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THE EUROPEAN UNION MODEL FOR THE FUTURE-PROOF REGULATION OF ARTIFICIAL INTELLIGENCE

FROM THE CHALLENGES OF DISRUPTIVE TECHNOLOGIES TO THE REGULATORY SANDBOXES OF THE AI ACT

THESES OF THE DOCTORAL DISSERTATION

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I. Relevance and Objectives of the Research

Law, serving as the instrument for establishing and maintaining social coexistence within peaceful and equitable frameworks, is continuously subjected to trials and an imperative to adapt in our era. One of the most intense sources of this pressure is constituted by so-called disruptive technologies.[1] By now, artificial intelligence (AI) has undeniably matured into such a technology: a horizontally operating, general-purpose innovation that simultaneously creates economic opportunities, transforms social relations, and poses severe regulatory challenges. Regarding AI, the legislator is tasked with embedding a technology - whose operation is technically complex, impacts are multifaceted, and whose developmental trajectory is only foreseeable to a limited extent - into normative frameworks that enforce and protect human values to the fullest level possible.

The stakes are highly considerable: should this endeavour fail or prove ineffective, we must confront the severe negative potential and consequences inherent in a technology that is proliferating globally at a rapid pace, appearing in virtually all spheres of life, while permeating and radically transforming human thought, as well as interpersonal, social, and economic relations. Therefore, the entities vested with regulatory authority must, first and foremost, create a regulatory regime ensuring that humans remain at the center and retain control throughout the creation, deployment, and operation of the technology. Subsequently, they must promptly and reassuringly address the multidimensional problems generated by AI. It is also indispensable for lawmakers to possess the relevant perspective, background knowledge, and methodological expertise that enable them to approach this complex phenomenon adequately. The primary driving force behind the preparation of this dissertation was the exploration and presentation of this knowledge.

The dissertation analyses the responses of law - and, in particular, of legislation - to challenges associated with artificial intelligence primarily through an examination of the European Union's AI regulatory model. In doing so, it traverses a broad analytical arc, from the general regulatory problems posed by disruptive technologies, through the structure and substance of AI law, to the role of AI regulatory sandboxes. The principal objective of the research is to identify the regulatory logic, guiding principles, and adaptation mechanisms - and the institutional conditions and structures - through which a normative framework may be developed that is capable of addressing the specific challenges generated by artificial intelligence, while simultaneously seeking to protect fundamental rights and legal certainty, foster innovation, and control the risks created or amplified by the technology.

Within this framework, the dissertation focuses on the normative structure, selected detailed provisions, achievements to date, limitations, and enforcement architecture of the EU AI regulatory model founded on the European Union's AI Regulation (the AI Act).[2] It also

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[1] Joseph L. Bower, 'Disruptive Technologies: Catching the Wave', *Harvard Business Review* 73 (January 1995): 43.

[2] Regulation (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 Laying down Harmonised Rules on Artificial Intelligence and Amending Regulations (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU) 2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU)

examines the regulatory methodology through which a future-proof AI legal regime capable of adapting to technological change can be developed. The dissertation further addresses in detail the role of AI regulatory sandboxes in this process

Research Questions:

Taking the characterization, regulatory specificities and difficulties of disruptive technologies as its starting point, the dissertation places artificial intelligence at the center of its analysis as the most disruptive technology of our time. Subsequently, it examines the characteristics of effective AI law and regulatory frameworks, analyzes how this has been achieved in the European Union, and finally presents AI regulatory sandboxes as potential arenas for the creation and development of "effective AI law."

To examine all of this through a horizontal overview while maintaining appropriate vertical depth in the case of essential questions, the legal doctrinal analysis of the dissertation - spanning four chapters and structured along a deductive logical chain, without formulating explicit hypotheses - proceeds along with the following **overarching question** and **main research questions**:

The overarching guiding question of the dissertation: What specific challenges does artificial intelligence pose to legal regulation, and under what conditions can the European Union's regulatory model, built upon the AI Act, be suitable for addressing them?

- **The main research question of Chapter I:** Is artificial intelligence a disruptive technology, and what regulatory difficulties follow from this quality?
- **The main research question of Chapter II:** Alongside the existing normative framework, does artificial intelligence necessitate a horizontal regulatory regime tailored to the specificities of the technology, and if so, how and with what normative content can it be established?
- **The main research question of Chapter III:** What normative organizing principles, adaptive mechanisms, institutional frameworks, and enforcement structures constitute the regulatory architecture of the AI Act, and how do these serve the future-proofing of the Regulation?
- **The main research question of Chapter IV:** Can the AI regulatory sandbox model established by the AI Act be suitable-under appropriate guarantees and enforcement conditions-for becoming an instrument supporting effective, future-proof, and innovation-friendly AI legislation and AI development?

2016/797 and (EU) 2020/1828 (Artificial Intelligence Act) Text with EEA Relevance. (2024). OJ L, 2024/1689, 12.6.2024.

II. Structure of the Dissertation

The chapters of the dissertation are structured in accordance with the logic of the research questions. The individual chapters are highly comprehensive, examining specific issues of AI regulation from numerous perspectives. **Chapter I** forms the **conceptual and theoretical foundation** of the dissertation. Rather than offering an overview of the history of technology for its own sake, it served as the domain for elaborating the theses that constitute the starting point of the entire argumentative arc. In this chapter, the research examines the general nature of disruptive technologies, analyzes the specific pressure these technologies exert on traditional models of legislation and law application. Finally, through particular aspects of the history and characteristics of artificial intelligence, the chapter investigates whether AI can be considered a disruptive technology, reviewing the factors and circumstances that substantiate this classification. The role of the chapter is foundational with respect to the dissertation as a whole: it establishes the conceptual and theoretical framework upon which subsequent chapters build.

Chapter II constitutes the **doctrinal core** of the dissertation. It is here that one of the defining theses of the work is elaborated: the concept, justification for the establishment, and normative architecture of *sui generis* AI law. In this chapter, which is divided into three major units, the dissertation first reviews the genesis, structural division, and normative stratification of AI regulation. Subsequently, it examines the construct of horizontal, specific *sui generis* AI law, the necessity of its establishment, and its relationship with other branches and fields of law and finally, through the presentation of the strategy of intervention points, it expounds the constituent elements of *sui generis* AI law and puts forward proposals regarding specific elements of their normative content. The dual role of this chapter is of paramount importance to the dissertation as a whole: on the one hand, it provides the theoretical justification for evaluating and analyzing the EU AI Act - which is examined in detail in Chapter III -not merely as a specific product safety instrument, but as the first comprehensive archetype of *sui generis* AI law. On the other hand, it establishes the direct doctrinal foundation for Chapter IV, as the prominent role of AI regulatory sandboxes can only be clearly understood once it has been clarified what must be regulated and why classical legislative methodology alone is insufficient for this purpose.

Chapter III represents the **doctrinal center of gravity** of the dissertation. Through a detailed analysis of the AI Act, it partially concretizes and substantiates the theoretical theses set forth in Chapter II. Proceeding from the premise that the AI Act can be regarded as the first comprehensive manifestation of *sui generis* AI law, an overarching examination of its regulatory framework allows numerous theoretical propositions, legal-technical devices, and methodological approaches examined throughout the research to be investigated in practice. The research explores the specific regulatory model through which the European Union sought to establish the legal framework for artificial intelligence. The first unit of the chapter uncovers the legislative and geopolitical context underlying the emergence of European AI regulation by presenting the preparatory and policy documents, strategic orientations, and codification steps that led to the adoption of the AI Act.

The second part of the chapter analyzes the internal regulatory logic of the AI Act across two complementary dimensions: its organizing principles and the adaptive mechanisms designed to ensure future-proofing. The dissertation thus does not merely undertake a partial presentation of the substantive content of the AI Act, but also demonstrates the normative, institutional, and methodological instruments through which the EU legislator sought to address the fundamental dilemmas of AI regulation: the speed of technological change, the legislator's knowledge deficit, and the tension between fundamental rights protection and innovation. Finally, the chapter reviews the two-tier organizational structure of AI Act enforcement, the institutional actors at both Union and Member State level, and the potential models of national implementation, thereby revealing the differing Member State approaches and the challenges surrounding the assurance of uniform European enforcement.

Chapter III also operates as a practical test of the *sui generis* AI law model: it demonstrates how the regulatory principles and intervention points identified in theory materialize in European Union legislation. Furthermore, this unit of the dissertation complements the context of Chapter IV by establishing that the role and institutional locus of regulatory sandboxes can only be fully comprehended if they are defined as one of the paramount instruments for the future-proofing of the AI Act and as practical arenas of normative adaptability.

Chapter IV serves as the **methodological capstone** of the dissertation, examining the theoretical and practical foundations of regulatory sandboxes as instruments supporting future-proof lawmaking directed at disruptive technologies. It outlines the principal characteristics and typologies of these constructs, followed by a granular analysis of their internal operation and structure. Because regulatory sandboxes have proliferated not only within AI regulation but across numerous sectors, the investigation also reviews experiences gained from deploying sandboxes for other disruptive technologies. In addition, the thesis analyzes and evaluates in depth how the AI Act integrates AI regulatory sandboxes into its system and the way it leverages their benefits to achieve effective AI regulation. The objective of this chapter is to demonstrate why the establishment of AI regulatory sandboxes is indispensable for legal systems seeking to develop genuinely effective artificial intelligence law without stifling innovation.

III. Research Methodology

The backbone of the research was provided by the doctrinal analysis of positive law, focusing particularly on the normative structure, detailed rules, and enforcement architecture of the AI Act. This was supported by a focused comparative legal analysis: the evaluation of the EU regulatory model was carried out through the parallel examination of specific Member State approaches alongside the Hungarian implementation and AI regulatory strategies. During the latter, I did not seek to provide an exhaustive comparative analysis. Hence, the research was not aimed at assessing every identifiable Member State AI governance model. My objective here was solely to uncover divergent institutional solutions to analyze the lessons they yield

concerning the national implementation of the AI Act. I supplemented the analysis of legal sources - primarily in the case of the AI Act - with the combined application of regulatory theory and functional assessment. The analysis focused on the content of the examined norms and, in parallel, on how the obligations respond to the regulatory problems arising from the rapid technological development of AI, and the extent to which they serve the future-proofing and adaptability of the legislation.

In addition, throughout the dissertation - primarily when uncovering the various legislative processes - I employed the method of analyzing and interpreting policy documents, preparatory materials, and expert reports capturing European and domestic processes, which extended equally to the examination of hard law and soft law sources. Alongside these, I relied substantially on processing the relevant domestic and international legal literature - specifically technology regulation scholarship - and other verified sources, to the extent permitted by a research subject situated at the intersection of law and technology.

Considering that artificial intelligence is strongly a socio-technical phenomenon, I did not conduct the research solely through a legal-doctrinal perspective, nor did I restrict it exclusively to the aforementioned sources. In the course of the research, it rapidly became evident that certain central issues of AI regulation cannot be genuinely understood without familiarity with their broader social, economic, historical-scientific, and technological context. For these reasons, employing an interdisciplinary approach in the dissertation, I sought to provide the necessary degree of insight into the extra-legal aspects of artificial intelligence regulation, as well as those exerting a direct impact on the law. In doing so, without losing focus I strived to present that body of knowledge closely linked to answering the research questions without which the dissertation would not have been complete. The doctrinal analysis was thus complemented by the examination of technical, economic, and social science literature that explores the nature, impacts, and challenges of the technology, alongside the analysis of related policy and technical documents.

Chronologically, the research coincided with the acceleration of EU AI-oriented legislation and the initial phase of the AI Act's implementation: by September 2020, the majority of policy documents outlining the EU's AI approach and laying the groundwork for the AI Act had already been adopted, while by the time the manuscript was finalized, several provisions of the AI Act had already become applicable. All of this enabled me to directly follow the entire codification process, through which numerous relevant and research-valuable aspects - including professional and political debates, as well as underlying background processes - unfolded and became accessible to examination. Consequently, the dissertation was able to analyze the challenges associated with AI regulation not only at the theoretical level of legal dogmatics and legal scholarship, but also through the specific details and developments that were made public throughout the legislative process.

The research was hindered by multiple factors:

1. The exponential pace of development in artificial intelligence, coupled with the continuous expansion of AI-based solutions, spheres of application, and concurrently, the available sources, created constant pressure to process new literature.
2. In the initial phase of my research, the low level of academic elaboration in this field necessitated the inclusion of grey literature (e.g., policy documents, reports from technology companies, and non-academic expert materials), which had to be subjected to strict source criticism.
3. The initially unregulated nature of AI as a legal field, followed by the increasingly detailed crystallization of its international - and primarily European - frameworks throughout the research. In particular, the incessant expansion of legislative texts and preparatory decision-making documents generated during the codification of the AI Act necessitated the continuous updating of the research material.
4. The significant "global noise" surrounding AI - although at first glance creating an illusion of an abundance of information - entailed heightened difficulty in filtering out valuable, relevant, and credible sources.

Sources

In order to examine the questions raised by AI regulation from multiple perspectives, the dissertation relies on a broad corpus composed of diverse types of sources. Nearly four hundred sources are cited throughout the work, the overwhelming majority of which were produced in the first quarter of the twenty-first century. Sources pertaining to European Union AI regulation date predominantly from between 2018 and 2026, whereas the legal-historical, technological-historical, and regulatory-theoretical analyses necessarily draw upon earlier scholarship as well. In selecting academic literature, I relied primarily on peer-reviewed scientific publications appearing in scholarly journals and the works of recognized domestic and international authors. Furthermore, for the reasons outlined above, I supplemented this academic foundation with selected, verifiable, and rigorously evaluated institutional, policy, and professional grey literature sources. The collection of sources was concluded on March 31, 2026.

The dissertation analyzes Hungarian, EU, and international AI-relevant legal sources, soft law instruments, legislative, policy, and AI governance documents, as well as legal and other academic literature related to the specific aspects of artificial intelligence under review. The research examined the relevant parts of the AI Act and related Union regulatory materials, alongside affected domestic and Member State legislation concerning AI, including the legal instruments executing the national implementation of the AI Act. In addition, the investigation extended to legal scholarship addressing the regulation of AI and disruptive technologies, as well as literature exploring the developmental history, economic and societal impacts, and technical specificities of AI.

Here, I would like to clarify that the dissertation adopts a deliberately broad understanding of the soft law instruments cited and employs the concept of soft law in a functional sense. It denotes a category encompassing all rules of conduct "which, in principle, have no legally binding force but which nevertheless may have practical effects."[3] Accordingly, following Petra Lánczos, I regard all formal and non-formal sources of EU soft law as soft-law norms, including EU "guidelines, communications, notices, green papers and white papers, comfort letters etc."[4] In addition, I classify as soft law a number of self-regulatory instruments containing normative content relevant to AI, such as codes of conduct, technical standards - for example, ISO/IEC and NIST standards - and AI-related recommendations or policy documents developed by international organizations and intergovernmental forums, including the OECD and the G7. Naturally, the foregoing do not constitute a uniform category of legal sources.

IV. Results and Main Findings of the Research

1. **Artificial intelligence is a disruptive technology that differs qualitatively from previously known disruptive technologies: its regulation necessitates not merely new regulatory content, but also a new methodology of legislative adaptation to exponential technological progress and can be conceived as a test of this very capacity.**

The pace of change in social conditions - and thus in technology - has always posed a challenge to legal regulation. The dissertation identified two phenomena - the Collingridge dilemma[5] and the pacing problem[6] of law - which illustrate that the timing of technological regulation can never be perfect and necessarily entails compromises. The essence of the Collingridge dilemma is the double-bind inherent in technology regulation: in the case of early regulatory intervention, there is insufficient information regarding the impacts of technology to establish appropriate norms, thus, one must anticipate that the emerging framework will stifle innovation or continuously require subsequent correction. Conversely, in the case of late regulation, the technology is already so deeply entrenched that altering it may prove exceptionally costly or ineffective. These phenomena emerge with heightened prominence in the case of disruptive technologies, whose common characteristics are the reconfiguration of economic structures, the transformation of social relations, and the compulsion of legal regulation to continuously adapt.

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[3] Francis Snyder, 'The Effectiveness of European Community Law: Institutions, Processes, Tools and Techniques', *The Modern Law Review* 56, no. 1 (1993): 32, https://doi.org/10.1111/j.1468-2230.1993.tb02852.x.
[4] Petra Lea Láncos, *The Many Facets of EU Soft Law* (Pázmány Press, 2022), 16–17.
[5] David Collingridge, *The Social Control of Technology* (Frances Pinter St. Martin's Press, 1982).
[6] See e.g. Gary Marchant, *The Growing Gap Between Emerging Technologies and the Law* (2011), 7:19–33, https://doi.org/10.1007/978-94-007-1356-7_2; Dave Lewis et al., 'Mapping the Regulatory Learning Space for the EU AI Act', arXiv:2503.05787, preprint, arXiv, 28 May 2025, https://doi.org/10.48550/arXiv.2503.05787; Hin-Yan Liu, 'Why Is AI Regulation so Difficult?', in *Artificial Intelligence for Human-Centric Society: The Future Is Here*, ed. Nina Tomaževič et al. (European Liberal Forum EUPF, 2024).

During the research, I examined whether artificial intelligence can be considered a disruptive technology. My analysis revealed that artificial intelligence is simultaneously a general-purpose technology, an economic infrastructure, and a phenomenon generating widespread impacts, affecting not merely isolated sectors but horizontally permeating numerous social subsystems. It was likewise substantiated that AI is not exclusively an instrument for increasing economic efficiency, but concurrently generates novel types of risks and hazards, particularly in the areas of fundamental rights enforcement, the labor market, informational autonomy and social inequalities.

Based on these findings, I concluded that artificial intelligence is a technological phenomenon that bears the defining characteristics of disruptive technologies, exhibiting them in a concentrated and exponentially amplified manner. Its exponential developmental dynamics distinguish it even among previously known disruptive technologies, rendering its existence a serious challenge for regulation. From this, it follows - and is substantiated in the dissertation - that its regulation cannot be fully accommodated within traditional sector or product-specific legislative models. Instead, it demands a holistic approach and novel instruments. I emphasized that in the case of AI, the law - relying on its current regulatory toolkit - is almost guaranteed to be forced into a reactive role. Furthermore, the potentially emerging problems, such as the risks stemming from a regulatory vacuum or an insufficient, deficient regime, may be exacerbated if the legislator chooses the moment of intervention incorrectly.

The regulation of AI is therefore not merely a substantive legislative task, but simultaneously a methodological challenge: the legislator must confine within normative boundaries a phenomenon that changes rapidly, is technologically complex, and whose societal impacts are only partially foreseeable. The regulation of AI is thus not simply the legal handling of a new disruptive technology, but a test of whether the law is capable of adapting its regulatory methodology to exponential technological changes. As substantiated in the dissertation, only that regulation of artificial intelligence can be effective and successful in the long term which is capable, in its methodology, of adapting to the nature of the phenomenon and managing the specific challenges stemming from the characteristics of the technology. From this follows the expectation that, in the course of AI regulation, the legislator should not merely formulate the content of legal norms pertaining to specific, detailed issues of the technology - concerning which the dissertation puts forward several proposals - but must also find the methodology for effective, adaptive, and durable AI regulation. The encouraging attempt made by the European Union to realize the latter in practice is presented in detail within the dissertation.

2. **The optimal regulation of artificial intelligence is realized in a hybrid structure from two perspectives: it is heterogeneous both in terms of the form and enforceability of the norms constituting the framework, and in the composition of its legal regime.**

The dissertation's research into the AI regulatory regime proceeds from the premise that the legal framework for artificial intelligence is dual-hybrid in structure. According to my

argument, the first dimension of this hybrid character stems from the fact that efforts aimed at regulating artificial intelligence cannot be described through the logic of a single, pure normative model: from an entirely unregulated, quasi-*laissez-faire* approach, through soft law instruments and binding national and supranational legal acts, to globally homogeneous legal norms, several partly competing, partly complementary regulatory forms have emerged. Consequently, I formulated several findings: I emphasized that the various levels are not mutually exclusive and may coexist in parallel within a given legal system, and that due to AI's nature, rapid development, and multifaceted impacts, neither exclusive self-regulation nor solutions relying purely on legal coercion offer a satisfactory response on their own.

The model of complete non-regulation - although remaining attractive for a long time to the tech sector subject to innovation pressure - partially lost support even among its former proponents with the explosive spread of generative AI. Soft law instruments - ranging from OECD and UNESCO recommendations, through ISO standards and the NIST framework, to the G7 Hiroshima Process - have proved insufficient on their own, as their enforcement ultimately depended on the willingness of market actors to exercise self-restraint. However, their normative content has become embedded in binding regulation and continues to play a decisive role as background norms today. I also considered it essential to emphasize that ensuring the future-proof nature of AI law would not be feasible without soft law instruments, whose substantive content is capable of tracking technological development far more flexibly than traditional legislation. Among legal regimes, the EU AI Act stands out as the first comprehensive, horizontal, and binding AI regulation. Global legal harmonization, while highly desirable in the case of AI - even if the Council of Europe's 2024 Framework Convention on Artificial Intelligence and Human Rights,[7] Democracy and the Rule of Law represents a landmark step forward - is not a realistic objective within the foreseeable future due to the divergent interests of major global powers. In light of these considerations, the conclusion set forth in the dissertation is that practically functioning AI regulatory regimes are necessarily hybrid in structure in terms of norm types, requiring coordination among distinct groups of norms possessing varying degrees of coercive force tailored to the specific characteristics of the technology.

Based on my research, it can also be established that AI law is not a unified, autonomous branch of law, but rather a structurally hybrid construct: its cornerstone is a *sui generis* AI legal regulatory system - the substantive core of which comprises algorithms, datasets, and other horizontal risk-management and compliance requirements spanning the entire AI lifecycle - upon which a cross-disciplinary and cross-sectoral normative coordination and adaptation responding to AI is superimposed. The toolkit of these latter sector-specific rules would be insufficient on its own for effective regulation, yet their complete replacement is neither necessary nor desirable. The legal regulation of artificial intelligence is therefore necessarily a dual-track task: on the one hand, establishing the horizontal, *sui generis* framework of AI law, on the other hand, executing the substantive "AI fine-tuning" of sectoral frameworks, which

[7] CM(2024)52-Final - Council of Europe Framework Convention on Artificial Intelligence and Human Rights, Democracy and the Rule of Law, Council of Europe (2024).

must be entrusted to the specific logic, dogmatic traditions, and application contexts of individual legal fields. This dual structure is not a contradiction, but rather, according to my argument, the prerequisite for an effective AI regulatory ecosystem: without solid horizontal foundations, sectoral adaptation would operate in a vacuum, whereas an exclusively general regulation that disregards the diversity of use cases is necessarily blind to real-world risks.

Based on the conclusions set forth in Chapter II of the dissertation, emerging fields bearing AI-legal aspects do not signify the birth of autonomous new legal branches, but rather the formation of complex regulatory fields organized at the intersection of several traditional legal disciplines. Their normative core is constituted by the horizontal compliance layer of *sui generis* AI law, supplemented by the dogmatics of existing sectoral law adapted to AI. This approach is also followed by the EU AI Act. It follows from the foregoing that *sui generis* AI law does not entail the total absorption of all legal questions concerning AI but rather serves as the foundational normative layer upon which rules tied to specific sectors and modalities of use can be constructed.

3. The regulation of artificial intelligence, in reality, entails the regulation of the technology's individual constituent elements and dimensions of existence, which simultaneously outlines the substantive content of *sui generis* AI law.

One of the central theses of the dissertation is that AI is elusive and therefore cannot be effectively regulated as a standalone entity. Accordingly, I argued that the legislator must identify its constituent elements and dimensions of existence with respect to which the formulation of normative requirements is feasible. In the dissertation, I identified AI ethical principles, data, and algorithms as such constituent elements, and examined potential "points of intervention" for legal regulation in relation to each.

My argument proceeded from the premise that the thesis of technological neutrality has become obsolete in the context of artificial intelligence: algorithmic design choices embody value judgments that can generate societal- and individual-level consequences through the operation of the system. From this, I concluded that AI regulation cannot be narrowed down to the establishment of technical standards. It rather necessarily rests on comprehensive ethical foundations, which I substantiated in the dissertation through a dual line of argument. Ethical principles are critically important, on the one hand, as safeguards for ensuring the human-centric operation of AI systems in conformity with human values. On the other hand, AI ethics provides a gap-filling normative orientation in regulatory domains where positive law is fragmented, partial, or deficient relative to the pace of technological development. The most salient AI ethical principles - transparency and explainability, accountability, human oversight, data and data security, robustness, and fairness - represent an established system of values crystallized in international soft law documents (such as OECD, UNESCO, and EU HLEG guidelines), which the EU AI Act operationalizes in the form of binding legal norms.

In the dissertation, I proceeded from the fundamental premise that the operation of artificial intelligence models and systems is heavily determined by data. Consequently, subsequent

points of intervention lie within the regulation of data associated with AI systems - a facet that constitutes one of the paramount components of *sui generis* AI law too. Regarding data, I identified two regulatory points of intervention: issues pertaining to data quality and cybersecurity.

Concerning data quality, I pointed out that flawed, biased, or improperly curated datasets do not merely yield inaccurate outputs but are capable of entrenching and amplifying existing societal inequalities, reproducing discriminatory patterns, and thereby potentially cutting marginalized groups off from the opportunity for upward mobility. Consequently, data utilized for AI cannot be viewed only as technical components: from a regulatory vantage point, they constitute dynamic risk factors without whose adequate management neither the safe development of the technology nor the protection of users and affected societal groups can be secured. The regulation of data quality is therefore not merely a technical requirement, but, in my view, a fundamental rights guarantee. In this context, I emphasized that while Article 10 of the AI Act builds upon this realization by enshrining requirements of relevance, representativeness, and error-freeness, the provision nonetheless remains a framework rule and lacks methodologically detailed criteria differentiated by application domain. As a *de lege ferenda* proposal, I argue that the Commission should clarify - via harmonized standards or implementing acts, particularly in law enforcement, healthcare, and judicial contexts - the testing and representation parameters that minimize the risk of discriminatory or distorted operation.

In the two-pronged analysis of data cybersecurity, I established that external security - the protection of databases against unauthorized access, data poisoning, and manipulation - and internal security - ensuring developers' competency levels alongside organizational safeguards for access management and logging - jointly guarantee that AI models are not conditioned on biased or manipulated inputs. Legal intervention regarding data must therefore concurrently address data quality issues, the risks of biases and discriminatory effects, and the cybersecurity vulnerabilities threatening databases and AI systems.

In the dissertation, I identified the algorithms underpinning AI models as the third target area of *sui generis* AI regulation and examined them along their lifecycle from three analytical perspectives. First, I pointed out that from the standpoint of legal regulation, it is not the technical nomenclature of the algorithm that is relevant, but rather its degree of decision-making autonomy, its training methodology, and the societal impact of its output. Machine learning algorithms - in contrast to classical systems built upon explicit, deterministic rules -refine their internal parameters autonomously from data patterns, which, owing to their partial autonomy and reduced predictability, poses distinct regulatory challenges in the areas of transparency, accountability, and the enforcement of rights.

During the examination of the training and testing phases, I revealed that the prerequisite for the reliable operation of algorithms is not merely an adequate dataset, but the training process itself, which forms an autonomous normative point of intervention. In this context, I identified an issue hitherto largely unaddressed in the literature: the annotation processes within

Reinforcement Learning from Human Feedback (RLHF) are capable of encoding selection bias into the system, which becomes an integral part of the model's behavior directly through the mediation of human evaluation. Consequently, I do not consider the regulation of dataset quality alone to be sufficient: documenting the demographic composition, representativeness, and competency level of the annotator pool is warranted *de lege ferenda* as an autonomous requirement, particularly in domains of application carrying fundamental rights relevance.

The third aspect and focal point of the inquiry into algorithms was the analysis of the so-called black-box effect and the potential avenues of intervention aimed at its mitigation. According to my argument, the limited transparency of AI systems' decision-making processes not only undermines user trust, but also materially restricts the prospects of legal redress following a rights violation, as the inaccessibility of the internal decision logic hinders or even precludes the identification of the causal link between the harmful conduct and the damage sustained. In this context, I drew attention to a crucial dilemma: the absolutization of transparency cannot in itself constitute a regulatory objective, as enforcing full technical transparency would, in numerous instances, compromise the operational performance of AI systems. Moreover, in many cases, neither users nor adjudicators and legal practitioners can reasonably be expected to possess a comprehensive technical understanding of complex algorithmic operations. Therefore, in my view, the desirable regulatory model must not mandate exhaustive technical comprehension, but rather adhere to the principle of risk-proportionate transparency: explainability safeguards necessary for accountability must be enforced in a manner calibrated to the level of risk. The AI Act partially realizes this approach; however, *de lege ferenda*, further refinement is necessary regarding the detailed methodological rules and potential sector-specific differentiation of requirements according to the domain of application.

4. **The EU AI Act is not merely another legislative act within the European codification wave targeting digital technologies, but rather the first comprehensive, binding manifesto of *sui generis* AI law, whose genesis substantiates the hybrid nature of AI regulation and which directly confronted the regulatory challenges inherent in disruptive technologies.**

A crucial conclusion of mine is that the EU AI Act did not come into existence as an isolated legislative act but rather represents the culmination of a deliberately constructed European AI policy maturation process spanning several years. Through the reconstruction of the milestones of the codification process, I demonstrated that prior to the birth of the AI Act, the European Union progressed through distinct regulatory stages and developmental tiers. Furthermore, the soft law phase traversed during this progression was not merely a series of political declarations of intent, but rather progressively translated into practice the ethical principles that the AI Act ultimately elevated into the normative system with binding legal force. By presenting these stages, I substantiated the previously formulated theses, namely that the cornerstone of *sui generis* AI law is the normative operationalization of ethical principles, and that an effective AI regime is necessarily hybrid in structure, comprising different types of norms - both soft law and hard law.

Based on the examined preparatory instruments, it is also evident that the dogmatic and regulatory logic of the AI Act did not emerge *ex nihilo* but was built upon an existing body of law that left AI-specific gaps. Initially, however, the Union's approach did not aim at establishing a fully autonomous, *sui generis* AI law, but proceeded from the premise that most problems could be managed through the appropriate adjustment of existing horizontal and sectoral regimes. The significance of the 2020 White Paper lies precisely in being the first to articulate that, alongside the existing legal frameworks, AI-specific regulatory gaps and enforcement difficulties could be identified which warranted an independent regulatory package tailored expressly to artificial intelligence. This further corroborates the previously elaborated thesis that *sui generis* AI law is not intended to replace existing norms entirely, but rather to resolve novel regulatory questions that positive law - or the regulatory fields emerging at its intersections - cannot satisfactorily address.

In the dissertation, I also interpreted the enactment of the AI Act as a practical illustration of the regulatory challenges inherent in disruptive technologies - and particularly in artificial intelligence. The codification process - and especially the proposals set forth in the Digital Omnibus on AI[8] package submitted by the Commission on November 19, 2025 - substantiated the theoretical propositions set out in Chapter I concerning the heightened difficulties of regulating disruptive technologies. The post-entry-into-force fine-tuning of the AI Act confirmed the theses of the Collingridge dilemma and the pacing problem: the legislator attempted to capture a technology whose developmental trajectory shifted substantially even during codification - the most conspicuous example being the *ex post* emergence of general-purpose AI models (GPAI) on the regulatory horizon. In my view, the incorporation of the GPAI regime is of exceptional significance because it not only introduced new rules into the Regulation, but also partially disrupted the original risk-classification logic. Following the conclusion of codification, the debate surrounding the Omnibus proposal and the withdrawal of the AI Liability Directive[9] highlighted the second dimension of the dilemma: by the time regulatory deficiencies, enforcement difficulties, and tensions stemming from timing became clearly identifiable, correction manifested not as simple technical clarification, but as a politically and economically encumbered, costly fine-tuning undertaking.

5. The regulation of artificial intelligence necessarily requires a dynamic, adaptive approach open to continuous calibration, hence the adaptability of the EU AI Act does not rely on a single regulatory technique, but on an interconnected system of complementary instruments.

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[8] Proposal for a Regulation of the European Parliament and of the Council on Amending Regulations (EU) 2024/1689 and (EU) 2018/1139 as Regards the Simplification of the Implementation of Harmonised Rules on Artificial Intelligence (Digital Omnibus on AI) 19. 11. 2025. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52025PC0836.

[9] Proposal for a DIRECTIVE OF THE EUROPEAN PARLIAMENT AND OF THE COUNCIL on Adapting Non-Contractual Civil Liability Rules to Artificial Intelligence (AI Liability Directive), 28.9.2022., https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A52022PC0496.

The internal coherence of the EU AI Act is not conferred by a single regulatory technique, but by a constellation of interconnected guiding principles and adaptive mechanisms, which I reviewed and evaluated in detail. Within the former category, I examined human-centricity, technological neutrality, and the risk-based approach, which may simultaneously be interpreted as the AI Act's responses to the regulatory challenges of disruptive technologies. These guiding principles are not mere declarations in the Regulation's recitals, but the load-bearing pillars of its normative architecture. In their aggregate, they embody a deliberate regulatory choice: the legislator did not bind itself to a single technological paradigm, did not pursue blanket ex ante prohibitions, and did not delegate the burden of risk management exclusively to public authorities. Human-centricity defines the normative value horizon of the regulation by widely giving effect to shared European fundamentals and AI ethical principles, while technological neutrality ensures that the "AI definition trap" identified in the dissertation - the dual peril of over-specification and normative obsolescence - is avoided to the greatest extent possible. Supplementing these, the risk-based approach enables the proportionate and differentiated design of legislative intervention, which can also be understood as a direct response to the Collingridge dilemma: if the law cannot foresee with precision which domains of AI application will become dominant, it can at least calibrate the intensity of its interventions to the level of foreseeable risks.

Based on the research, the principles of the AI Act are horizontally bound together by the objective of future-proofing, which aims to ensure that the Regulation does not merely align with the technological state of the art known at the moment of codification, but possesses the capacity to adapt to subsequent - and in the domain of AI, inevitable - advancements. The significance of my finding in this regard lies in the proposition that the future-proof nature of AI regulation does not stem from the one-off perfection of the normative text, but from the coordinated operation of its embedded adaptive mechanisms. In examining the factors aimed at ensuring future-readiness, I focused on four concrete legal instruments and mechanisms:

- **Flexible definitions:** The technology-neutral approach is manifested most concretely in the definitions employed by the Regulation. Among these, the concepts of "AI system" and "general-purpose AI model" are sufficiently broad to remain resilient against technological paradigm shifts, yet sufficiently precise to preserve legal certainty.
- **Delegated acts:** These afford the Commission the capacity for rapid, targeted adjustments without undergoing the full legislative procedure required for amending the Regulation itself. The most prominent instances include: the power to amend Annex III concerning high-risk AI application domains (AI Act Article 7); the adjustment of conformity assessment methodologies and procedures (AI Act Articles 43 and 47); and specific regulatory aspects governing general-purpose AI models (AI Act Articles 51–53).
- **Risk management obligations:** Deriving from the risk-based approach, Article 9 of the AI Act mandates an iterative risk management process spanning the entire lifecycle of high-risk AI systems. This indirectly reinforces the future-proof character of the regulation by enhancing the resilience of the AI systems themselves.

- **Mandatory review mechanisms:** The evaluation and reporting obligations imposed upon the Commission under Article 112 of the AI Act - typically operating on a four-year cycle - provide a normative guarantee that the AI Act functions not as a closed, static text, but as a dynamically re-evaluable regime. The dissertation pointed out, however, that four-year cycles may be deemed overly protracted relative to the pace of AI development: the emergence of ChatGPT in 2022 and the ensuing generative AI explosion provide empirical corroboration for this, thereby substantiating a *de lege ferenda* proposal to shorten the statutory review interval.

The aforementioned resilience mechanisms fulfill a function that guiding principles alone could not accomplish: they provide a concrete toolkit for temporal adaptation. As the highlighted examples demonstrate, the EU AI Act established the capacity for swift intervention across several critical domains. By simultaneously striving to ensure legal certainty and flexibility, these mechanisms play a prominent role in promoting the future-proof character of the Regulation. My research substantiated that by proactively identifying risks, facilitating multi-level adaptability, and continually developing the normative text, this approach is capable of forging an enduring, flexible, yet stable and predictable framework for the European AI ecosystem. Through the establishment and deployment of these mechanisms, the Regulation is expected to withstand future uncertainties and challenges. However, the practical stress-testing of these tools remains ahead, which exposed certain inherent limitations of the current research.

Furthermore, I firmly maintained that the decisive prerequisite for the efficacy of this future-proofing toolkit is timing, as these mechanisms operate effectively only if the legislator employs them from a proactive rather than a reactive posture. Regulators can draft norms and enact amendments within the AI Act that concurrently protect the rights of EU citizens and foster innovation only if they monitor technological developments at close quarters and gain the clearest possible comprehension of industry development trajectories alongside actual technological trends. AI regulatory sandboxes (Articles 57–60 of the AI Act) - which are addressed separately as the most essential institutional safeguards for promoting future-readiness - can serve as exemplary venues for this direct monitoring process.

6. **The success of the EU AI Act does not depend solely on the quality of its normative text, its actual viability will ultimately be determined by the capacity, coordination, and unifying enforcement power of its institutional implementation architecture, which nonetheless faces numerous structural challenges.**

A salient thesis of the dissertation is that enacting adequate AI law is insufficient on its own: its enforcement requires a stable AI governance framework. To substantiate this, I examined in detail why the enforcement regime of the EU AI Act constitutes one of the Regulation's most complex yet central components, emphasizing that the actual realization of its statutory objectives ultimately hinges upon the quality of institutional implementation. The findings of my research demonstrate that European AI governance is not organized around a centralized

apex authority, but is built upon a multi-level, functionally divided institutional structure. The collective constellation of the AI Office, the AI Board, the Advisory Forum, the Scientific Panel, and the national competent authorities establishes an enforcement regime that deliberately combines supranational coordination, national administrative presence, independent scientific expertise, and the channeling of market and societal stakeholders into decision-making and enforcement. This approach aligns with the collaborative governance paradigm and clearly illustrates that the legislator conceives the regulation of AI not only as a matter of authoritative command and control, but as an ongoing regulatory task requiring continuous learning and cooperation.

As a crucial lesson of the dissertation, I established that the primary strength of the AI Act's enforcement architecture is concurrently the source of its greatest structural risk. Institutional pluralism, specialized competences, and the division of labor among multiple actors allow bodies with genuine expertise to participate in enforcement, enabling regulation to respond with greater sensitivity to divergent technological and sectoral contexts. Nevertheless, this same model can generate substantial coordination demands, overlapping jurisdictional competences, informational fragmentation, and, in certain cases, legal uncertainty. The dissertation argues that the system can therefore succeed only if inter-agency cooperation, information sharing, and task alignment are realized not merely as formal requirements, but as genuinely operational practices.

The national enforcement system of the AI Act follows a hybrid logic: alongside the horizontal vision of a single market surveillance authority with general competence, it affords Member States the discretion to leverage the sectoral expertise of existing regulatory bodies in market surveillance. The system of notified bodies - as an *ex ante* conformity assessment mechanism for designated high-risk AI systems - likewise fits into this logic. Statutory provisions and the finite capacities of public administration cannot guarantee direct and continuous state surveillance over every AI system. Therefore, the Regulation partially delegates conformity assessment to private entities while retaining state responsibility for maintaining the quality filter. The AI Act thus consistently applies a collaborative administrative approach that does not concentrate enforcement burdens on a single actor, but distributes them across state, market, and civil society spheres, while channeling the expertise accumulated among stakeholders into decision-making.

A comparative analysis of the Spanish, Italian, Finnish, and Hungarian implementation models reveals that Member States readily utilize the considerable institutional discretion left to national legislators by the AI Act. However, because the Regulation does not mandate a uniform enforcement template but permits divergent administrative models subject only to minimum institutional requirements, it introduces substantial risks to the uniform application targeted by the Regulation. While the AI Act respects national administrative traditions and institutional cultures, greater national organizational diversity places a heavier burden on EU-level coordination, the AI Office, the AI Board, and the soft law instruments designed to foster uniform interpretation. In light of this, I emphasized that the organizational flexibility of the AI Act - while advantageous for initial implementation - may yield uneven enforcement quality in

the medium term, creating direct friction with the integrity of the internal market. The genuine guarantee of uniform application resides in the efficacy of the EU coordination mechanisms counterbalancing enforcement pluralism. Presently, the harmonizing activity of the AI Board and the institutionalized exchange of best practices within regulatory sandboxes offer only a partial solution to the regulatory divergence stemming from this diversity.

In the dissertation, I also identified an aspect of this issue that appears advantageous at first glance but entails significant risks, which the EU AI Act failed to regulate adequately. Should Member States follow the baseline rule of the Regulation by establishing a model comprising multiple market surveillance authorities, a single legal entity may be subjected to inspections by several authorities acting on partial information, resulting in a mutually burdensome situation. This is particularly true when multiple AI systems of the same entity are overseen by different authorities, or when multiple use cases of the very same AI system fall under the jurisdiction of distinct bodies. While these scenarios can be partially mitigated through the rational allocation of competences and appropriate coordination, their resolution at the EU level is warranted to safeguard uniform enforcement.

In the dissertation, I specifically examined the domestic AI governance framework and established that the applicable Hungarian regime is the outcome of a multi-stage, continuously refined legislative process. A structure has emerged that leverages the organizational flexibility afforded by the AI Act yet concurrently carries normative and institutional risks at several junctures. The concentration of market surveillance responsibilities within ministerial competences and the delay in finalizing the institutional structure are both factors that may test the effective operation of the system in the short term. At the same time, the Hungarian model thoughtfully applies the principle of collaborative governance: the broad stakeholder engagement of the Hungarian Artificial Intelligence Council, the coordinating role of the Government Commissioner for AI, and the integration of existing sectoral authorities collectively reflect an approach that conceives the domestic implementation of the AI Act not merely as an administrative task, but as the deliberate construction of an AI ecosystem.

These findings clearly demonstrate that the operation of the AI governance regime outlined in the AI Act transcends the traditional boundaries of administrative adjudication: authorities must not only inspect, but also interpret, mediate, support, and actively shape the functioning of the regulated ecosystem. The enforcement architecture of the AI Act is deliberately built not on administrative simplicity, but on functional differentiation, rendering it capable of simultaneously securing fundamental rights protection, market surveillance, the integration of expert knowledge into decision-making, and the promotion of innovation. However, the more complex this architecture becomes, the more decisive effective coordination and the practical execution of enforcement will be.

7. The regulatory sandbox is not merely an innovation-enabling instrument, but one of the potential - and by no means risk-free - institutional learning mechanisms and imperatives of future-proof AI regulation.

A fundamental paradox of modern technology regulation is that the most urgent regulatory intervention would be required precisely where legislators and public authorities possess the least direct experience: in the domain of rapidly evolving disruptive technologies whose risks are only partially understood. According to my analysis, the construct of the regulatory sandbox is designed specifically to counterbalance this predicament: it is not just an innovation-incentivizing tool, but an institutionalized mechanism for reducing the knowledge asymmetry between the regulator and the regulated. By narrowing the gap between legal regulation and technological reality, regulatory sandboxes can contribute to ensuring that the legal framework for innovative technologies operates not as a static body of norms, but as a continuously learning and recalibrating regulatory regime.

This construct also serves as a forum for alleviating the regulatory uncertainty arising from the Collingridge dilemma - an institutional space in which legal experimentation can occur under controlled conditions with reversible consequences. The primary operational value of this mechanism lies in institutionalizing a two-way flow of information: on the one hand, participants gain the opportunity to test under real-world market conditions within a controlled environment free from the risk of administrative penalties. On the other hand, the competent authority channels first-hand structured feedback directly into the legislative process. I argued that it is precisely through this mechanism that sandboxes directly mitigate the severity of the pacing problem. Sandboxes attenuate the risks stemming from the widening gap between the pace of technological development and legislative reaction time, which emerge with particular acuity in the context of artificial intelligence. Participation in a sandbox simultaneously fosters safe and human-centric technology development, offering developers extensive testing opportunities in an environment where they need not fear the full spectrum of legal liabilities that would otherwise stifle innovation, thereby significantly facilitating market access.

In the dissertation, I reviewed regulatory sandboxes both in terms of typology and fields of application. The typological analysis demonstrated that the difference between technological and regulatory sandboxes is not evolutionary, but fundamentally functional: the former primarily serves technical testing and validation, whereas the latter concurrently provides a forum for testing legal compliance and fostering regulatory learning. In reviewing fields of application and sectoral practices, I formulated a significant finding: the analysis revealed that regulatory sandboxes perform optimally in two distinctly different regulatory contexts. In domains where an existing, heavily regulated regime creates barriers to market entry - such as the energy or financial sectors - sandboxes serve to make compliance burdens manageable. Conversely, in spheres of life characterized by a regulatory vacuum and legislative uncertainty, sandboxes facilitate the formulation of an adequate regulatory framework by enabling regulatory learning. The significance of sandboxes is therefore particularly profound for AI, as AI is simultaneously a disruptive, general-purpose, and fast-evolving technology whose impacts can frequently be evaluated only within a concrete context of application. For AI,

therefore, regulatory sandboxes serve not merely to facilitate market access, but as indispensable instruments for reducing regulatory information deficits and empirically testing legal norms.

An examination of the structure and internal operational logic of regulatory sandboxes brought crucial dynamics to the fore: the institutionalized proximity between authorities and market actors - arising from the need to reduce information asymmetry - while constituting one of the construct's greatest strengths, simultaneously represents the primary source of the risk of regulatory capture. According to Zarra,[10] this phenomenon can manifest fundamentally when well-capitalized industry representatives with substantial lobbying power are disproportionately involved in the decision-making processes establishing the sandbox, shaping it "in their own image" and thereby indirectly steering the substantive content of the legal norms governing them to their own advantage. The ramifications of this phenomenon are far-reaching: a lesser concern is that the dominance of larger corporations may crowd out smaller enterprises, thereby undermining the very innovation-promoting objectives of the sandboxes. A more severe, detrimental side effect of regulatory bias is that establishing authorities - in an effort to attract as many innovators as possible into the sandbox - progressively lower regulatory expectations, particularly regarding quality assurance criteria for admission and operation, as well as the stringency of supervisory oversight. The conduct of competing jurisdictions may lead to regulatory arbitrage, fostering the phenomenon known as a *race to the bottom*,[11] wherein jurisdictions outbid one another by creating ever more permissive legal environments to attract market actors. In my assessment, these risks can be averted and their impacts attenuated by ensuring adequate transparency alongside the provision of sufficient operational resources.

Beyond the foregoing, I argued that the regulatory sandbox can emerge as an essential instrument for governing disruptive technologies because it enables the operational stress-testing of abstract regulatory requirements: it demonstrates the extent to which legal mandates are feasible in technological practice, identifies where they require clarification, and highlights areas necessitating differentiated or adaptive solutions. In view of this very characteristic, the regulatory sandbox should be recognized not merely as an ancillary adjunct to technology regulation, but as an institutional prerequisite for forging effective AI law. At the same time, I affirmed that a well-designed AI regulatory sandbox is a necessary, yet in itself insufficient, condition for AI governance. Its efficacy hinges primarily on technical, institutional, and procedural prerequisites. I identified factors such as regulatory human resource capacity,

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[10] Zarra, A. 'Operationalizing AI Regulatory Sandboxes: A Look at the Incentives for Participating Start-Ups and SMEs beyond Compliance'. In *Regulatory Sandboxes for AI and Cybersecurity. Questions and Answers for Stakeholders*, edited by Filippo Bagni and Fabio Seferi, 101-115. Cybersecurity National Lab, 2025, 111.

[11] See e.g. Kate Francis, 'The Need for an Ethical Approach to Regulatory Sandboxes"', in *Regulatory Sandboxes for AI and Cybersecurity: Questions and Answers for Stakeholders*, ed. Filippo Bagni and Fabio Seferi, 192-206, (Cybersecurity National Lab, 2025), 199,; Claudio Novelli et al., 'Getting Regulatory Sandboxes Right: Design and Governance Under the AI Act', SSRN Scholarly Paper no. 5332161 (Social Science Research Network, 30 June 2025), 21, https://doi.org/10.2139/ssrn.5332161; Hannah Ruschemeier, 'Thinking Outside the Box?: Regulatory Sandboxes as a Tool for AI Regulation', in *Bridging the Gap Between AI and Reality*, vol. 14129, ed. Bernhard Steffen, Lecture Notes in Computer Science (Springer Nature Switzerland, 2025), 328, https://doi.org/10.1007/978-3-031-73741-1_20.

alongside whether participation is genuinely attractive and accessible to market actors, as decisive determinants.

My conclusion on this issue is that the existence and implementation of regulatory sandboxes do not entirely resolve the Collingridge dilemma but can serve to meaningfully mitigate it. However, sandboxes can fulfill this function only if underpinned by an appropriate legal framework, expert supervisory capacity, effective coordination, and an operational model that remains accessible and compelling to market participants.

8. The EU AI Act integrated AI regulatory sandboxes into the Regulation's architecture as a pivotal instrument for effective and future-proof European AI legislation; however, their actual regulatory value is decisively determined by the quality and success of their national implementation

The dissertation pointed out that during the drafting of the EU AI Act, the legislator correctly recognized that effective AI law cannot be formulated solely at the negotiating table; rather, it necessarily requires institutionalized spaces where the technology and the overseeing regulator can interact in a controlled setting. This is precisely what AI regulatory sandboxes accomplish, functioning within the architecture of the AI Act not as ancillary instruments of innovation policy, but - according to my analysis - as the primary organizational prerequisites for future-proof, adaptive, and genuinely enforceable AI legislation.

The analysis of the AI Act's sandbox framework was conducted on the basis of Articles 57–60 of the Regulation and the draft implementing act laying down detailed rules for AI regulatory sandboxes, published for consultation by the Commission in December 2025[12] pursuant to Article 58 of the AI Act. As a result of this analysis, it can be established that activities within the sandbox simultaneously encompass compliance guidance, technological testing, and regulatory learning. Regarding the former two functions, the AI Act constructs a controlled, *ex ante* compliance and development environment in which innovative AI systems can be developed and validated under regulatory supervision prior to being placed on the market. Within the sandbox, providers receive not only general information, but tailored legal and technological assistance, risk-management guidance, and, under specific conditions, support that facilitates and accelerates compliance. According to my findings, the Regulation thereby establishes a dual incentive structure: it reduces the legal costs and time required for market

[12] European Commission, 'Commission Seeks Feedback on Draft Implementing Act to Establish AI Regulatory Sandboxes under the AI Act', Accessed 29 March 2026., https://digital-strategy.ec.europa.eu/en/consultations/commission-seeks-feedback-draft-implementing-act-establish-ai-regulatory-sandboxes-under-ai-act.

entry, while providing authorities with first-hand insight into the practical feasibility of the AI Act's technical and organizational obligations during development.

A crucial finding of my research is that the AI regulatory sandbox within the AI Act serves not only to manage compliance risks and ease market entry, but has the potential to become a venue for the practical development, empirical substantiation, and continuous calibration of European *sui generis* AI law. In this regard, a further finding of the dissertation is that the AI Act's sandbox model was designed for two-way learning. Knowledge accumulated within the sandboxes is channeled back - via the AI Office and national competent authorities pursuant to the regulatory text - into non-binding guidelines, annual reports, and potentially future amendments to primary Union legislation. I emphasized that this does not constitute contingent, informal communication, but rather structured processes operating through institutionalized transmission mechanisms, which are expected to actively advance the future-proof lawmaking highlighted throughout these theses.

In the dissertation, I examined how, to maximize learning efficacy, the AI Act conceives AI regulatory sandboxes not as isolated national institutions, but as an interconnected European learning infrastructure linked across multiple axes. The mandatory cooperation between national authorities, information and reporting obligations toward the AI Office and the AI Board, and transparency mechanisms toward the public collectively serve the objective of preventing knowledge generated within sandboxes from remaining localized, ensuring its integration into EU AI governance. This architecture is particularly significant for AI, where traditional legislative cycles relying on protracted feedback loops prove inadequate given the pace of technological change.

Based on the dissertation's analysis, it is established that the AI Act elevates regulatory sandboxes to instruments of normative resilience: it deploys them as transmission mechanisms through which AI law can stay closely aligned with the evolving state of technological reality. As an additional conclusion, I emphasized that the future-proof nature of the AI Act does not depend solely on textual flexibility, but equally on the enforcement system's institutional capacity to feed sandbox-derived empirical insights back into the subsequent interpretation, application, and refinement of the regulatory framework.

In the course of the research, I devoted specific attention to examining the normative efforts of the EU AI Act aimed at managing the risk of regulatory capture. Based on these inquiries, I concluded that the safeguard of adequate resources mandated under Article 57(4), mutual oversight among authorities, and the coordination and transparency functions of the AI Office collectively constitute a system of guarantees that - provided Member States genuinely fulfill their funding obligations - can mitigate the risk of the sandbox degenerating into a biased, arbitrary regulatory channel subordinated to a narrow group of market players. The analysis pointed out, however, that this safeguard system remains predominantly declaratory where national resource allocation remains subject to political discretion rather than binding legal obligations. For this reason, adequate resource provision and institutional independence cannot be contingent, as they represent prerequisites for the actual viability of the construct.

Following the review of the operational baseline conditions for EU AI regulatory sandboxes, I formulated several findings. A crucial lesson is that the AI Act infused the technological testing dimension of the sandbox with substantive content through its integration into the broader EU AI innovation ecosystem, leveraging existing and planned AI innovation capacities to forge the testing infrastructure necessary for full-fledged operation. While this approach promises flexibility and resource efficiency, it carries the risk that the actual technological capacity of the sandbox becomes fragmented, depending on the availability of participating entities and their operational funding. The success of this construct is therefore by no means automatic: while the AI Act provides a detailed, forward-looking regulatory framework, the actual viability of sandboxes ultimately hinges upon institutional and capacity-related conditions. The lack of adequate human expertise, the absence of infrastructure required for technological testing, the failure to actively utilize coordination mechanisms, and the shortage of resources ensuring regulatory independence can easily hollow out the model. Should these conditions be compromised, the sandbox forfeits its "regulatory" character and deteriorates into a mere innovation incubator - devoid of normative added value. In connection with the Collingridge dilemma, this could lead to particularly grave consequences: the authority would forfeit the valuable window of intervention precisely where the pacing problem could be addressed most effectively.

Among EU Member States, the dissertation examined in detail the models of Spain and Denmark, both of which are advanced in establishing regulatory sandboxes. The Spanish agency AESIA launched a pilot program as early as 2022 to establish a practical model for European AI regulatory sandboxes and played a pioneering role in formulating the requisite domestic legal framework. In April 2025, its AI Act-compliant regulatory sandbox commenced operational activities, through which it has thus far tested twelve high-risk AI systems across six sectors. Denmark’s Agency for Digital Government (*Digitaliseringsstyrelsen*) and the Danish Data Protection Agency (*Datatilsynet*) launched their first testing cycle in 2024 - attracting significant interest and executing successful projects - with applications for the second cohort open through May 2026. Following this, I briefly reviewed the specificities of the Hungarian situation: while the domestic implementation currently falls short of the level demanded by Union expectations due to the absence of dedicated AI supervisory authority capacity and an autonomous sandbox infrastructure, specific legislative provisions and exceptional resources within the domestic innovation ecosystem can already be identified that provide cause for optimism.

Considering the foregoing, my overarching conclusion is that the AI regulatory sandbox construct outlined by the AI Act has a realistic prospect of becoming an international benchmark, provided that Member State implementation efforts prove successful in the long term. This is reinforced by the functioning Member State practices examined in the concluding part of the dissertation, which substantiate not only the abstract regulatory potential of sandboxes, but also provide early empirical evidence supporting their utility and legitimacy in advancing AI regulation and technological development. It is this iterative mechanism - positioning both the regulator and the regulated in a learning posture - that distinguishes AI sandboxes from traditional market surveillance instruments, and through which the AI Act’s

sandbox model, supported by adequate national capacity and coordination, can emerge as one of the most promising instruments for realizing an effective, innovation-friendly, yet human-centric AI regulatory framework.

V. Publications Related to the Research

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