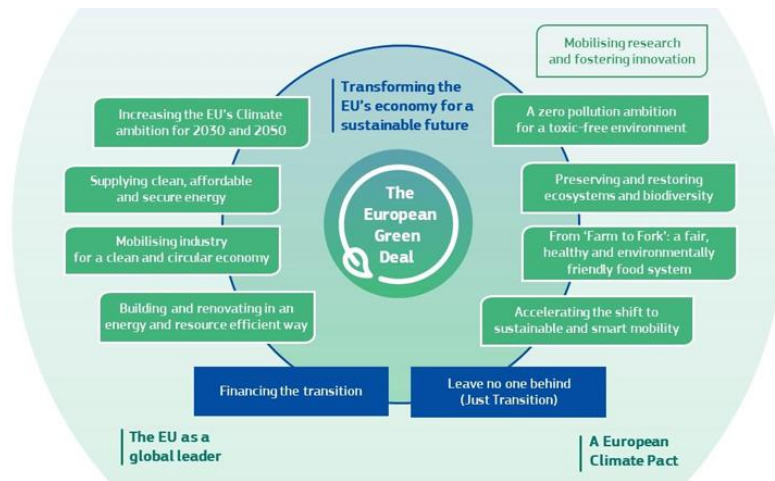
The European Green Deal¹⁷, launched in 2019, presents a comprehensive strategy for transforming the EU’s economy into a sustainable one by converting climate and environmental challenges into opportunities across various policy sectors, ensuring that the transition is fair and inclusive for everyone. The European Green Deal focuses on enhancing resource efficiency through a shift towards a clean, circular economy while addressing issues like climate change, restoring biodiversity, and reducing pollution. It details the required investments and available financing mechanisms, as well as how to ensure that the transition is equitable and inclusive¹⁸. That is, this regime establishes a package of policy initiatives to initiate a path of green transition and achieve climate neutrality by 2050¹⁷. In this regard, this framework has established six objectives that must be met in order for the EU to become the first climate-neutral region in the world by 2050.

¹⁶ Due to the fact that this is an important part of this Dissertation, yet not the principal scope of it, it will be analysed briefly.

¹⁷ Text published by the European Council - “*European Green Deal*”, available in [European Green Deal - Consilium](#).

¹⁸ Switch 2 Green: “*The EU Green Deal – a roadmap to sustainable economies*”, available in [The EU Green Deal – a roadmap to sustainable economies](#).

Figure 1: European Green Deal strategy



As it is illustrated in **Figure 1**, this constitutes the roadmap that the European Commission drew to implement the United Nations’ 2030 Agenda and the Sustainable Development Goals¹⁹.

Firstly, climate neutrality²⁰, that, in accordance with the European Council, *EU countries are legally committed to fight climate change by shifting to a climate-neutral economy with net-zero greenhouse gas emissions by 2050*. The transition to a more sustainable economy is a must to tackle the climate crisis, and it brings significant opportunities for economic growth in markets and technological development.

Secondly and thirdly, it is pivotal that there is a growing supply of clean, affordable, and secure energy, namely through decarbonisation, with the creation of a developed power sector taking into consideration renewable energy sources and processes, but also through increasing cooperation between Member States to ensure a feasible and efficient transition towards climate neutrality⁷. In that sense, from a cleaner environment point of view, the Green Deal aims to create a more sustainable and ecologically balanced ecosystem that enhances public health and well-being.

¹⁹ Text published by the United Nations – “*Transforming our world: the 2030 Agenda for Sustainable Development*”, available in [Transforming our world: the 2030 Agenda for Sustainable Development | Department of Economic and Social Affairs](#).

²⁰ Text published by the European Council – “*Climate change: what the EU is doing*”, available in [Climate change: what the EU is doing - Consilium](#).

Furthermore, circular economy is pivotal, as the European Commission envisions breaking the connection between economic growth and resource consumption. This transition towards circular systems in both production and consumption is crucial for the EU to achieve climate neutrality by 2050. In that sense, the transition to a green economy constitutes an opportunity to create and offer new potential activities and jobs. In addition, this also aims to slow the overall consumption of products that constitute a significant waste for the planet. In that context, this plan includes a “sustainable products” policy that will prioritise the reduction of “one-time used items” and re-usage of materials before recycling them. Thus, it will help businesses to foster and grow, but also set minimum requirements to prevent environmentally harmful products from being placed on the EU market²¹.

Moreover, this regime seeks to establish more sustainable farming practices by fundamentally transforming the methods employed in Agriculture. The primary objectives are to enhance environmental health, boost agricultural productivity, and ensure food security. To achieve these goals, the regime emphasises the reduction of chemical inputs, specifically synthetic pesticides and fertilisers, which are known to have detrimental effects on ecosystems and human health. In addition to minimising chemical usage, the regime also focuses on providing support for farmers, encouraging practices that promote local produce. This dual approach aims not only to safeguard the environment but also to empower local agricultural communities, fostering a resilient food system that can sustainably meet the needs of the population.

Lastly, climate justice and fairness reflect the commitment to equity in the transition to a sustainable economy. The Green Deal recognises that climate change disproportionately impacts vulnerable communities and aims to ensure that all citizens benefit from this transition, particularly those in economically disadvantaged regions. Engaging diverse stakeholders is crucial to ensure policies address the needs of all society segments. The proposal for a Just Transition Fund aims to assist affected regions and workers by providing financial and technical support to diversify economies and create jobs in sustainable sectors. Furthermore, the Green Deal emphasises the EU's

²¹ Communication from the Commission to the European Parliament, the European Council, the European Economic and Social Committee and the Committee of the Regions, *The European Green Deal*, available at [resource.html](#).

responsibility to support developing countries in their climate actions, reinforcing international cooperation for global sustainability efforts.

In addition to the European Green Deal, the EU Taxonomy, is a pillar of the EU's sustainable finance, establishing criteria and a classification system for determining the environmental sustainability of economic activities. In that sense, the EU policymaker created an harmonised definition for what “*sustainable*” can be understood as and which types of economic activities can be assessed as sustainable. That is, it creates a clear framework for the concept of sustainability, exactly defining when a company or enterprise is operating sustainably or providing environmentally friendly services/items. Taking that into consideration, the EU Taxonomy provides a unified framework for both financial and non-financial companies to define economic activities that can be classified as environmentally sustainable.

This harmonisation is essential to eliminate obstacles in the internal market concerning fundraising for environmentally responsible projects and to prevent the potential development of future barriers to such initiatives²². In that context, this regime also enables the robustness of the concepts of sustainability and environmental responsibility correlated with crypto-assets holders' protection. Consequently, it serves a crucial function in facilitating the scaling up of sustainable investments within the EU, by establishing clarity for crypto-assets holders, safeguarding private crypto-assets holders against greenwashing, assisting companies in adopting more climate-friendly practices, and reducing market fragmentation.

In addition to the aforementioned, SFDR strengthens transparency in how financial market participants identify and assess sustainability risks. By requiring standardised

²² Recital (12) of EU Taxonomy: “*The criteria for determining whether an economic activity qualifies as environmentally sustainable should be harmonised at Union level in order to remove barriers to the functioning of the internal market with regard to raising funds for sustainability projects, and to prevent the future emergence of barriers to such projects. With such harmonisation, economic operators would find it easier to raise funding across borders for their environmentally sustainable activities, as their economic activities could be compared against uniform criteria in order to be selected as underlying assets for environmentally sustainable investments. Such harmonisation would therefore facilitate cross-border sustainable investment in the Union*”.

disclosures on environmental and social considerations, the SFDR aims to mitigate greenwashing and build investors' confidence, thereby enabling crypto-assets holders to make better-informed decisions regarding their sustainable investments²³.

MiCA represents a significant advancement in establishing a cohesive and sustainable regulatory framework for the EU crypto-assets market. By setting clear and uniform rules for issuers and service providers, the Regulation seeks to align blockchain innovation with environmental sustainability objectives while supporting economic growth and job creation. In doing so, MiCA aims to ensure that market participants and crypto-assets holders have a clear understanding of the environmental consequences of the activities in which they participate.

A central feature of MiCA is its emphasis on environmental disclosure, in particular the obligation to report the impacts of the consensus mechanisms used to validate crypto-assets transactions. Requiring issuers to disclose energy usage, greenhouse gas emissions, resource consumption, and related effects increases transparency, reduces the risk of misrepresentation, and fosters accountability within the sector. These disclosures both inform holders about potential environmental risks and incentivise issuers to adopt more climate-friendly practices.

MiCA is closely aligned with broader EU sustainability initiatives - notably the European Green Deal, the EU Taxonomy, and the SFDR - and supports the objectives of the Paris Agreement. Together, these frameworks facilitate the transition to a low-carbon economy by addressing resource overconsumption, biodiversity loss, and social equity. Considering MiCA alongside these instruments is therefore essential to understanding the full scope of the EU's policy aims and the regulatory measures being deployed to achieve climate neutrality by 2050.

Finally, MiCA promotes regulatory harmonisation within the internal market by encouraging a common understanding of what constitutes environmentally sustainable economic activity in the blockchain domain. This harmonisation reduces barriers to cross-border fundraising for sustainability projects, improves market integrity by limiting

²³ Text published by FinVerde - ESG e Finanças Sustentáveis - “O que é o SFDR - ‘Sustainable Finance Disclosure Regulation?’”, available at [IAPMEI - Página Inicial](#).

greenwashing and abuse, and helps ensure that blockchain innovation remains accountable and transparent. As such, MiCA functions as a foundational regulatory element that integrates sustainability principles into the evolving cryptoassets landscape.

Consensus Mechanisms

Blockchain technology and DLT have revolutionised transaction recording and verification procedures.

Blockchain is a specialised form of DLT²⁴ that structures data as a series of interconnected blocks. Each block contains a collection of transactions, and once a block is added to the chain, it forms a secure link with the preceding block. This interlinking creates a chronological and immutable ledger, ensuring that the recorded information is permanent and resistant to tampering or alteration.

Thus, Blockchain typically has a defined structure and often uses consensus mechanisms, such as PoW or PoS, to validate transactions. Furthermore, under article 2.º/1 (3) of MiCA, consensus mechanisms are “*the rules and procedures by which an agreement is reached, among DLT network nodes, that a transaction is validated*”. *That is, these mechanisms solve the problem of consistency in the distributed system through the consensus algorithm, so that each node can be recognised and cannot be tampered with*²⁵.

This chapter will explore these two prominent consensus models, detailing their operational mechanisms, strengths and limitations, and highlighting the environmental consequences of adopting one or the other.

²⁴ Article 3.º/1 (1) and (2) of MiCA, DLT means a “*technology that enables the operation and use of distributed ledgers. That is, DLT constitutes a broader term that encompasses various technologies used to record, share, and synchronise transactions across multiple sites or institutions without a central authority*”.

²⁵ YAN, Shi, *Analysis on Blockchain Consensus Mechanism Based on Proof of Work and Proof of Stake* In 2022 International Conference on Data Analytics, Computing and Artificial Intelligence, China, p.464-467.

Technical process of Proof of Work (PoW)

In recent years, blockchain technology has increasingly permeated everyday life, with many individuals actively engaging with it and many more recognising its presence. A blockchain is, as explained in the previous chapter, a decentralised and distributed network architecture that organises data into distinct blocks (in which each block has a collection of transactions) generated by network participants. As new transactions are introduced, miners, a specialised group of users, verify and incorporate these transactions into the blockchain's blocks. Once included in the blockchain, transactions are immutably and permanently recorded in the network's ledger.

Central to any blockchain network is the consensus protocol, with PoW being one of the most prevalent models, notably used by crypto-assets like Bitcoin. In the PoW framework, miners compete to solve computational puzzles (*mining*), with specific computing equipment. When a new block is announced, the accuracy of its solution is verified, and the originating miner is rewarded. A key feature of PoW is validation through computational effort, where the miners compete to solve complex mathematical puzzles (the so-called PoW problems), processing the transaction simultaneously and independently from each other. This process necessitates significant computational power and energy, as the first miner to solve the puzzle earns the right to add a new block of transactions to the blockchain and is rewarded with a newly coin in addition to the corresponding fee²⁶.

In terms of security and immutability, the PoW mechanism enhances security by making it computationally expensive and time-consuming to alter any part of the blockchain. To change a previously confirmed block, a malicious actor would need to overpower the majority of the network's hashing power—a task that becomes increasingly resource-intensive as more blocks are added²⁷.

²⁶ PACKIN, Nizan Geslevich; SMITH, Sean Stein, *ESG, Crypto, And What Has The IRS Got To Do With It?*, SSRN Electronic Journal, 2022.

²⁷ SMUSEVA, Daria; MALAKHOV, Ivan; MARIN, Andrea; ROSSI, Sabina, *Crisis of Trust: Analysing the Verifier's Dilemma in Ethereum's Proof-of-Stake Blockchain* In 2023 IEEE International Conference on Blockchain (Blockchain).

Moreover, PoW fosters decentralisation by allowing anyone with the necessary computational resources to participate in the mining process²⁸. This prevents any single entity from controlling the network, which aligns with the ethos of blockchain technology.

Taken together, these characteristics strengthen PoW's reliability and efficiency as a consensus mechanism, safeguarding blockchain networks by maintaining security, decentralisation, and resistance to manipulation or attacks.

Limitations of Proof of Work

While PoW is esteemed for its reliability and security, it presents significant limitations that affect its sustainability.

A primary criticism of PoW is its considerable energy consumption - the computational power needed for mining translates into substantial electricity usage, raising serious environmental concerns and contributing to a significant carbon footprint. This high electricity use not only threatens environmental sustainability but also results in increasing operational costs for miners.

Although the system is designed to promote decentralisation, in practice, mining can often become concentrated in regions with lower energy costs or among well-resourced entities, leading to centralisation risks. This phenomenon can result in mining pools - groups of miners who combine their computational resources to increase their chances of earning rewards. While mining pools can improve efficiency, they also undermine the network's decentralised ethos by concentrating power in the hands of a few participants.

Another significant inefficiency related to PoW is selfish mining. In this scenario, miners withhold newly mined blocks to gain a long-term advantage over others. That is, the miner finds valid blocks to add to the blockchain but chooses not to broadcast and release them immediately, by storing them in a parallel chain and releasing the valid block

²⁸ DE FILIPPI, Primavera; DAVIDSON, Sinclair; POTTS, Jason, *Economics of Blockchain*, In IRPN: Governance, 2016.

at strategic times, to ensure that the weaker and honest miners waste time and resources, increasing their rewards²⁹. This behaviour reduces fairness and security within the network, as it allows more resource-rich miners to capitalise on their advantage at the expense of smaller miners. Honest miners may waste computational power trying to compete against these selfish miners, further exacerbating the energy waste associated with PoW. Hence, for some the decentralisation is one of the most characteristic aspects to look into in a consensus mechanism, propagating the idea that PoW is the only one that ensures that quality, but, from this case, we can already see that it is not the case sometimes, enabling centralisation.

Effectively addressing these challenges is crucial for the long-term viability of crypto-assets utilising PoW protocols. The inefficiencies and environmental implications of PoW reinforce the need for regulatory frameworks like MiCA, which promote alternatives such as PoS. This consensus mechanism is seen as a more sustainable solution, offering greater energy efficiency and reducing the risks associated with potential centralisation and unfair mining practices.

Technical process of Proof of Stake (PoS)

PoS appeared as an alternative sustainable permissionless blockchain (i.e., one that does not expend an exorbitant amount of energy)³⁰.

Contrary to PoW, within this mechanism, the quantity of crypto-assets held by nodes serves as a substitute for the computation-intensive process of solving hash values, when compared to PoW³¹. In that sense, the more crypto-assets a miner possesses, the higher their chances of successfully mining and adding new nodes into the chain.

²⁹ LI, Sheng-Nan Li; CAMPAJOLA, Carlo; TESSONE, Claudio, *Statistical detection of selfish mining in proof-of-work blockchain systems*, Scientific Reports, 2024.

³⁰ SALEH, Fahad, *Blockchain without Waste: Proof-of-Stake* In The Review of Financial Studies, March 2021, Vol. 34, N° 3, pp. 1156-1190, published by Oxford University Press.

³¹ ALFAR RODRIGUES, André, *Manual de Inovação Financeira – Uma Introdução das criptomoedas e da Blockchain*, pp.127-134.

In this system, the selection of *validators* — those responsible for confirming transactions and creating new blocks — is determined primarily by the amount of crypto-assets they hold and are willing to "stake" or lock up as collateral³².

In that sense, the process begins with users who wish to participate in the network by staking their coins (i.e., users must demonstrate ownership of a particular number of crypto-assets)³³. This stake serves as a financial commitment to the network, ensuring that validators have a vested interest in maintaining the integrity and security of the blockchain. The more crypto-assets a user stakes, the greater their likelihood of being selected as a validator for the next block³⁴. That is, users are selected to add a new block to the blockchain based on the quantity of tokens they own and the period of time they have held them³³. However, this selection process is not purely deterministic; it can also incorporate factors such as the age of the coins staked, thereby promoting a level of randomness and reducing the risk of centralisation.

Once a validator is chosen, they are responsible for validating transactions within the proposed block. This involves verifying the legitimacy of the transactions and ensuring that they adhere to the network's rules. After validation, the new block is created and added to the blockchain. The validator then receives rewards, typically in the form of transaction fees and a portion of newly minted coins, as compensation for their effort.

The PoS mechanism inherently discourages malicious behaviour, as validators stand to lose their staked coins if they act dishonestly or attempt to validate fraudulent transactions. This financial disincentive fosters a system of accountability among validators, as their economic interests align with the security and reliability of the network.

³²YAN, Shi, *Analysis on Blockchain Consensus Mechanism Based on Proof of Work and Proof of Stake* In 2022 International Conference on Data Analytics, Computing and Artificial Intelligence, China, p.464-467.

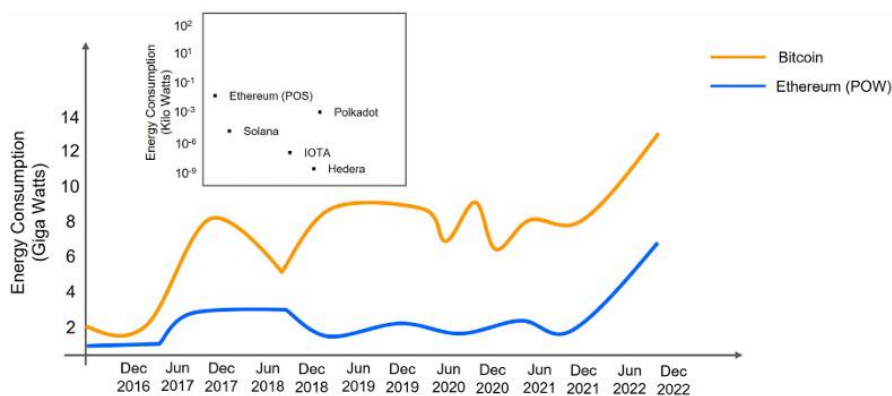
³³ ASIF, Rameez; HASSAN, Syed Raheel, *Shaping the future of Ethereum: exploring energy consumption in Proof-of-Work and Proof-of-Stake consensus*, published in *Frontiers Blockchain*, August 2023.

³⁴ YAN, Lawrence [et. al], *Mastering AI: Big Data, Deep Learning, and the Evolution of Large Language Models- Blockchain and Applications*, 2024.

Energy efficiency compared to PoW

A key advantage of PoS is its significantly lower energy consumption compared to PoW, as illustrated in **Figure 2**³⁵. In this Figure, we can see that, firstly, even using PoW, Ethereum presented better results in terms of lower energy consumption when compared to Bitcoin. In addition, we can start to identify that Ethereum (PoS) presented much lower energy consumption levels than PoW. This reduction in energy usage arises from the absence of intensive computational mining, allowing PoS to operate more efficiently. Additionally, since validators are selected to add new blocks based on the number of tokens they hold, the likelihood of any individual miner or group of miners gaining control over the network is mitigated³⁴.

Figure 2: Energy Consumption of Ethereum (prior PoS) and green Blockchain systems



Moreover, related to the previous aspect, PoS reduces the competitive environment present in PoW systems. In PoW, miners engage in a perpetual race to solve puzzles quickly, which results in increased energy expenditure. PoS, however, mitigates this issue by employing a selection process for validators that is based on the amount of crypto-assets staked rather than the computational power available. This balanced approach diminishes the competitive pressure.

Additionally, PoS networks typically exhibit lower activity levels during the validation process. The lack of intensive calculations in PoS means that the network experiences

³⁵ ASIF, Rameez; HASSAN, Syed Raheel, *Shaping the future of Ethereum: exploring energy consumption in Proof-of-Work and Proof-of-Stake consensus*, published in *Frontiers Blockchain*, August 2023.

reduced operational activity compared to PoW systems, ultimately resulting in lower energy requirements.

Furthermore, PoS protocols are generally designed with sustainability in mind. By minimising energy consumption and carbon emissions, PoS aligns more closely with global sustainability initiatives, rendering it a more attractive option in an era increasingly focused on environmental conservation.

Finally, the incentive structure of PoS encourages validators to maintain the integrity and security of the network over the long term. By committing their tokens, validators have a personal interest in promoting a sustainable and efficient operation, which fosters responsible practices that further mitigate energy consumption.

Thus, the design and operational characteristics of PoS facilitate a substantial reduction in energy use, establishing it as a more environmentally friendly and sustainable consensus mechanism for blockchain technologies.

In that sense, given that MiCA supports the adoption of sustainable consensus mechanisms in the issuance of crypto-assets³⁶, this further represents an indirect endorsement of PoS and other low-energy consensus models. By promoting environmentally sustainable practices, MiCA aligns regulatory efforts with broader goals of reducing the carbon footprint associated with blockchain operations.

Comparative summary between PoW and PoS

As argued by SEDLMEIR, BUHL, FRIDGEN, and KELLER³⁷, the energy consumption of PoW blockchains is built, in fact, “*by design*”, that is, the security of PoW blockchains is grounded in their substantial energy consumption. An attacker would need

³⁶ Recital (7) of MiCA: “*The consensus mechanisms used for the validation of transactions in crypto-assets might have principal adverse impacts on the climate and other environment-related adverse impacts. Such consensus mechanisms should therefore deploy more environmentally-friendly solutions and ensure that any principal adverse impact that they might have on the climate, and any other environment-related adverse impact, are adequately identified and disclosed by issuers of crypto-assets and crypto-asset service providers*”.

³⁷ SEDLMEIR, Johannes, BUHL, Hans; FRIDGEN, Gilbert; KELLER, Rober, *The Energy Consumption of Blockchain Technology: Beyond Myth*, In *Business & Information Systems Engineering*, Vol. 62, pp. 599-608, 2020 available at *s12599-020-00656-x.pdf.

to control a significant share of the total computational power used by miners, and thus bear an equivalent portion of the overall energy costs, to manipulate or dominate the system. Consequently, the higher the market value of a PoW-based cryptocurrency, the stronger its protection against attacks, demonstrating that PoW constitutes a deliberately robust security design that requires an attacker to bear a high percentage of the total computing power that miners use for mining.

However, this mechanism cannot be constantly celebrated and its usage perpetuated since other mechanisms can ensure security while promoting a more sustainable option, like PoS.

Firstly, PoS eliminates the need for computational mining. In PoW, miners engage in solving complex mathematical puzzles, which demand considerable computational power and result in high electricity consumption. Conversely, PoS does not involve such mining activities, significantly reducing overall energy usage³⁷.

Secondly, PoS requires lower hardware specifications. PoW necessitates specialised and often expensive hardware to support its mining operations, contributing to increased energy consumption. In contrast, PoS allows participants to validate transactions using standard computers, further decreasing energy demands.

Additionally, the selection process for validators in PoS is based on the number of tokens they hold and are willing to stake, rather than their computational capabilities³⁴. This approach eliminates the competitive, energy-intensive race inherent in PoW mining, which requires constant electricity expenditure to outperform other miners.

Moreover, PoS reduces network loads since it does not require continuous calculations to validate blocks. As a result, the overall energy requirements of the network are lower, as fewer resources are expended in maintaining system operations.

Furthermore, PoS networks align more closely with sustainability goals due to their reduced carbon footprint compared to PoW mechanisms, which have garnered increasing concern over their environmental impact.

Lastly, the incentive structures in PoS promote participants to act in the best interests of the network without resorting to energy-intensive validation processes. The financial stake that validators hold encourages a commitment to honesty and reliability, contributing to a more efficient operational model.

In that context, **Figure 3** presents a comparison of energy consumption across various blockchain platforms, specifying both global energy use in kilowatts (kW) and energy consumption per transaction in kilowatt-hours per transaction (kWh/tx). Notably, Ethereum 2.0 shows a marked reduction in energy consumption, with a global usage of 14.6 kW and an energy per transaction of only 0.00803 kWh. This efficiency is indicative of the platform's transition to a Proof of Stake consensus mechanism, which prioritises sustainability³⁸.

In stark contrast, Bitcoin's energy consumption is dramatically higher, recording a global usage of 3,373,287.7 kW and 360.393 kWh per transaction. This stark difference underscores the significant energy demands associated with Proof of Work systems, raising concerns about their environmental impact³⁸.

Overall, the data presented in **Figure 3** illustrates the pressing need for blockchain platforms to prioritise energy efficiency, particularly in light of the increasing scrutiny over environmental sustainability in technology. The findings highlight the advantages of newer consensus mechanisms, such as PoS, in contributing to a more sustainable blockchain landscape³⁸.

Figure 3: Energy Consumption Comparison Among Various Blockchain Platforms

Platform	Global (kW)		Per transaction (kWh/tx)	
Eth. 2.0 [★]	14.6 –	445.3	0.000 26 –	0.008 03
Algorand	6.2 –	189.3	0.000 17 –	0.005 34
Cardano	48.8 –	1491.7	0.037 16 –	1.135 62
Polkadot	1.6 –	49.9	0.003 78 –	0.115 56
Tezos	2.2 –	67.1	0.000 36 –	0.010 96
Hedera	3.5 –	6.9	0.000 02 –	0.000 04
Bitcoin	3 373 287.7 –	34 817 351.6	360.393 00 –	3691.407 00
VisaNet		22 387.1		0.003 58

[★] Ethereum Mainnet measurements used as approximation

³⁸ TASCA, Paolo; XU, Jiahua; VADGAMA, Nikhil; IBÁÑEZ, Juan Ignacio, *The Energy Footprint of Blockchain Consensus Mechanisms Beyond Proof-of-Work*, 2021 *IEEE 21st International Conference on Software Quality, Reliability and Security Companion*, 2021.

Alternative consensus mechanisms

Delegated Proof of Stake (DPoS)

DPoS extends the foundational structure of the previously discussed PoS and is frequently considered a more secure mechanism than traditional PoS implementations³⁹. DPoS operates through a 'democratic' voting system that empowers token holders to elect delegates to represent their interests. These elected delegates streamline the network by concentrating responsibilities, thereby enhancing efficiency and reducing complexity.

DPoS can be effectively utilised in various applications, including decentralised applications and social media platforms. By electing representatives to participate in the consensus process, DPoS improves both the performance and scalability of the PoS model. In decentralised applications, it enables prompt transaction confirmations and establishes robust governance mechanisms, while ensuring reliable data exchange and user interaction. In the context of social media, DPoS facilitates swift and seamless information transfer among users. These advantages have contributed to the growing popularity of DPoS in the field of decentralisation, positioning it as a preferred choice for systems seeking to enhance operational efficiency³⁹.

However, a potential drawback of DPoS is its vulnerability to centralisation. If a small number of delegates acquire a significant share of the voting power, the decentralised nature of the network may be at risk. The degree of centralisation depends largely on the specific implementation of DPoS and the distribution of tokens among the voters.

Proof of Authority (PoA)

PoA is a consensus mechanism that combines elements of PoW and PoS to enhance the performance of distributed consensus in a blockchain while prioritising security and efficiency. In a PoA system, inspired by BFT⁴⁰, the validator/sealer is chosen based on personal credibility rather than through crypto-assets' collateral or computational power.

³⁹ HEWETT, Joe; ETMAN, Mark; MARSEGLIA, Robbie; PICKERSGILL, Mella Tomas; LEEKE, Matthew, *Towards a Dependable Energy Market: Proof of Authority in a Blockchain-based Peer-to-Peer Microgrid*, In 2022 IEEE 27th Pacific Rim International Symposium on Dependable Computing, Beijing, China, 2022, pp. 109-118.

⁴⁰ ZHANG, Xinrui; RUJIA, Li; WANG, Qin; DUAN, Sisi; WANG, Qi, *Time-manipulation Attack: Breaking Fairness against Proof of Authority Aura* In The ACM Web Conference 2023, pp. 2076-2086.

That is, PoA measures the authority of a node based on real-world reputation, ensuring reliability and accountability³¹. In that sense, PoA grants the sealers the power to create new blocks and validate transactions, but also to finalise a block by cryptographically signing it. This group of sealers can evolve, depending on the consent of a subset of the participants, making it suitable for dynamic consortia. PoA presents an attractive option for industries with stringent security needs⁴¹. Because validators are pre-approved, and their actions are tied to their identities, this discourages malicious behaviour because their reputation is at stake⁴². This design allows the PoA blockchain to operate under a trusted authentication node within a scalable framework.

However, while PoA offers advantages in terms of efficiency, it also introduces potential centralisation and security risks⁴³. In that context, the current PoA algorithms are vulnerable to attacks that manipulate time and order because they use a fixed system for leader rotation and block proposals. Malicious users can take advantage of these aspects to alter timestamps or postpone block creation, which can upset the order of transactions and blocks while undermining the stability of the consensus process. To combat these risks, incorporating randomness into the leader selection procedure is crucial.

In this context, as analysed by PARINYA, GRAMOLI and JOURGON⁴⁴, multiple malicious validators are created to take control of a PoA network, exposing the risks of relying on a small set of trusted validators and highlighting the need for more resilient consensus mechanisms. In that context, a particularly concerning attack vector is the "Cloning Attack," as detailed by PARINYA, GRAMOLI and JOURGON. The Cloning Attack demonstrates that even a small number of malicious actors can compromise the integrity of PoA systems. By cloning a sealer's identity across multiple nodes, an attacker

⁴¹ YASH, Bobde; NARAYANAN, Gokuleshwaran; JATI, Manas; PETER RAJ, Raj; Cvitic, Ivan; PERAKOVIC, Dragan, *Enhancing Industrial IoT Network Security through Blockchain Integration*, 2024.

⁴² ISLAM, Md. Mainul; MERLEC, Mpyana Mwamba; IN, Hoh Peter, *Proof of Random Leader: A Fast and Manipulation-Resistant Proof-of-Authority Consensus Algorithm for Permissioned Blockchains Using Verifiable Random Function*, In *IEEE Transactions on Services Computing*, Vol. 18, n°. 3, pp. 1655-1668, May-June 2025.

⁴³ SHU-PING, Lu; LEI, Chin-Laung; TSAI, Meng-Han, *An Efficient Proof-of-Authority consensus scheme against cloning attacks*, 2024.

⁴⁴ PARINYA, Ekparinya; GRAMOLI, Vincent; JOURJON, Guillaume, *The Attack of the Clones against Proof-of-Authority*, 2019.

can effectively create a "*shadow majority*"⁴⁵, manipulating the block selection process and enabling double-spending. This attack undermines the fundamental assumption of PoA – that a known and trusted set of sealers can reliably secure the blockchain.

The success of the Cloning Attack depends on the attacker's ability to create network partitions, isolate subsets of sealers, and control message flow between them. In that context, the attacker carefully manipulates the order of sealers to maximise the weight of the malicious branch.

PARINYA, GRAMOLI, and JOURJON⁴⁴ propose countermeasures to mitigate the Cloning Attack, primarily focusing on carefully defining the number of sealers required to validate a block. In that sense, requiring a majority of sealers shall be insufficient to guarantee security in partially synchronous networks. They suggest that the number of validators must be carefully calibrated based on the number of potentially malicious actors and the network's communication characteristics.

Thus, the Cloning Attack and the proposed countermeasures underscore the importance of rigorous security analysis for PoA systems. While PoA offers advantages in terms of efficiency and control, it is not a silver bullet. Careful consideration must be given to potential attack vectors and the underlying assumptions of the consensus mechanism.

Therefore, while PoA is a significant consensus mechanism that has gained traction for its ability to achieve rapid consensus with low computational and energy demands, it also presents several shortcomings. Addressing these deficiencies will be essential moving forward, potentially through the development of a hybrid model that integrates the reputation-based approach with a more secure alternative.

⁴⁵ The attacker fraudulently duplicates the identity of a legitimate block validator across several different nodes within a blockchain network.

Newer developments regarding MiCA

The European Union's approach to regulating crypto-assets, as shown in MiCA and its supplementary delegated act of December 17, 2024⁴⁶, demonstrates a nuanced strategy for promoting the adoption of more sustainable consensus mechanisms⁴⁷.

In that context, it explicitly analyses the importance of deepening a proper identification and disclosure of the climate and other environment-related adverse events linked to the use of consensus mechanisms to issue crypto-assets⁴⁸. Therefore, as foreseen by the EU policymaker, the core principle of this element is to enable crypto-assets holders to receive fair, accurate, clear, and non-misleading information regarding the ecological footprint of the technologies that enable the creation and distribution of crypto-assets so that they are sure and can make well-informed decisions based on their beliefs⁴⁹. In that sense, it would be created a list of specific, mandatory, and optional indicators to measure the environmental impact of consensus mechanisms so that the crypto-assets holders could have an harmonised and standardised approach to be able to compare the consensus mechanisms between them⁴⁸.

In this regime, there is also a stricter set of rules designed for CASPs⁵⁰. According to articles 66.º/5 and 9.º/1 MiCA (fiduciary duties conferred to CASPs)⁵¹, offerors and crypto-assets providers shall share publicly any information in the white paper regarding adverse environmental events that the consensus mechanism used in the crypto-asset can have⁵². Hence, NCAs shall analyse and assess if CASPs are complying with this role, that

⁴⁶ Adopted in 17th December 2024, but published in March 2025 (due to the scrutiny period of 3 months).

⁴⁷ Delegated act details regarding Regulation (EU) 2025/422 of 17 December 2024, available in Delegated act details - Register of delegated acts.

⁴⁸ Regulation (EU) 2025/422 of 17 December 2024.

⁴⁹ Text published by ESMA, *Final Report - Draft Technical Standards specifying certain requirements of the Markets in Crypto Assets Regulation (MiCA) – second package*, 2024.

⁵⁰ Accordingly to Article 3.º/1 (15) of MiCA, HOBZA and VONDRÁCKOVÁ in *Crypto-Asset Services under the Draft MiCA Regulation*, CAPSs consist of entities or persons that dedicate themselves to the provision of crypto-assets to third parties on a professional matter against payment. In this definition, the key element to categorise an entity as a CASP is the existence of a payment in return for the provision of the crypto-asset.

⁵¹ ZETZSCHE, Dirk; SINNIG, Julia, *The EU Approach to Regulating Digital Currencies*, In *Law and Contemporary Problems*, Vol.87, Nº2, 2024.

⁵² Article 66.º/5 of Regulation (EU) 2025/422 of 17 December 2024 amending MiCA: “*Crypto-asset service providers shall make publicly available, in a prominent place on their website, information related to the principal adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanism used to issue each crypto-asset in relation to which they provide services. That information may be obtained from the crypto-asset white papers*”.

is, if they are acting in a clear, fair and professional manner, taking into account the best interest of the client⁵³.

Hence, these modifications in MiCA brought a burden to the service providers to provide all relevant information and indicators for the crypto-assets holders, including the name and legal entity of the white paper writer, the specific features of the consensus mechanisms used for the validation of the transactions, and the reference (or estimate) period of the statement. Furthermore, this provision highlights the stricter requirements imposed upon CASPs, including enhanced transparency, clarity, accuracy, fairness, and the management of conflicts of interest. This created an harmonised approach and clarifies that CASPs must not use clients' assets on their accounts and establishes limits to crypto business models, resulting in value transfers from clients to the CASPs⁵¹. Thus, by establishing and clarifying the rules in this regard, the EU policymaker seeks to foster a transparent and protective market environment – one that ensures comparable information, safeguards against fraud and abuse, and provides the vital conditions for efficient markets and sustainable market development⁵⁴.

Moreover, they shall also provide a comprehensive website so that the crypto-assets holders can access the environmental impacts of the consensus mechanism⁵⁵, according to articles 6°/1 first subparagraph, 19°/1 first subparagraph point (h) and 51°/1 first subparagraph point (g) of MiCA.

While the regulation does not explicitly mandate the use of specific consensus mechanisms, it requires enhanced transparency regarding their environmental impact and formulating a comprehensive set of indicators that address these constraints, thereby equipping crypto-assets holders with clear and comparable insights into the negative

⁵³ ESMA published an *Opinion to support the convergent application of MiCA*, July 2024.

⁵⁴ ZETZCHE, Dirk; ARNER, Douglas; BUCKLEY, Ross; KIRKWOOD, Jamieson, *The Financialization of Crypto: Lessons from FTX and the Crypto Winter of 2022-2023* In UNSW Law & Justice Research Series, 2023.

⁵⁵ Recital (7) of Regulation (EU) 2025/422 of 17 December 2024 amending MiCA: “*To facilitate investors' ability to compare between the adverse impacts of the consensus mechanisms on which are issued different crypto-assets, the information on crypto-asset service providers' websites should allow the public to compare the adverse impacts on the climate and other environment-related adverse impacts of the consensus mechanisms and their incentive structures across all the crypto-assets in relation to which the crypto-asset service provider provides crypto-asset services*”.

effects of consensus mechanisms. In that context, this impact demonstrably steers the market toward greater sustainability.

Moreover, the Delegated Act significantly deepens the knowledge and requirements surrounding consensus mechanisms by mandating detailed disclosure of sustainability indicators, including key metrics such as energy consumption and GHG emissions, going beyond MiCA's initial, less-specific requirements, as analysed in *Summary of MiCA's sustainability provisions* section. The level of detail required is that crypto-assets holders receive sufficient information to assess the environmental impact of various crypto-assets. Further, the regulation introduces standardised methodologies for calculating and presenting this data, thus promoting comparability between different crypto-assets and eliminating ambiguity. This standardised reporting enables crypto-assets holders to easily compare the environmental footprint of various assets.

The regulation also promotes the use of quantitative metrics whenever feasible; although it acknowledges the challenges in obtaining perfect data, it emphasises the use of estimates only when necessary, always requiring a clear explanation of the methodology and underlying assumptions. This focus on transparency minimises the likelihood of "greenwashing" — misleading claims about the sustainability of certain crypto-assets.

The regulatory approach employs a balanced strategy, avoiding overly prescriptive measures while actively encouraging the adoption of sustainable practices. The regulation serves as a strong, albeit indirect, signal of the EU's support for more sustainable consensus mechanisms. By demanding transparent disclosure of environmental impacts, the regulation naturally favours crypto-assets based on energy-efficient consensus mechanisms, potentially influencing market dynamics towards greater sustainability. This is a "market-based" approach, indirectly promoting sustainability without explicitly restricting less efficient technologies. Simultaneously, while the regulation provides crypto-assets holders with comprehensive data, it doesn't replace the need for individual due diligence and independent research. They are still expected to understand the provided information and use it to assess the risks and sustainability implications of their investments. The regulation empowers crypto-assets holders through increased

knowledge, but ultimately leaves the investment choice to their informed decision-making⁵⁶.

In conclusion, the EU's approach to regulating consensus mechanisms in crypto-assets is a calculated blend of directive and discretionary strategies, due to the fact that by designs clear rules that help solve problems and encourage market participants (CASPs and crypto-assets holders) to act responsibly and ethically. This approach adopted in MiCA enables the market participants to, indirectly through inducement and disincentivation of the adoption of a hazardous consensus mechanism for the environment, follow this Regulation⁵⁷.

As highlighted by PARKIN and SMITH⁵⁸, proper and unambiguous regulation and supervision of such emerging technology is key to protecting investors, avoiding market abuse, and exploitation of the weaknesses of fragile law enforcement.

The enhanced disclosure requirements serve as a strong incentive for market participants to adopt and promote more sustainable consensus mechanisms. Additionally, while not explicitly forcing a particular technology, the enhanced transparency regarding the environmental impact of consensus mechanisms significantly facilitates informed decision-making, empowering them to prioritise sustainability in their investments. This approach recognises the complexities of rapidly evolving technologies and the need for a balance between regulation and crypto-assets holders' autonomy. That is, the regulation provides the tools – comprehensive, standardised data – but doesn't mandate specific actions. Crypto-assets holders are free to interpret the information and make choices based on their individual risk tolerance, investment strategies, and ethical considerations.

⁵⁶ Recital (3) of Regulation (EU) 2025/422 of 17 December 2024 amending MiCA: “It is important that investors receive accurate, fair, clear, not misleading, simple, concise and comparable information on the impacts of the technologies underpinning issuance of crypto-assets on the climate and the environment (...) It is therefore necessary to develop a list of indicators that considers those constraints to provide investors with understandable and comparable information on the adverse impacts of consensus mechanisms, based on accessible and reliable data, including estimates where necessary and duly justified”.

⁵⁷ SUNSTEIN, Carl; Thaler, Richard, *Libertarian Paternalism is not an Oxymoron* In The University of Chicago Law Review, 2003, Vol. 70, N.º 4 pp. 1159-1202.

⁵⁸ PACKIN, Nizan Geslevich; SMITH, Sean Stein, *ESG, Crypto, And What Has The IRS Got To Do With It?*, SSRN Electronic Journal, 2022.

Therefore, while the regulatory framework strongly guides crypto-assets holders toward more sustainable options, it ultimately leaves the final decision in their hands.

In that sense, in the regulatory package ESMA from December 2024 established⁵⁹, in this sector, a detailed review and set of recommendation on how CASPs can provide their crypto-asset services and management of crypto-assets reliably and suitably, in a similar way as defined by MiFID II⁶⁰.

Later on, in 31th January 2025, ESMA issued a supervisory debriefing⁶¹ where it authorises crypto-asset service providers (CASPs), in which is analysed the risk level of CASPs, their role as market participants, and assessed the riskiness of their presence in the market.

In that sense, as analysed in the supervisory briefing⁶¹, to assess the impact that CASPs have and their difference to financial institutions, ESMA adopts a risk-based approach where analyse that CASPs are not financial institutions, and in that context, they are not obliged to comply with the strict regulatory compliance and supervision requirements and legislation, and, in that context, increase the probability of engaging in criminal activity such as Money Laundering due to the easiness of onboarding customers from multiple jurisdictions or even use different technologies to transfer crypto-assets easily across the globe. Hence, ESMA analysed some key elements to assess the riskiness of a given CASPs, such as: size (CASPs that are larger in terms of number of clients and amount of assets have a potential to be riskier in the sense that if the act in a non-diligent of non-compliant way, the harm caused would be larger as well); complexity of group structure (where does exist a highly complex group structure, the more difficult it is to understand

⁵⁹ Idem.

⁶⁰ In MiFID II regime, this activity is regulated in a similar manner through articles 4.º/1 (5), 5.º, 11º/1, 13.º/1 (requirements of authorisation, whereas each Member State should require that the provision of investment services or performance of investment activities on a professional capacity should be subject to a prior authorisation granted by each Member State's competent authority, namely a specification of the services and activities that these CAPSs are authorised to perform). In that sense, the competent authorities may sustain their assessment on the reputation of the proposed acquirer, the financial reputation of the proposed acquired.

⁶¹ ESMA published a *Supervisory Briefing - Authorisation of CASPs under MiCA*, available in ESMA75-453128700-1263 Supervisory Briefing on the Authorisation of CASPs under MiCA.

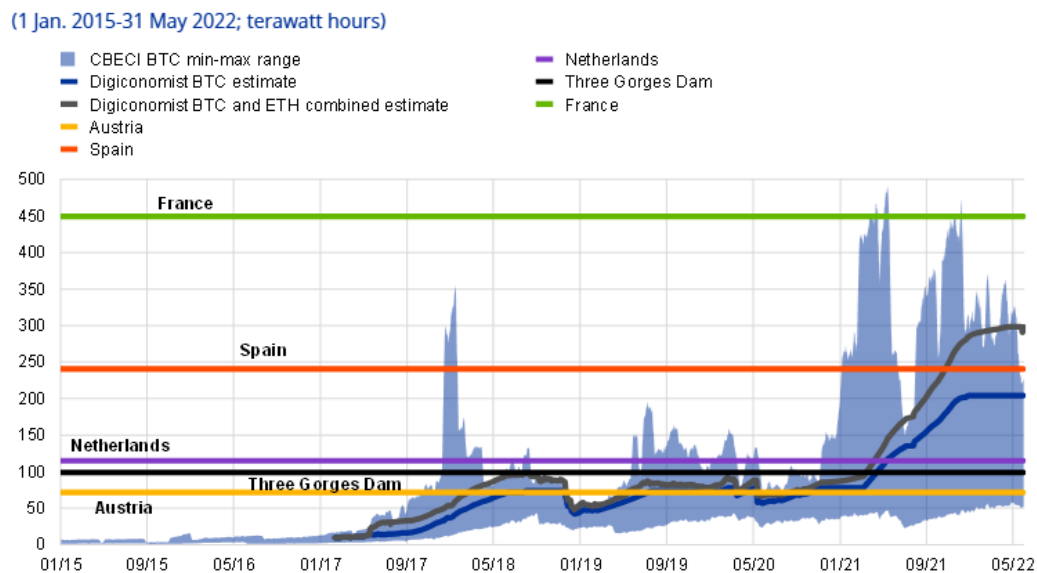
the given structure, potential multiple authorisation throughout different legal frameworks, large number of entities involved, creating an additional hazard in terms of AML, conflict of interest (article 72.º MiCA) and ability of national competent authorities (NCAs) to assess and supervise the CASPs conduct); cross-border activity (intertwined with the last key element, if a CASP as a significant level of cross-border activity, it would be more difficult of NCAs to supervise the activity, creating additional layers of risk, hazard and responsibility. In that sense, mutual protocols and accords between different NCAs are crucial to ensure that there is proper supervision and that the MiCA standards are met); role of ecosystem (CASPs that have a crucial role in the crypto-assets environment, present a higher risk as their activities can easily influence other CASPs); supervisory history (the historical supervisory of a given entity, shareholders or other relevant member is pivotal to determine the level of scrutiny during authorisation, namely acquiring information regarding CASPs being blacklisted, warnings, fines and sanctions, supervisory reports or potential investigations), among others.

Therefore, MiCA provided NCAs autonomy to analyse and make decisions on their EU policy, namely, assess and supervise CASPs in accordance with their internal policies, adopting a critical and restrictive approach in determining if governance arrangements intervene with the effective exercise of their supervisory function.

Institutional Point of view

In regards to the transition into environmentally friendly consensus mechanisms that do not compromise security and decentralisation, some organisations and European authorities have deepened their research. For instance, BCE analysed the estimated carbon footprint of various crypto-assets (Bitcoin) and explored the reasons behind it⁶². In that sense, as previously discussed in *Technical process of Proof of Work (PoW)* section, the crypto-assets that use PoW, as the elected consensus mechanism to validate the transactions, have a significant consumption in terms of carbon footprint, presenting similar estimates as individual countries like Spain or France, as can be seen in the chart below (**Figure 4**). Here the amount has increased more rapidly since 2021. Hence, this contributes to *elevated climate transition risk for the financial system*⁶³.

Figure 4: Estimation of annual electricity consumption compared to Bitcoin electricity consumption



Sources: Cambridge Bitcoin Electricity Consumption Index (CBECI), Digiconomist, Cambridge Centre for Alternative Finance, International Energy Agency, Morgan Stanley and ECB calculations.

Note: The horizontal lines denote the annual electricity consumption of countries in 2020 and the annual electricity production capacity of the Three Gorges Dam.

Moreover, because the shift towards a more environmentally friendly consensus mechanism is purely voluntary, there is still a very conservative approach from either

⁶² ECB, *Mining the environment – is climate risk priced into crypto-assets?*, Macprudencial Bolletin, 2025, available in *Mining the environment – is climate risk priced into crypto-assets?*.

⁶³ Idem.

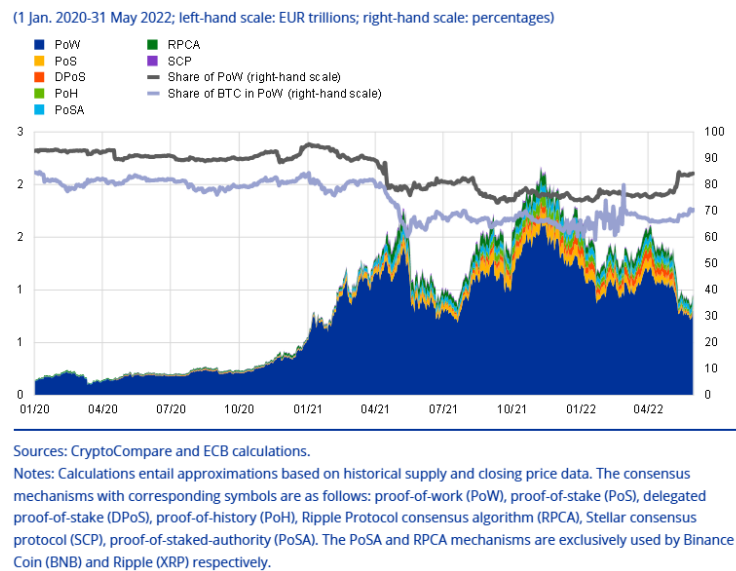
regulators and financial authorities or even the crypto-assets holders themselves regarding the security that PoW provides due to the computation-intensive process of solving hash values used in this mechanism⁶². On the other side, PoS sets a list of validators that are chosen based on the amount of crypto-assets they currently have to proceed with the validation of the nodes and solving the cryptographic protocols, which can lead to centralisation of the procedure⁶⁴.

Moreover, within the EU there have been, and continue to be, numerous efforts to establish comprehensive and effective legislation addressing GHG emissions and their global impact. Initiatives such as the European Green Deal demonstrate the EU's strong commitment to reducing GHG emissions. However, if there isn't a collective effort and a more harmonised approach worldwide, the impact level is relatively minimal.

Furthermore, as analysed in **Figure 5**, PoW remains popular and reliable among the market players, making up a significant portion of the market, accounting for about 80% of the total crypto-asset market. Bitcoin owners and miners often prefer PoW, considering it is the mechanism they are used to opt for, and are more reluctant about this change.

⁶⁴ Decentralisation is one of the crucial elements to take into consideration when analysing a given consensus mechanism, due to the fact that it provides network integrity and trust, by enabling, according to the Danish Supervisory Authority, market actors to develop and make self-executing and autonomous software available which users can use to receive services with crypto assets and establish decentralised governance layers. That is, this element enables the system to distribute decision-making and the validation of nodes into the blockchain throughout market participants, crypto-assets holders, and such, without the intervention of a central authority. In that sense, this would allow all the validators to compete fairly since the criteria would be only the speed in solving the cryptographic protocol (in the PoW mechanism, where this topic is the most prominent when compared to other consensus mechanisms). Hence, by spreading the source of decision-making analysis and the opportunity to solve the cryptographic puzzles and including the need into the blockchain, decrease also decreases the probability of data manipulation. However, in a more accentuated way, PoS stipulates that the validation must be made through a pre-selection of validators that are nominated as such, taking into account the amount of crypto-assets and tokens owned by each of them. In that sense, the ones that have a higher amount of tokens have a higher probability of being nominated as validators. This, as one of the main criticisms of PoS, is correlated to centralisation risk, since the validators with a higher amount of tokens are easily nominated as such and come to wield disproportionate influence over the network.

Figure 5: Market capitalisation of consensus mechanisms (2020-2022)



However, as discussed further in *0*, Ethereum, through a gradual shift, showed that PoS can also provide similar functionalities, ensuring at the same time security, a certain level of decentralisation, and scalability. In that sense, as HEWETT, ETMAN, MARSEGLIA, PICKERSGILL, and LEEKE⁶⁵ mention, and also Ethereum Foundation suggests that moving the Ethereum blockchain from PoW to PoS would dramatically reduce energy consumption by 99.95% while ensuring the same functionality. A PoS-based Ethereum would put the blockchain’s energy consumption not on the scale of countries, but that of a small town of around 2,100 homes in the United States⁶⁵.

Nevertheless, as pointed out by GSCHOSSMANN, VAN DER KRAAIJ, BENOIT and ROCHER in *Mining the environment – is climate risk priced into crypto-assets?*⁶¹, renewable energy is limited. The share of renewables in global electricity generation was 29% in 2020⁶⁶. Hence, it will take time to have a fully renewable energy supply. Using existing renewable energy sources to mine bitcoin generally implies that less renewable energy can be used for other purposes such as providing electricity to households, as well as to eventually cover the required climate transition, that according to the IEA Electricity

⁶⁵ Research published by Ethereum Foundation blog, *Ethereum's energy usage will soon decrease by ~99.95%*, available at [Ethereum's energy usage will soon decrease by ~99.95% | Ethereum Foundation Blog](#).

⁶⁶ IEA, *A new energy economy is emerging, 2021*, In World Energy Outlook 2021, available in [A new energy economy is emerging – World Energy Outlook 2021 – Analysis - IEA](#).

report 2024⁶⁷, wholesale electricity prices although decreases in Europe and Asia due to moderation in energy commodity consumption, they are still above pre-pandemic levels.

Moreover, public authorities have a crucial role in assessing whether the significant carbon footprint of these crypto-assets conflicts with their environmental goals. In that sense, the shift toward environmentally sustainable practices poses risks for the valuation of crypto-assets. Hence, as mentioned, achieving net-zero emissions requires crucial political, legislative, and social decisions regarding energy sources and their consumption levels.

For instance, as already analysed, the EU has been acting as a pioneer in this field, namely because of the continuous effort to legislate and incentivise crypto-assets holders and more generally market players to acknowledge their duties to the counterparty (particularly issuers towards crypto-assets holders), providing more information regarding the environmental impact of specific consensus mechanism a crypto-asset has, and so on. In that context, the EU, in alignment with the European Green Deal, EU Taxonomy and, fundamentally, with the commitment undertaken in the Paris Agreement, is trying to orient the legislative, social, and political compass towards a more sustainable and environmentally-conscious approach. That is, policymakers might prioritise specific activities that align with climate goals, ensuring they don't divert the limited renewable energy away from uses like crypto-assets mining.

For that matter, the Swedish Financial Supervisory Authority (*Finansinspektionen*) considered that PoW and other energy-intensive consensus mechanisms pose serious hazards towards essential services. This analysis was conducted because crypto-assets holders saw Sweden as an advantageous country for their crypto investment strategy, given that prices were low, taxes for mining-related activities were favourable, and there was good access to renewable energy⁶⁸. In addition, this was not enabling Sweden to meet the Paris Agreement requirements.

⁶⁷IEA, *Electricity Report 2024 – Analysis and forecast to 2026*, available at [Electricity 2024 - Analysis and forecast to 2026](#).

⁶⁸ Text published by Finansinspektionen, *Crypto-assets are a threat to the climate transition – energy-intensive mining should be banned*, 2021, available in [Crypto-assets are a threat to the climate transition – energy-intensive mining should be banned | Finansinspektionen](#).

Hence, they proposed to the EU, in 2021, a ban on the energy-intensive PoW mining method⁶⁸, similarly to China, which banned crypto-assets transactions⁶⁹, by claiming that this system would enable financial crime, posing a rising risk to China's financial system due to its speculative nature.

The primary reasons for this proposal, beyond its potential to disrupt essential services for Swedish citizens, are its significant negative environmental impact and the threat it poses to the urgent climate transition. Mining operations, particularly those using energy-intensive methods, produce large amounts of greenhouse gases, contributing to climate change. Additionally, such activities can be exploited for criminal purposes, such as money laundering and ransomware payments⁶⁸. The complex nature of crypto mining also presents serious consumer risks, as consumers can be misled or lack the necessary information to make well-informed decisions about their investments^{Error! Bookmark not defined.}.

However, as crypto-assets became more important worldwide and their possibilities for economic development and increased financial inclusion became clearer, Sweden started to develop a more supportive regulatory approach⁷⁰, applying MiCA in their Member State. Hence, on one side, to permit the permeability of crypto-assets into the market, they suggested enhanced AML and Anti-Terrorism Financing policies, while also introducing stringent compliance requirements for crypto-related businesses⁶².

Although Bitcoin investors have not considered the potential negative environmental impacts, and the possible actions authorities might take in response, it is important to reflect on the environmental and humanity's needs into the legislation and overall foster in society, as *Finansinspektionen* has been trying to implement, the imperative need to transition and shift towards more conscious options and mechanisms that still ensure security, decentralisation and scalability, such as PoS.

Lastly, BCE evaluated potential policy measures for regulators and emphasised the importance of considering climate-related factors in the practices of crypto-assets holders. That is, the public authorities shall measure and evaluate whether the outsized carbon

⁶⁹ SHIN, Francis, *What's behind China's cryptocurrency ban?*, 2022, available in [What's behind China's cryptocurrency ban? | World Economic Forum](#).

⁷⁰ Sweden's Cryptocurrency Legislation Landscape in 2024, available in [Sweden's Cryptocurrency Legislation Landscape in 2024 – Welcome to Cryptocurrency.Law](#).

footprint of certain crypto-assets undermines the achievement of their green transition to net-zero greenhouse gas emissions. In addition, they shall see the adequacy of inserting these elements into the relevant legislation and allow controlled economic growth and innovation⁶².

In this context, as analysed in *Newer developments regarding MiCA*, the EU, in alignment with the EU Taxonomy, European Green Deal, Paris Agreement, and other relevant documentation, decided to intervene, in the name of consumer's protection, still fostering digital innovation but not at the expense of not educating and helping crypto-asset holders make well-informed decisions and allowing a more gradual and necessary transition towards a more sustainable economy⁶². For instance, as presented by GSCHOSSMANN, VAN DER KRAAIJ, BENOIT and ROCHER, financial institutions, such as Banks, would have to start implementing and incorporating the climate-related financial risks of crypto-assets into their business model, more precisely, their climate strategy. For instance, BCBS's report⁷¹ emphasises that Banks should properly assess the material impact that climate-related risk drivers have on their businesses and on the environments in which they operate. In that sense, they shall analyse the potential impact that these risks have on the resilience and flexibility of their business model and adapt accordingly. Additionally, banks should review whether including climate-related financial risks requires changes to their compensation policies, ensuring these policies align with the bank's overall risk management, values, and long-term interests.

This report adds that even stricter capital requirements for crypto climate transition risk could range from risk weights to more punitive capital treatment. For the banking sector, the BCBS could consider imposing uniform additional capital requirements the banks' engagement in crypto-assets that have a significant carbon footprint. In that sense, this would disincentivise financial institutions from engaging with crypto-assets with a significant carbon footprint.

⁷¹ BCBS, *Principles for the effective management and supervision of climate-related financial risks*, June 2022, ISBN 978-92-9259-575-3 (online), available in [*Principles for the effective management and supervision of climate-related financial risks](#)

Case Study: Ethereum 2.0

The consensus mechanism transition that occurred in 2019, from PoW to PoS, with the launch of Ethereum 2.0, represents a landmark in the crypto-assets field, serving as a true case study in terms of a sustainable blockchain shifting towards a more sustainable method.

In that sense, the intricacies of this transition shall be analysed as well as environmental implications, economic consequences, and the impact of the trajectory towards blockchain sustainability.

Inefficiencies of PoW and shift towards PoS

As discussed in the section *Technical process of Proof of Work (PoW)* section, PoW requires a significant decentralised network of miners to compete in solving computationally intensive cryptographic puzzles. Thus, the miner who first succeeds in solving the computational puzzle is granted the right to append a new block of verified transactions to the blockchain

By using this mechanism, the intense computational power used could be explained based on a probabilistic approach: that is, for a single miner to have a higher probability of solving a cryptographic puzzle, he needs to use more computational power. In that sense, applying the same logic, but for multiple miners, would mean that the computational power used would be higher, taking into consideration the augmentation attempts to solve the puzzle. That is, the energy used by miners to solve mathematical problems is not directly proportional to the value added to the network, as a significant amount of energy is spent on unsuccessful attempts, leading to a substantial overall energy consumption and considerable carbon emissions⁷².

Thus, although this competitive process can ensure security through decentralisation, is inherently wasteful.

⁷² REGHENZANI, Federico; MASSARI, Giuseppe; FORNACIARI, William, *A Probabilistic Approach to Energy-Constrained Mixed-Criticality Systems* In IEEE/ACM International Symposium on Low Power Electronics and Design (ISLPED): 1-6., 2019, DOI: [10.1109/ISLPED.2019.8824991](https://doi.org/10.1109/ISLPED.2019.8824991).

In that sense, Ethereum decided to make a shift from PoW and started implementing PoS, as an attempt to address energy-consumption issues analysed above, supported by evidence that PoS could present a positive solution regarding energy-consumption, scalability, and security.

Ethereum 2.0: A Technological and Philosophical Shift to Proof-of-Stake:

As analysed in the section above, Ethereum 2.0. aimed to solve some fundamental and architectural issues regarding PoW and its environmental impact.

Hence, Ethereum, by transitioning into PoS mechanism, altered the way transactions were validated into the block. In that context, as analysed in *Technical process of Proof of Stake (PoS)* section, PoS operates through a validation process in which participants are selected to confirm transactions and generate new blocks according to the quantity of crypto-assets they hold. That is, validators not only have the burden of proposing new blocks, but also of attesting and validating them to add them to the blockchain. Moreover, the validators are chosen based on the size of their stake, creating a lottery system weighted by the amount of crypto-assets committed. Thus, by implementing this system, it significantly reduces the need for extensive computational power, because it is not based on a competition to solve cryptographic puzzles, but on a previous selection of validators, minimising the amount of computational power wasted and carbon emissions.

However, this transition was not immediate in order to not disrupt the market and was meticulously designed to mitigate risks and ensure network stability. These phases included the Beacon Chain launch, a crucial step to introduce the PoS mechanism, followed by the merging of the Beacon Chain with the existing Ethereum network.

Firstly, Beacon Chain was a blockchain created to ensure that PoS system would work properly and would be feasible and sustainable before being used on the main Ethereum's network⁷³. To not disturb the network, this system⁷³ worked in parallel the already existing PoW.

Beacon Chain initially had only empty blocks and did not process any transactions. In that sense, gradually, to switch from PoW to PoS was set up to only accept transaction

⁷³ LI, Li, *Mitigating Challenges in Ethereum's Proof-of-Stake Consensus: Evaluating the Impact of EigenLayer and Lido*, October 2024.

data and agree on active validators and their account balances⁷⁴, bundle them into blocks, and maintain a new blockchain based on PoS. At the same time, the original Ethereum clients stopped mining and managing blocks, handing over those tasks to the Beacon Chain - this process is called *The Merge*.

After The Merge, there was only one Ethereum blockchain—the PoS version. Now, each node runs two types of clients: the Beacon Chain, which manages the PoS consensus and organises blocks, and the execution layer, which handles transactions and the current state of Ethereum.

Lessons to be learned

The impact of the transition from PoW to PoS has been substantial.

Firstly, the dramatic reduction in Ethereum's energy consumption translates into significantly lower carbon emissions. In that sense, as previously shown in *Technical process of Proof of Stake (PoS)* section, there is an undeniable order-of-magnitude reduction from PoW to PoS. Hence, beyond the environmental impacts, the shift to PoS has also had a significant economic impact, namely through the fact that reduced energy costs associated with PoS have potentially lowered the barrier to entry for validators, potentially increasing decentralisation – regarding this issue, criticism of PoS arise from the non-existence of decentralisation, since the validators are those who have larger amounts of crypto-assets. However, as a response to this criticism, if more potential validators enter the system, there is a higher probability of existing more validators with more crypto-assets. That would mean that there would be a higher chance of decentralising this system⁷³.

In addition, in PoS there is a conduct of penalising those validators who act maliciously. In that sense, this would prevent a validator from acting maliciously or attempting to dominate the validation process, being an additional safeguard against centralisation, reinforcing this method's resilience.

⁷⁴ Text published by Ethereum.org, *The Merge*, 2025.

However, this mechanism also presents challenges, as the resilience of PoS systems against various attacks remains a subject of ongoing research. Maintaining the decentralisation of the network and preventing the concentration of staking power among large entities is also critical. Furthermore, scaling PoS to handle the ever-increasing volume of transactions on Ethereum continues to be a focus of development efforts. The regulatory landscape is also evolving, with governments worldwide increasingly scrutinising crypto-assets and their energy consumption⁷⁵.

In conclusion, Ethereum 2.0's transition from PoW to PoS is a landmark achievement, showcasing the potential for sustainable blockchain technology and significantly impacting the crypto-assets industry. While challenges remain, the transition demonstrates a viable path towards more environmentally responsible blockchain development. It has not only significantly reduced Ethereum's environmental footprint, but also inspired numerous other projects to adopt PoS, leading to a broader industry-wide shift toward greater sustainability.

Although this transition is purely voluntary by nature, it can serve as a compelling role model for future blockchain innovation, highlighting the interplay between technological advancement, environmental responsibility, and economic considerations in the evolution of the crypto-asset landscape. The long-term impact, however, will depend on ongoing technological developments, regulatory frameworks, and the continued commitment of the industry to prioritise sustainability.

⁷⁵ MOTEPALLI, Shashank; JACOBSEN, Hans-Arno, *Decentralization in PoS Blockchain Consensus: Quantification and Advancement*, IEEE Transactions on Network and Service Management, 2025.

Conclusion

This Dissertation highlights the significant role of MiCA in shaping a more sustainable trajectory for blockchain technology, both within the European Union and on a global scale, serving as a model by combining openness with balance, while also strengthening the protection of crypto-asset holders and ensuring they are not left without access to essential information and data.

Indeed, MiCA and its recent updates have increasingly aligned with other key treaties and sustainability initiatives, including the Paris Agreement, the EU Taxonomy, the European Green Deal, and similar frameworks. In this context, by emphasizing a consistent focus on encouraging sustainable development and the adoption of more eco-friendly consensus mechanisms, while supporting innovative technologies, MiCA is well-positioned to foster economic growth. At the same time, it aims to ensure that market participants have a clear understanding of the environmental effects related to their activities.

Moreover, there is a significant emphasis in MiCA in regards to environmental disclosures by CASPs, particularly concerning the consensus mechanisms used in the issuance of crypto-assets, which highlights the EU's commitment to sustainability and responsible investing. By mandating the disclosure of the environmental consequences of different consensus mechanisms, MiCA not only protects crypto-assets holders from potential misrepresentations and misinformation, but also fosters a culture of accountability within the crypto market.

Therefore, this constant effort in implementing a more sustainable approach to the diverse sector, being crypto-assets, has made it clear that the EU is attempting to make a shift towards a more sustainable, environmentally thoughtful way of living, taking into account the already changing nature and decrease in the availability of natural resources at this moment. Hence, MiCA is one of many regulations that are perfectly designed in alignment with the overall commitment the European Union onboarded in terms of gradually shifting towards a more sustainable economy and financial markets.

Furthermore, although there is no perfect solution yet, and based on the clear motif and aim of the EU to lower the carbon emissions, the EU is in a continuous and

progressive pursuit of greener alternatives throughout various areas, and in this case it is not different - opt for a greener consensus mechanism, a mechanism that, although with some limitations, has shown greater involvement in terms of environmental impact.

In that sense, MiCA has introduced some pivotal concepts and additional requirements that are crucial to capture the core principles of this regulation: for instance, CASPs must fulfill to ensure compliance, not only with the expectations of crypto-asset holders but also in adherence to the core principle of enhancing information transparency. This aims to enable crypto-assets holders to make well-informed decisions confidently. For example, it requires CASPs to create a standardised list of indicators to measure the environmental impact of the consensus mechanisms they adopted (with criteria defined by the Regulation), enabling crypto-asset holders to evaluate and contrast the different consensus mechanisms. Moreover, NCAs have a pivotal role in supervising and analysing the compliance of the CASPs regarding the rules imposed by the Regulation.

Therefore, through the modifications and developments that MiCA had, it is clear an enhancement in terms of increasing the requirements that CASPs may comply with, all the transparent, public, and clear information that they shall provide to crypto-assets holders for them to be able to make well-informed decisions regarding the sustainability of the consensus mechanisms the provider chose.

On one hand, it can be a disincentivisation in the sense that applying many additional requirements to be in total compliance with the regime may be seen by crypto-assets providers as a disincentive to be in the EU and go to a more tech-savvy and more “liberal” regulatory regime that allows them to not disclose all the elements. However, despite the increased transparency requirements imposed by the EU, crypto-assets providers have compelling reasons to remain within the EU market: For instance, these regulations, while more rigorous, ultimately foster a more trustworthy and stable environment for all stakeholders, potentially attracting a much broader base of crypto-assets holders. In that sense, by adhering to high standards of transparency, providers can build greater confidence among crypto-assets holders, potentially expanding their market reach and reputation. Furthermore, being compliant with EU regulations may facilitate easier access to a large and mature market, offering long-term growth opportunities that outweigh the

short-term compliance costs. Ultimately, such regulations can contribute to the development of a more sustainable and reputable crypto ecosystem within Europe.

Concerning the topic regarding the existence or non-existence of encouragement in MiCA to adopt PoS over PoW, and in alignment with the analysed above, we cannot definitively conclude that MiCA incentivises directly the adoption of a more environmentally responsible consensus mechanism, as there is no clear or direct “favouritism” toward PoS or other more sustainable consensus mechanisms compared to PoW; hence, it does not directly encourage the adoption of a more sustainable consensus mechanism such as PoS. However, we can observe that the legislation the EU has been drafting and publishing shows an active and ongoing effort for EU’s organizations, competent authorities, and policymakers to redesign the framework and make it more environmentally friendly. This includes establishing some constraints, increasing due diligence procedures, or imposing stricter requirements that any crypto-asset issuer must meet, such as transparency obligations and requiring white papers to detail every aspect of the potential environmental impact of the consensus mechanism, among other measures.

Therefore, upon this research, it can be concluded that the EU policymakers have been making a continuous effort to pursue a more sustainable approach in the EU regulations, and in this particular case, MiCA. By applying enhanced and additional transparency and regulatory requirements to CASPs when disclosing information regarding the consensus mechanism adopted, the EU aims to foster the pursuit of a more sustainable, trustworthy, and reliable market and allow crypto-assets holders to have all the essential information to be able to make well-informed decisions. Additionally, CASPs build a more easily-replicated reputation among crypto-assets holders as they are reliable because they are compliant with the EU regulations.

Hence, although we cannot clearly state that the EU has created clear restrictions or boundaries for crypto-assets providers to use crypto-assets with consensus mechanisms that are less sustainable for the environment, we can affirm that the new developments in MiCA have posed additional challenges and requirements, but also enhanced supervision by NCAs of the crypto-assets providers in the issuance of crypto-assets.

Therefore, the EU policymakers have, through inducement and indirect approach, adopted a recommendation in terms of favouring the adoption of low-energy consensus mechanisms such as PoS.

Bibliography

ALFAR RODRIGUES, André, *Manual de Inovação Financeira – Uma Introdução das criptomoedas e da Blockchain*, AAFDL Editora, 2ª Edição, 2025, Lisboa, ISBN: 978-989-9252-24-0.

ASIF, Rameez; HASSAN, Syed Raheel, *Shaping the future of Ethereum: exploring energy consumption in Proof-of-Work and Proof-of-Stake consensus*, published in *Frontiers Blockchain*, August 2023, DOI: 10.3389/fbloc.2023.1151724.

BARCZENTEWICZ, Mikolaj; André de, GÂNDARA GOMES, *Crypto-Asset Market Abuse Under EU MiCA*, *European Journal of Risk Regulation*, 2024.

Basel Committee on Banking Supervision, *Principles for the effective management and supervision of climate-related financial risks*, June 2022, ISBN 978-92-9259-575-3 (online), available in **Principles for the effective management and supervision of climate-related financial risks*.

Article published by the Danish Financial Supervisory Authority, *Decentralised finance and the markets for crypto-assets: When is your offering exempt from regulation?*, June 2024.

DE FILIPPI, Primavera; DAVIDSON, Sinclair; POTTS, Jason, *Economics of Blockchain*, In IRPN: Governance (Sub-Topic) (2016), DOI: 10.2139/ssrn.2744751

ECB, *Mining the environment – is climate risk priced into crypto-assets?*, *Macroeprudencial Bolletín*, 2022, available in *Mining the environment – is climate risk priced into crypto-assets?*

ECB, *Crypto-Assets: Implications for financial stability, monetary policy, and payments and market infrastructures*, Paper nº 223, 2019, available in *Crypto-Assets: Implications for financial stability, monetary policy, and payments and market infrastructures*.

ESMA, *Supervisory Briefing - Authorisation of CASPs under MiCA*, available in ESMA75-453128700-1263 Supervisory Briefing on the Authorisation of CASPs under MiCA.

Ethereum Foundation blog, *Ethereum's energy usage will soon decrease by ~99.95%*, available at Ethereum's energy usage will soon decrease by ~99.95% | Ethereum Foundation Blog.

Ethereum.org, *The Merge*, 2025.

Finansinspektionen, *Crypto-assets are a threat to the climate transition – energy-intensive mining should be banned*, 2021, available in Crypto-assets are a threat to the climate transition – energy-intensive mining should be banned | Finansinspektionen.

HEWETT, Joe; ETMAN, Mark; MARSEGLIA, Robbie; PICKERSGILL, Mella Tomas; LEEKE, Matthew, *Towards a Dependable Energy Market: Proof of Authority in a Blockchain-based Peer-to-Peer Microgrid*, In 2022 IEEE 27th Pacific Rim International Symposium on Dependable Computing, Beijing, China, 2022, pp. 109-118, DOI: 10.1109/PRDC55274.2022.00025.

HOBZA, Martin; and VONDRÁČKOVÁ, Aneta, *Crypto-Asset Services under the Draft MiCA Regulation*, Prague Law Working Papers Series, 2021, DOI: DOI:10.2139/ssrn.3984355.

IEA, *A new energy economy is emerging, 2021*, In World Energy Outlook 2021, available in A new energy economy is emerging – World Energy Outlook 2021 – Analysis - IEA.

IEA, *Electricity Report 2024 – Analysis and forecast to 2026*, available at Electricity 2024 - Analysis and forecast to 2026.

ISLAM, Md. Mainul; MERLEC, Mpyana Mwamba; IN, Hoh Peter, *Proof of Random Leader: A Fast and Manipulation-Resistant Proof-of-Authority Consensus Algorithm for Permissioned Blockchains Using Verifiable Random Function*, In *IEEE Transactions on*

Services Computing, Vol. 18, n°. 3, pp. 1655-1668, May-June 2025, DOI: 10.1109/TSC.2025.3536315.

LI, Li, *Mitigating Challenges in Ethereum's Proof-of-Stake Consensus: Evaluating the Impact of EigenLayer and Lido*, October 2024, DOI:10.48550/arXiv.2410.23422.

LI, Sheng-Nan Li; CAMPAJOLA, Carlo; TESSONE, Claudio, *Statistical detection of selfish mining in proof-of-work blockchain systems*, Scientific Reports, 2024, DOI: 10.1038/s41598-024-55348-3.

MOTEPALLI, Shashank; JACOBSEN, Hans-Arno, *Decentralization in PoS Blockchain Consensus: Quantification and Advancement*, IEEE Transactions on Network and Service Management, 2025, DOI: 10.1109/TNSM.2025.3561098.

PACKIN, Nizan Geslevich; SMITH, Sean Stein, *ESG, Crypto, And What Has The IRS Got To Do With It?*, SSRN Electronic Journal, 2022, DOI: 10.2139/ssrn.4206195.

PARINYA, Ekparinya; GRAMOLI, Vincent; JOURJON, Guillaume, *The Attack of the Clones against Proof-of-Authority*, 2019, DOI: 10.14722/ndss.2020.24082.

PERESTRELO DE OLIVEIRA, Madalena; BOURA, Marta, *MiCA e DeFi: onde fica a regulação no caminho da descentralização?*, In *MiCA: Estudos sobre a nova Regulação Europeia de Criptoativos*, pp. 289-332, Edições Almedina S.A., 2023, ISBN: 978-989-40-1657-1.

SALEH, Fahad, *Blockchain without Waste: Proof-of-Stake In The Review of Financial Studies*, March 2021, Vol. 34, N°. 3, pp. 1156-1190, published by Oxford University Press, DOI: 10.1093/rfs/hhaa075.

SEDLMEIR, Johannes [et al.] - *The Energy Consumption of Blockchain Technology: Beyond Myth*, In *Business & Information Systems Engineering*, Vol. 62, pp. 599-608, 2020 available at *s12599-020-00656-x.pdf.

SHU-PING, Lu; LEI, Chin-Laung; TSAI, Meng-Han, *An Efficient Proof-of-Authority consensus scheme against cloning attacks*, 2024, DOI: 10.1016/j.comcom.2024.107975.

SMUSEVA, Daria; MALAKHOV, Ivan; MARIN, Andrea; ROSSI, Sabina - *Crisis of Trust: Analysing the Verifier's Dilemma in Ethereum's Proof-of-Stake Blockchain* In 2023 IEEE International Conference on Blockchain (Blockchain), DOI: 10.1109/Blockchain60715.2023.00058.

SUNSTEIN, Carl; Thaler, Richard, *Libertarian Paternalism is not an Oxymoron* In The University of Chicago Law Review, 2003, Vol. 70, N.º 4 pp. 1159-1202.

Sweden's Cryptocurrency Legislation Landscape in 2024, available in Sweden's Cryptocurrency Legislation Landscape in 2024 – Welcome to Cryptocurrency.Law.

Text published by ESMA, *Final Report - Draft Technical Standards specifying certain requirements of the Markets in Crypto Assets Regulation (MiCA) – second package*, 2024.

VIEIRA DOS SANTOS, João; MAIA, Guilherme, *MiCA and DeFi* (“Proposal for a Regulation on Market in Crypto-assets” and “Decentralised Finance”), *Econometric Modeling: Financial Markets Regulation eJournal* (2021).

YAN, Lawrence [et. al], *Mastering AI: Big Data, Deep Learning, and the Evolution of Large Language Models- Blockchain and Applications*, 2024, DOI: [10.48550/arXiv.2410.10110](https://doi.org/10.48550/arXiv.2410.10110).

YAN, Shi - *Analysis on Blockchain Consensus Mechanism Based on Proof of Work and Proof of Stake* In 2022 International Conference on Data Analytics, Computing and Artificial Intelligence, China, p.464-467, DOI: 10.1109/ICDACA157211.2022.00098.

YASH, Bobde; NARAYANAN, Gokuleshwaran; JATI, Manas; PETER RAJ, Raj; Cvitic, Ivan; PERAKOVIC, Dragan, *Enhancing Industrial IoT Network Security through Blockchain Integration*, 2024, DOI: 10.3390/electronics13040687.

ZETZSCHE, Dirk; SINNIG, Julia, *The EU Approach to Regulating Digital Currencies*, In Law and Contemporary Problems, Vol.87, Nº2, 2024, DOI:10.2139/ssrn.4707830.

ZETZSCHE, Dirk; ARNER Douglas; BUCKLEY, Ross; VAN ER, *Remaining Regulatory Challenges in Digital Finance and Crypto-Assets after MiCA* In UNSW Law & Justice Research Series, June 2023, DOI: 10.2139/ssrn.4487516.

ZETZSCHE, Dirk; ARNER Douglas; BUCKLEY, Ross, *Decentralized Finance (DeFi)*. IEL Issue Brief 02/2020, European Banking Institute Working Paper Series 59/2020, University of Hong Kong Faculty of Law Research Paper No. 2020/010, University of Luxembourg Faculty of Law, Economics & Finance WPS, Journal of Financial Regulation – forthcoming, DOI: 10.1093/jfr/fjaa010.

ZETZSCHE, Dirk; ARNER, Douglas; BUCKLEY, Ross; KIRKWOOD, Jamieson, *The Financialization of Crypto: Lessons from FTX and the Crypto Winter of 2022-2023* In UNSW Law & Justice Research Series, 2023, DOI:10.2139/ssrn.4372516.

ZETZSCHE, Dirk; ANNUNZIATA, Filippo; ARNER, Douglas; BUCKLEY, Ross, *The Markets in Crypto-Assets Regulation (MiCA) and the EU Digital Finance Strategy*, In Law Working Paper Series Paper number 2020-018, 2020, DOI: 10.2139/ssrn.3725395.

ZHANG, Xinrui; RUJIA, Li; WANG, Qin; DUAN, Sisi; WANG, Qi, *Time-manipulation Attack: Breaking Fairness against Proof of Authority Aura* In The ACM Web Conference 2023, pp. 2076-2086, DOI: 10.1145/3543507.3583252.

Index

Introduction	1
Context.....	1
Significance of the research	5
Research questions.....	6
Literature review.....	8
Summary of MiCA’s sustainability provisions.....	8
EU Green Deal and climate neutrality goals – MiCA’s alignment	12
Preliminary overview of MiCA’s role in Blockchain sustainability	Error! Bookmark not defined.
Consensus Mechanisms	17
Technical process of Proof of Work (PoW).....	18
Limitations of Proof of Work.....	19
Technical process of Proof of Stake (PoS).....	20
Energy efficiency compared to PoW	22
Comparative summary between PoW and PoS.....	23
Alternative consensus mechanisms.....	26
Delegated Proof of Stake (DPoS).....	26
Proof of Authority (PoA)	26
Newer developments regarding MiCA	29
Institutional Point of view	35
Case Study: Ethereum 2.0	41
Inefficiencies of PoW and shift towards PoS	41
Ethereum 2.0: A Technological and Philosophical Shift to Proof-of-Stake:	42
Lessons to be learned	43
Conclusion.....	45
Bibliography	49

Index of Figures

Figure 1: European Green Deal strategy.....	13
Figure 2: Energy Consumption of Ethereum (prior PoS) and green Blockchain systems	22
Figure 3: Energy Consumption Comparison Among Various Blockchain Platforms	25
Figure 4: Estimation of annual electricity consumption compared to Bitcoin electricity consumption.....	35
Figure 5: Market capitalisation of consensus mechanisms (2020-2022).....	37