European Journal of Risk Regulation (2026), 1–26
doi:10.1017/err.2026.10093

CAMBRIDGE UNIVERSITY PRESS

ARTICLE

A Conceptual Framework for Regulating Autonomous Inland Shipping in Europe

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Abstract

This paper examines the regulatory challenges and opportunities surrounding the introduction of autonomous inland shipping in Europe. As regulators navigate this shift, they must strike a balance between innovation, safety, legal certainty and private actors' interests. Drawing on principles guiding innovation, such as outcome-based, risk-based and adaptive regulation, as well as the precautionary, proportionality and technological neutrality principles, the paper proposes a framework for developing regulatory responses. It also analyses the relevance of EU horizontal digital regulations, including the AI Act and the Data Act, in shaping the governance of autonomous systems in inland waterways. The paper explores how the existing divisions of regulatory competence between European institutions and river commissions may hinder harmonisation, and proposes mechanisms to improve regulatory and judicial coherence in a multilevel governance context.

Keywords: AI Act; autonomous vessels; European inland waterways; risk regulation

I. Introduction

The regulation of disruptive technology poses significant challenges. Autonomous inland vessels can be classified as disruptive technology, as they do not fit neatly into current regulatory regimes and their deployment raises complex legal, institutional and governance issues. This paper addresses possible approaches to the regulation of disruptive technologies, exemplified by autonomous inland vessels, and explores how harmonisation within a multilevel governance system in a transnational context, such as Europe's inland waterways, can be accomplished to ensure legal certainty and compliance. To identify regulatory guidance and harmonisation opportunities, the study essentially addresses the regulation of autonomous inland shipping from two angles:

The first angle analyses how regulators should address issues that require regulatory intervention. This initial question concerns the regulatory approach, determining the depth to which rules are formulated. Innovation-guiding principles further influence the choice of regulatory approach and guide the regulator towards the right balance between risk management and innovation development. The regulation of any artificial intelligence (AI)-driven system within the EU must be considered in conjunction with recently enacted EU legislation, providing further input for regulators in establishing regulatory provisions for autonomous inland vessels.

Nonetheless, a regulatory framework is likely to fail if it is not adopted and implemented harmoniously across Europe's inland waterways. The second angle therefore

examines who, amongst the various regulators in European inland shipping, should regulate autonomous inland vessels. Whilst a uniform deployment within the EU and beyond should be the ultimate regulatory objective, achieving a high level of harmonisation will also require substantial changes in national legal practices, institutional design and (national) enforcement mechanisms.

By addressing these two angles, this paper aims to provide a conceptual framework for regulating autonomous inland shipping, offering substantive guidance for European regulators in both the initial and the subsequent implementation phases:

Section II of the paper addresses the first angle, that is, how the regulation of autonomous inland shipping should be designed. It first analyses the regulatory approach(es) for autonomous inland shipping, then introduces a set of innovation-guiding principles and assesses their relevance and value in guiding the regulatory choices for autonomous inland vessels. It continues by examining the role of EU horizontal digital legislation and the implications of this legislation for the regulation of autonomous inland vessels.

Section III addresses the structural challenge posed by the current division of competences in European inland waterway governance. It argues that fragmented national approaches could hinder the development and cross-border deployment of autonomous inland vessels. To address this, this section explores possible mechanisms, both regulatory and judicial, to achieve a sufficient level of harmonisation.

Section IV concludes by summarising the key insights gained from the discussion of how autonomous inland shipping in the pan-European context should be regulated and who should do the regulating.

II. How to regulate autonomous inland shipping: approaches, guiding principles and implications of EU horizontal legislation

1. Approaches in regulation

Two general approaches exist for the achievement of regulatory objectives: a rules-based regulatory (RBR) approach and a goals-based regulatory (GBR) approach. An RBR approach consists of clearly defined, specific and prescriptive rules. It informs regulatees about permitted and prohibited actions, with few or no exceptions, offering minimal flexibility in specific factual situations.[1] This approach typically articulates a definitive legal outcome that ensues from one or more triggering circumstances.[2] The GBR approach, in turn, focuses on setting goals, outcomes or standards.[3] Before regulating, it is vital to understand the specific impact that each approach can have on the regulator, on the one hand, and the regulatee or regulated subject, on the other. This is because the chosen approach may affect risk allocation,[4] regulatees' incentives and behaviours, and the nature and methods of regulatory enforcement.[5] Because of the advantages and disadvantages associated with each approach,[6] it is necessary to consider these when deciding which to follow.

[1] C Decker, "Goals-based and Rules-based Approaches to Regulation" (2018) BEIS Research Paper 8, 5.

[2] RB Korobkin, "Behavioral Analysis and Legal Form Rules vs. Standards Revisited" (2000) 79 Oregon Law Review 23, 23–4.

[3] Decker (*supra*, note 1) 5.

[4] Council of Australian Governments, "Principles and Guidelines for National Standard Setting and Regulatory Action by Ministerial Councils and Standard Setting Bodies" (2004) 5.

[5] S Shavell, "The Optimal Structure of Law and Enforcement" (1993) 36(1) The Journal of Law & Economics 255, 259–60, 280; L Kaplow, "Rules Versus Standards: An Economic Analysis" (1992) 42 Duke Law Journal 557.

[6] Decker (*supra*, note 1) 5.

a. Rules-based vs. goals-based

Rules-based regulation provides precision and certainty for regulatees by setting clear requirements, which also makes enforcement more consistent[7] and thereby limits regulatory discretion.[8] It places ultimate accountability on the regulator, ensuring a strong, centralised role in determining and enforcing compliance.[9] However, this approach relies less on trust in regulatees,[10] and can stifle flexibility and innovation, as it is less adaptable to changing circumstances.[11] Because the regulator must fix detailed rules prior to market introduction, the cost of achieving compliance is high for the regulator; once the rules are in place, the cost of making their behaviour compliant is low for regulatees, since they only need to follow the prescribed standards.[12] Whilst this approach offers clarity and uniformity, its rigidity can make it harder for both regulators and regulatees to respond effectively to new risks or evolving market conditions.

In contrast, goals-based regulation offers several advantages. It gives flexibility,[13] thereby allowing regulatees to experiment with alternative methods of compliance,[14] and it can therefore be adapted more easily to changing markets or environments.[15] Therefore, GBR makes the regulatory framework more adaptable to rapid market changes driven by innovation by allowing regulatees to modify their behaviour, such as their compliance methods, without new regulations being required.[16] By placing greater trust in regulatees,[17] it encourages them to assume responsibility, consider the broader consequences of their actions,[18] and thereby innovate in meeting regulatory goals. It also enables regulators to customise enforcement approaches rather than relying on rigid, one-size-fits-all rules and deterrent actions.[19] However, because regulatees must demonstrate how they achieved the set goals, the cost of achieving compliance is high for them, and predictability may be jeopardised if it is unclear which methods will be deemed acceptable.[20] By contrast, the cost of compliance is relatively low for the regulator, as the burden of proof rests with the regulatee.[21]

[7] Kaplow (*supra*, note 5) 575.

[8] Korobkin (*supra*, note 2) 26–27; F Akinbami, "Is Meta-regulation All It's Cracked Up To Be? The Case of UK Financial Regulation" (2013) 14 Journal of Banking Regulation 16, 21.

[9] Akinbami (*supra*, note 8) 23.

[10] H Dakin, "Civil & Administrative Penalties: Discretion & Fairness in Penalty Procedures" (2001) 24 Australian Law Reform Commission Reform Journal 79, 38–43, 39.

[11] C Ford, "Principles-based Securities Regulation in the Wake of the Global Financial Crisis" (2010) 55(2) McGill Law Journal 257, 306.

[12] Korobkin (*supra*, note 2) 26–7; Akinbami (*supra*, note 8) 22; Kaplow (*supra*, note 5) 557; Decker (*supra*, note 1) 7.

[13] S Arjoon, "Striking a Balance Between Rules and Principles-based Approaches for Effective Governance: A Risks-based Approach" (2006) 68 Journal of Business Ethics 53, 74; J Black, "Forms and Paradoxes of Principles Based Regulation" (2008) LSE Working Paper 13/2008, 3.

[14] Akinbami (*supra*, note 8) 22.

[15] RE Löfstedt, *Reclaiming Health and Safety For All: An Independent Review of Health and Safety Legislation* (Cm 8219, 2011) p 55; Decker (*supra*, note 1) 21; J Pelkmans and A Renda, Does *EU Regulation Hinder or Stimulate Innovation?* (CEPS Special Report No. 96 2014) 8, para. 1.4.3; J Pelkmans and Andrea R, "How Can EU Legislation Enable and/or Disable Innovation?" (European Commission 2014) 22, at 3.1.4.

[16] Decker (*supra*, note 1) 32.

[17] Dakin (*supra*, note 10) 39.

[18] Akinbami (*supra*, note 8) 23; Kaplow (*supra*, note 5) 605.

[19] Kaplow (*supra*, note 5) 575.

[20] Korobkin (*supra*, note 2) 26–7; Akinbami (*supra*, note 8) 22; Kaplow (*supra*, note 5) 557, 614–15; Decker (*supra*, note 1) 7.

[21] Korobkin (*supra*, note 2) 26–7; Akinbami (*supra*, note 8) 22; Kaplow (*supra*, note 5) 557, 614–15.

b. The regulatory approach spectrum

Both approaches have benefits and drawbacks, and the context in which regulation is sought has an impact on the approach chosen. Notably, the chosen method can incorporate features of both, resulting in hybrid versions;[22] this is also described by saying that the methods span a spectrum and do not just have pure forms.[23]

At one extreme, there exists a pure RBR approach, which establishes explicit and precise rules without exceptions or qualifications.[24] Conversely, at the opposite end of the spectrum, a pure GBR approach is characterised by broadly defined, high-level objectives, which, however, lack accompanying guidance or safe harbours.[25] A hybrid RBR approach has binding rules supplemented by non-binding elements, such as statements of regulatory goals, exceptions, or qualifications to the rules.[26] Similarly, a hybrid GBR approach involves binding goals complemented by non-binding guidance, whereby regulated entities may be required to justify deviations from the non-binding guidance and demonstrate that their compliance measures are aligned with the regulatory objectives.[27] Typically, binding rules within this framework are further supported by non-binding guidance, safe harbours, prior decisions or best practice guidelines.[28]

c. Choosing the right approach(es) for autonomous inland shipping: A question of balancing costs and risks

In the light of the above, it appears that GBR is better suited to innovative sectors, such as autonomous inland shipping, as it can be adapted to market changes.[29] Although it is likely that the regulated subjects, namely shipowners, shipping companies and technology providers, will embrace the flexibility to experiment with their operational and technical performance to achieve the set objectives, the costs of compliance or the risk of not meeting the set objectives might be unacceptably high for them, risking either over- or under-compliance.

On the one hand, the vague nature of the GBR approach could become very costly for regulatees if they need to seek expert advice on what actions align with the regulatory goals, leading to over-compliance.[30] Conversely, the GBR approach could become risky for regulatees if they interpret a regulatory goal in a way that aligns with their own interests rather than the original intent of the regulator, potentially leading to under-compliance.[31]

As for the regulators, whilst the cost of implementing GBR influence is significantly less than the cost of RBR, they might find themselves increasingly reliant on the judgment of industry experts to define or interpret a regulatory goal *ex post*.[32] This will ultimately pose challenges concerning regulatory matters that necessitate clarity and predictability in

[22] Decker (*supra*, note 1) 42–5.
[23] Korobkin (*supra*, note 2) 24.
[24] Decker (*supra*, note 1) 42.
[25] Ibid.
[26] Ibid, 43.
[27] Ibid.
[28] Ibid.
[29] R Deighton-Smith, "Process and Performance-Based Regulation: Challenges for Regulatory Reform" in P Carroll, R Deighton-Smith, H Silver and C Walker (eds), *Minding the Gap: Re-visiting the Promise and* Performance *of Regulatory Reform in Australia* (Canberra, ANU Press 2008) p. 101; OECD, Regulatory Policy and Governance: Supporting Economic Growth and Serving the Public Interest (OECD Publishing 2011) p. 42; J Black, "Making a Success of Principles-Based Regulation" (2007) Law and Financial Markets Review 191, 195; C Coglianese, J Nash, and T Olmstead, "Performance-Based Regulation: Prospects and Limitations in Health, Safety, and Environmental Protection" (2003) 55(4) Administrative Law Review 705, 723; Black, "Forms and Paradoxes" (*supra*, note 13) 3.
[30] Decker (*supra*, note 1) 25.
[31] Ibid.
[32] Ibid, referring to this as a "subtle form of regulatory capture."

advance. Moreover, for regulatory issues whose outcomes are not measurable because of a lack of predefined criteria, metrics or thresholds, the GBR approach is generally ill-suited.[33]

It follows that, whilst innovation is the key contextual driver for advocating GBR in autonomous inland shipping regulation, regulatory issues whose outcomes are not measurable should generally be phrased as rules. Accordingly, RBR should be applied to regulatory issues requiring clarity and predictability *ex ante*, such as accountability issues, authorisation and certification, technical standards specifying the minimum equipment required, the storing, reporting and sharing of relevant operational and safety-critical data, enforcement and inspection procedures, and risk mitigation measures.

However, even in these areas, if the costs of implementing RBR are too high for the regulator because the technology is still maturing, especially when there is limited access to information,[34] a hybrid RBR approach should be considered, to transfer some of the costs onto regulatees. For instance, responsibility issues could be paired with GBR-like duty-of-care obligations, rules on core technical equipment could leave open the possibility for operators and technology providers to experiment with additional safety features, standardised reporting obligations could be softened by performance indicators such as accuracy and completeness, enforcement could be implemented based on risk profiles, and risk mitigation measures could be supplemented by less measurable goals such as the non-occurrence of critical aspects during operations.

In contrast, the GBR approach will be most effective with regard to issues subject to ongoing technological development, such as operational and safety performance, system reliability and operational efficiency, as the cost of regulation would simply be too high for the regulator whilst regulatees are in the best position to determine how the goal can be achieved.

Again, when regulatees are unable to bear the costs and risks associated with either over-compliance or under-compliance, a hybrid GBR version should be considered. Outcome-oriented regulations, such as collision avoidance requirements, should be supplemented with minimum safety standards, including emergency procedures. Requirements to demonstrate operational performance could be delineated by baseline criteria pertaining to reliability and redundancy of components. Additionally, objectives concerning infrastructure and supply integration might be governed by minimum standards for interconnectivity and operability.

Another aspect that warrants consideration when choosing the regulatory approach is that of is potential impact on harmonisation efforts: The inherent flexibility of GBR can increase divergence in regulatory *ex post* interpretation of goals-driven rules as the competent regulatory institutions, in particular at the national and regional levels, may yield inconsistent compliance expectations and oversight practice. A hybrid GBR could reduce divergence in *ex post* interpretation by the different regulatory entities, provided that the accompanying non-binding guidance would itself be developed and applied in a sufficiently harmonised manner. On the other side, RBR, as well as its hybrid version, could promote a higher degree of harmonisation from the outset since this approach leaves less discretion for *ex post* evaluation and oversight strategies, thereby reducing opportunities of national or regional discrepancies in implementation and enforcement.

Consequently, harmonisation efforts from the outset will also entail higher coordination costs, as regulators must align not only broad objectives but also their accompanying non-binding guidance, in the case of hybrid GBR, or align more detailed rules, in the case of (hybrid) RBR. This will be further discussed in Section III.

[33] Ibid, 41, Table 3.
[34] Ibid, 29.

In conclusion, it should be noted that, rather than selecting a single approach, the regulation of autonomous inland shipping necessitates multiple approaches, adopting different approaches for different issues. The choice of regulatory approach for each issue will need to be determined by balancing the associated costs and risks between the regulator and the regulatees. The initial consideration in this balancing exercise should be the measurability of the intended outcome. However, as technology advances and more information becomes available to the regulator, the costs associated with promulgating RBR-like rules will diminish. This will also enable the reassessment of the initial choices regarding the regulatory approach (see Figure 1).

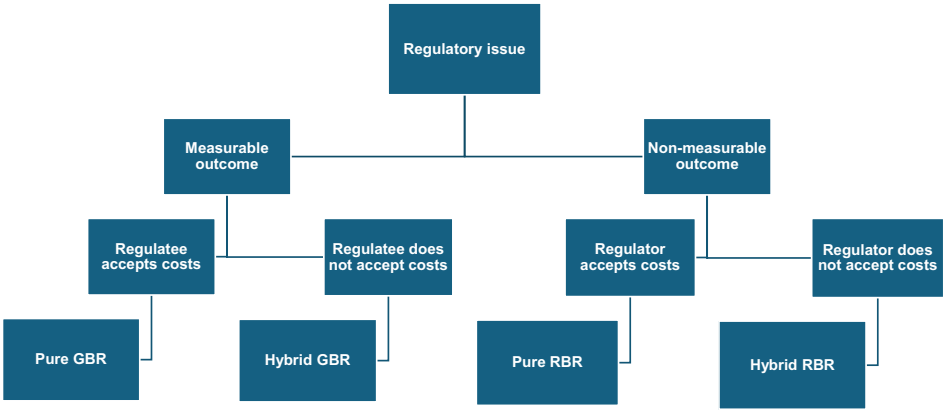

Figure 1. Decision tree on regulatory approach.

The following sub-section discusses the pertinent innovation-guiding principles that will further inform the process of finding the right regulatory approach for each regulatory issue in the initial and subsequent regulatory phases.

2. *Innovation-guiding principles and their influence on regulatory intervention*

Regulating disruptive technology necessitates the development of innovative solutions to address emerging issues, thereby requiring the implementation of novel regulatory mechanisms. These mechanisms can be based on particular principles, including well-established principles of EU law applied within the new contextual framework, as well as more recently developed principles.

a. Adaptiveness of regulation, regulatory approach and governance

Although an initial choice of regulatory approach must be made, this does not mean that the choice is final: the impact of contextual factors such as costs and innovation may only become apparent over time, thereby necessitating potential adjustments to the balancing of costs exercise between regulator and regulatees as circumstances evolve.[35] The data gathered during the initial implementation phase will be the most comprehensive, continuously providing regulators with information that requires existing regulations to be amended. On the basis of the improved availability of more specific information, the regulator will also be able to reconsider the initial choice of regulatory approach if GBR was selected previously because of a lack of information or an anticipated rapid

[35] Ibid, 45.

technological development. Once sufficient information becomes available, the cost of compliance for regulatees under GBR will decrease as the regulatory approach shifts towards RBR.

Given that technology generally advances more rapidly during the initial development stages,[36] regulators are more likely to depend on the industry's self-regulatory knowledge to regulate effectively during the first implementation phase.[37] For early regulation in fast-changing environments to be effective, collaboration and transparency between regulator and regulatees are pivotal, particularly in the innovation context.[38] Nevertheless, this is more easily said than done, as regulators and regulatees typically pursue divergent interests during the process of innovation governance.

On the one side, regulators prioritise social interests and follow the "prevention principle,"[39] a principle originally derived from the environmental law context. This is generally defined as "an anticipatory principle that seeks to avoid foreseeable risks."[40] According to this principle, it is assumed that the technology is susceptible to risks in the absence of demonstrated safety evidence. Conversely, industry usually emphasises economic drivers and follows the "precautionary principle," considering technology to be safe unless it is proved to be dangerous.[41]

To overcome this difference, the concept of "adaptive governance" or "anticipatory regulation" has emerged, under which regulators and regulatees must collaborate to develop a governance framework that can accommodate their interests; this also engages both public and private actors, thereby ensuring better democratic legitimacy.[42] In line with this concept, new regulatory tools have emerged, including experimental legislation within so-called "regulatory sandboxes" as a dynamic and responsive tool, which also facilitates collaboration between regulators and regulatees in the risk mitigation process.[43] Regulatory sandboxes enable regulators and regulatees to collaborate during development, to their mutual benefit.[44] Regulators gain insights into emerging technologies so that they can craft tailored regulations, whilst entrepreneurs can develop compliant products without legal risks.[45] The EU AI Act explicitly recognises "regulatory sandboxes" designed to promote AI innovation.[46] AI systems solely for research are exempt from the

[36] K Knez, "Technology Diffusion and Uneven Development" (2023) 33 Journal of Evolutionary Economics 1171, 1173; WG Johnson, "Caught in Quicksand? Compliance and Legitimacy Challenges in Using Regulatory Sandboxes to Manage Emerging Technologies (2023) 17 Regulation & Governance 709, 711; Ford (*supra*, note 11) 277; MK Kołacz, A Quintavalla and O Yalnazov, "Who Should Regulate Disruptive Technology?" (2019) 10(1) European Journal of Risk Regulation 4.

[37] Ford (*supra*, note 11) 278.

[38] WD Eggers, M Turley and P Kishnani, "The Future of Regulation, Principles for Regulating Emerging Technologies" (2018) Deloitte Insights 17.

[39] Shavell (*supra*, note 5) 259.

[40] LA Duvic-Paoli, *The Prevention Principle in International Environmental Law* (Cambridge, Cambridge University Press 2018) p. 8.

[41] X Cao and others, "Adaptive Governance, Loose Coupling, Forward-Looking Strategies and Responsible Innovation" (2020) 8 IEEE Access 228163, 228164.

[42] Ibid; K Yordanova and N Bertels, "Regulating AI: Challenges and the Way Forward Through Regulatory Sandboxes" in HS Antunes and others (eds), *Multidisciplinary Perspectives on Artificial Intelligence and the Law* (Cham, Springer 2024) p. 451.

[43] Yordanova and Bertels (*supra*, note 42) 445; M Fenwick, EPM Vermeulen and M Corrales, "Business and Regulatory Responses to Artificial Intelligence: Dynamic Regulation, Innovation Ecosystems and the Strategic Management of Disruptive Technology" in M Corrales, M Fenwick and N Forgó (eds), *Robotics, AI and the Future of Law* (Singapore, Springer 2018); Ford (*supra*, note 11) 261.

[44] Johnson (*supra*, note 36) 709.

[45] T Madiega and AL Van De Pol, "Artificial Intelligence Act and Regulatory Sandboxes" (European Parliamentary Research Service, 2022) 2.

[46] Reg. (EU) 2024/1689 of the European Parliament and of the Council of 13 June 2024 laying down harmonised rules on artificial intelligence and amending Regs. (EC) No 300/2008, (EU) No 167/2013, (EU) No 168/2013, (EU)

AI Act's strict rules, but AI regulatory sandboxes are not.[47] The Act allows some flexibility for developers to test AI in real conditions whilst maintaining safety, rights and transparency.[48]

In inland waterway transport, regulatory sandboxes have also emerged in the context of automated shipping operations.[49] They essentially provide a mechanism for hybrid GBR, as regulatees are granted considerable flexibility in achieving the prescribed objectives, within the same general safeguards as are embedded in the AI Act. Therefore, regulatory issues with measurable outcomes, which would lead to excessively high compliance costs for regulatees under a pure GBR approach, can be managed through regulation. The combined approach of GBR with regulatory sandboxes can reduce the impact of entry requirements and regulatory compliance burdens, particularly for entrepreneurs and innovation developers.[50] The role of a regulator in this context has thus evolved from simply overseeing to becoming a partner in promoting safe and effective technologies, thereby fostering greater confidence in these innovations amongst the public.[51] Through collaborative regulation-making, not only can compliance costs under GBR be reduced by fostering trust between regulator and regulatee, but the adaptability of regulation can also be enhanced through improved information exchange, making information more accurate and more rapidly accessible to regulators, which may consequently accelerate the transition from GBR towards RBR.

Despite these benefits, concerns exist about relying on experimentation for regulatory agility. Sandboxes may cause regulatory arbitrage, with regulators lowering safeguards to attract innovators,[52] and testing parameters may diverge across EU Member States, leading to fragmented regulatory proposals.[53] Consequently, although the inputs obtained from regulatory sandboxes are important for regulators in formulating new regulatory provisions for emerging technologies, regulators must exercise caution and remain vigilant throughout the process. It is therefore imperative to consider the potential for unknown risks, with the principle of proportionality serving as a vital guide in this regard.

b. Risk-based regulation in the light of the proportionality principle

Despite its high flexibility, GBR does not imply a system in which risks are unregulated; instead, it can be pursued in accordance with a risk-based approach to regulation.[54] To attain a level of risk mitigation that satisfies both regulators and regulatees, risk regulation needs to be balanced. More specifically, adequate regulation of innovation must be proportional to the risk level of the system and not unnecessarily burden innovation.[55]

2018/858, (EU) 2018/1139 and (EU) 2019/2144 and Directives 2014/90/EU, (EU) 2016/797 and (EU) 2020/1828 (Artificial Intelligence (AI) Act) [2024] OJ L 2024/1689 Recital 139.

[47] AI Act, Recital 79, Art. 2(6).

[48] AI Act, Arts. 57–9.

[49] Automated sailing tests have been conducted or are currently underway in several EU Member States, including Belgium, the Netherlands, Germany, and France. Additionally, the Central Commission for the Navigation of the Rhine (CCNR) is coordinating pilot projects on the Rhine.

[50] Pelkmans and Renda, *Does EU Regulation Hinder or Stimulate Innovation?* (*supra*, note 15) 10; S Van Uytsel, "Artificial Intelligence and Collusion", in M Corrales, M Fenwick, and N Forgó (eds), *Robotics, AI and the Future of Law* (Springer 2018) p. 176.

[51] Eggers and others (*supra*, note 38), 12–13.

[52] European Regulation & Innovation Forum, "Better Regulation, Prosperity, Transition and Resilience" (2023) Communication 23, 5.

[53] Madiega and Van de Pol (*supra*, note 45) 3.

[54] Solicitors Regulation Authority, "Attitudes to Regulation and Compliance in Legal Services" (Solicitors Regulation Authority 2011) p. 14; Arjoon (*supra*, note 13) 77.

[55] E Magrani and PGF da Silva, "The Ethical and Legal Challenges of Recommender Systems Driven by Artificial Intelligence" in HS Antunes and others (eds), *Multidisciplinary Perspectives on Artificial Intelligence and the Law* (Cham,

Proportionality, as a fundamental principle of EU law, limits the exercise of authorities' powers by requiring a balance between the means employed and their intended aim.[56] It can also be seen as a way to prevent over-regulation: a proportionate approach in EU rulemaking seeks to simplify rules and emphasises the importance of freedom to innovate.[57] The AI Act incorporates proportionality, balancing regulation and development by differentiating risk levels, thereby regulating different AI applications in different ways according to their assessed risk levels.[58] Moreover, through the AI Act, the European legislator has established a mandatory, and therefore enforceable, risk classification scheme, assigning to Member States a key role in the application and enforcement of the Act through the designation of national competent authorities to ensure implementation and enforceability.[59]

Risk-based regulation for autonomous inland shipping could be achieved by tailoring oversight to the differentiated risk profiles of specific operations. Rather than applying uniform requirements across all operational contexts, the regulation would define thresholds for when autonomous navigation is permissible and when stricter safeguards are required.[60] For example, vessels operating in low-traffic or less environmentally sensitive waterways could benefit from simplified, lighter regulatory requirements. In contrast, vessels in congested or ecologically critical areas would face stricter safety, cybersecurity, and performance checks. Real-time data collection on vessel performance and incident reports would enable regulators to update risk assessments continuously and modify the requirements accordingly. This approach would have the benefit of creating risk-based regulation that is proportional, whilst avoiding over-regulation.[61] With regard to *ex post* risk assessment, a risk-based regulatory approach will further ensure that newly identified risks are systematically integrated into subsequent evaluations, thereby creating regulatory responses that remain proportionate to the risks observed in practice.

Moreover, the principle of proportional risk-based regulation can enhance both RBR and GBR regulation. RBR can become more flexible by varying the conditions under which stricter or lighter obligations apply. Conversely, GBR can become more organised by aligning performance obligations with risk categories. In other words, under the influence of proportional risk-based regulation, hybrid versions of each approach can be achieved: RBR becomes more adaptable to the context, whilst still prioritising clarity, and GBR becomes slightly more predictable.

c. Principles of innovation, precaution and technological neutrality

In the context of a regulatory approach, the level of intervention by public regulators can be seen to lie on a spectrum, ranging from extensive, precautionary regulation at one end (i.e., RBR) to minimal regulation at the other end (i.e., GBR).[62] Consequently, the more precautionary the regulation, the less freedom innovators may have, and the less

Springer 2024) p. 163; C Ducuing, "A Legal Principle of Innovation? Need for an Assessment Against the Principle of Democracy" (2022) 14(2) Law, Innovation and Technology 237, 251; J Czarnocki, "Saving EU Digital Constitutionalism Through the Proportionality Principle and a Transatlantic Digital Accord" (2021) 20(2) European View 150, 154; OECD, Regulatory Policy and Governance (*supra*, note 29) 145.

[56] Consolidated version of the Treaty on the European Union (TEU) [2012] OJ C 326, Art. 5(4).

[57] Czarnocki (*supra*, note 55) 154.

[58] A Keller, C Martins Pereira, and ML Pires, "The European Union's Approach to Artificial Intelligence and the Challenge of Financia Systemic Risk" in HS Antunes and others (eds), *Multidisciplinary Perspectives on Artificial Intelligence and the Law* (Cham, Springer 2024) p. 430.

[59] AI Act, Recitals (153), (154), Art. 70.

[60] This implies that autonomous vessels do not constitute a separate category of vessels, but rather that autonomy represents one of several operational modes a vessel may adopt.

[61] Czarnocki (*supra*, note 55) 151.

[62] Eggers and others (*supra*, note 38) 9.

restrictive (precautionary) the framing of innovation regulation, the greater the flexibility granted to regulatees. The precautionary principle, initially established as a fundamental principle of EU environmental law,[63] when applied to innovation, states that if a technological advancement may pose a risk to the public or the environment, then those proposing the technology should bear the responsibility of proving that it does not.[64]

As a counterbalance, the innovation principle has been introduced, ensuring that policy and regulation generally support innovation.[65] Moreover, if a science-based interpretation of the precautionary principle is followed, one that assesses and mitigates potential risks based on continuous evidence-gathering, the two principles can complement each other in a balanced, future-oriented regulatory approach.[66] In fact, EU regulations have increasingly supported innovation by reducing unnecessary restrictions, in many instances by applying the precautionary principle more loosely, thereby making the EU more market-oriented.[67]

The principle of technological neutrality can be considered as a mediator between the precautionary and the innovation principles; it ensures that regulations do not favour or discriminate against specific technologies.[68] In applying this principle, technological neutrality could also mean that provisions should leave open the type of technology that can be used to achieve a regulatory objective. Applying this principle would also support a more innovation-friendly and science-based view of the precautionary principle, which advocates for a restrictive application when scientific evidence is lacking.[69]

For the regulation of autonomous inland shipping, it is likely that all three principles will be influential; however, in contrast to the opinion that the innovation principle and the other principles should be given equal weight,[70] it is here suggested that the weightings may vary depending on the implementation phase. Whereas a GBR approach will ensure innovation-friendliness in the initial phase, the precautionary principle can justify RBR as an effective means of risk management by providing a legal basis for acting in the interests of safety despite the scientific data being incomplete, thereby preventing harm whilst further research is ongoing.[71] Nevertheless, any measure taken based on the precautionary principle should also be proportional to the risk level,[72] as discussed above.

When there are risks that are only partially understood, the precautionary principle grants regulators the authority to act pre-emptively to mitigate these uncertainties before they lead to significant harm. Specifically, autonomous systems rely on complex algorithms, sensors and decision-making processes. These components may interact in unpredictable ways, and the precautionary principle allows regulators to mandate robust safeguards, redundancy procedures, and human oversight to manage potential failures. A

[63] Consolidated version of the Treaty on the Functioning of the European Union (TFEU) [2012] OJ C 326, Art. 191(2).

[64] D Castro and M McLlaughlin, "Ten Ways the Precautionary Principle Undermines Progress in Artificial Intelligence" (2019) Information Technology & Innovation Foundation 2.

[65] SC Orzechowski "Regulatory Scoping Exercise for the Future Adoption of Autonomous Inland Vessels in Europe" (2024) 9 Journal of Shipping and Trade 2, 15–16.

[66] Ibid.

[67] Pelkmans and Renda, *Does EU Regulation Hinder or Stimulate Innovation?* (*supra*, note 15) 14, para. 3.1.

[68] Keller and others (*supra*, note 58) 429.

[69] Orzechowski (*supra*, note 64).

[70] European Economic and Social Committee, "Opinion on "Future proof Legislation"" C 487/51 OJ, para 2.18.

[71] YG Lee and others, "Transformative Impact of the EU AI Act on Maritime Autonomous Surface Ships" (2024) 13(5) Laws 61, 1, 12.

[72] European Commission DG Environment and Science Communication Unit, UWE "The Precautionary Principle: Decision making Under Uncertainty" Future Brief 18, 9, 13.

better-researched and tested technology is likely to reveal more risks or evidence, gradually allowing precautions to be reduced and leading to a long-term, technology-neutral regulatory framework.[73]

Furthermore, from a risk assessment perspective, these three principles provide the foundation for the evidentiary standard applicable to *ex ante* risk evaluations, which should be carried out on the basis of the scientific evidence available at the time of assessment.[74]

d. Legal certainty and harmonisation

The pacing issue associated with innovation and regulation also possesses an additional critical dimension: the more frequently regulation is adapted, the greater the risk of there being a conflict with the fundamental principle of legal certainty, which is itself a precondition for the industry to engage in entrepreneurial activities.[75] In the initial phase, in particular, a balance must be struck between, on the one side, excessive regulatory uncertainty that may cause inaction within industry, and, on the other, too frequent changes of regulatory requirements that may frustrate technological progress.[76] In addition, the principle of legitimate expectations safeguards individuals from arbitrary legislative actions, requiring legislators to act, as far as possible, in accordance with expectations they have legitimately created.[77] However, when risks are unforeseeable, the legal system may be unable to prevent or remedy harm, thereby ultimately undermining legal certainty.[78] For legislation to effectively mitigate risk and ensure legal certainty, its scope must be clearly defined through precise legal terminology (i.e., language that clearly defines the subject-matter(s) and delineates the circumstances and contexts in which the regulation applies) and detailed definitions, thereby ensuring effective applicability and compliance, without creating opportunities for circumvention due to ambiguity arising from legislative ambiguity.[79]

Nevertheless, a regulatory framework for innovation must be legally sound if it is to be sustainable, despite the need for flexibility and exemptions that foster innovation. This essentially means that, despite the requirements for adaptability and flexibility, the regulation of autonomous inland vessels will need to establish clear definitions, particularly concerning novel terminology such as "autonomous vessel" or "autonomous mode," as well as stipulating the required safety, operational and environmental standards to avoid ambiguity or inadequacy in law and compliance. Accordingly, whilst precision in regulation is essential from the outset, it should be pursued with a view to preserving the framework's adaptability and preventing legal rigidity. Moreover, the rule of law necessitates that regulators establish formal processes to assess, sanction and adapt policies to emerging issues, avoiding sudden or unexpected changes that could destabilise

[73] SC Orzechowski, W Verheyen and C Sys, "A Systematic Literature Review of Factors Influencing the Regulation of Autonomous Inland Shipping in Europe" (2024) 16 European Transport Research Review 54.

[74] AI Act, Arts. 9, 11.

[75] Ducuing (supra, note 55) 264; OECD, Regulatory Policy and Governance (supra, note 29) 102; Pelkmans and Renda, "How Can EU Legislation Enable and/or Disable Innovation?" (supra, note 15), 7, para. 1.4.4; G Sinha and R Dunbar, "Artificial Intelligence and its Regulation in the European Union" in DM Bielicki (ed), *Regulating Artificial Intelligence in Industry* (New York, Routledge 2022) p. 4.

[76] NA Ashford, C Ayers and RF Stone, "Using Regulation to Change the Market for Innovation" (1985) 9(2) *Harvard Environmental Law Reform* 419–66, 426.

[77] M Weisbrot, "Application of the Principle of Protection of Legitimate Expectations in Recovery of Unduly Paid Subsidies in the Context of Judicial Coherence in the European Union" (2015) 8(2) Review of European Administrative Law 347, 351.

[78] G Argüello and others, "Introduction to Regulation of Risk" in AB Bal and others (eds), *Regulation of Risk, Transport, Trade and Environment in Perspective* (Leiden/Boston, Brill/Nijhoff 2022) p. 3.

[79] Yordanova and Bertels (*supra*, note 42) 443.

the market and hinder innovation, even at later stages of implementation. This is crucial when moving between the various phases of implementation and revising existing provisions in the light of newly available knowledge.

Furthermore, the principle of legal certainty must be considered in parallel with considerations on harmonisation, especially within the context of Europe's inland waterways. Within such an international sector, harmonisation of regulations becomes crucial to ensure a stable and predictable regulatory environment, enabling autonomous inland vessels to operate seamlessly across different jurisdictions, within the EU and beyond. However, given the need for flexibility and exemptions to foster innovation as provided under the GBR approach, excessive or premature harmonisation from the outset of the development of a novel regulatory framework may also risk to lock in suboptimal risk thresholds, reduce the capacity of local authorities to respond to context-specific or case-specific hazards, and to suppress regulatory experimentation that is central to adaptive governance, as shown above. Accordingly, any harmonisation efforts should be considered as a continuous process, and it should be acknowledged that realisation thereof might in certain cases not even beneficial, as will be discussed in Section III.

Additionally, numerous EU Directives and Regulations are sector-specific, directly influencing innovation incentives and shaping technological development.[80] Some directives focus on broad policy goals whilst leaving technical specifics to European standardisation bodies.[81] The resulting standards, often linked to EU objectives in secondary legislation, give companies a presumption of conformity, thereby easing access to the internal market, which has been described as "a key driver of innovation."[82] The role such industry standards can play in achieving harmonisation will be discussed in more detail in Section III. EU regulation that is not sector-specific, and thus of horizontal application, will nevertheless play a significant role in shaping the regulatory framework for autonomous inland shipping.

3. *Implications of EU horizontal digital regulation*

Although sector-specific regulation will primarily govern autonomous inland shipping, EU regulations that are not sector-specific, like the AI Act,[83] the General Data Protection Regulation (GDPR),[84] the Data Act[85] and the Data Governance Act (DGA),[86] will also inevitably influence and shape the data-related aspects of autonomous inland shipping.

a. The AI Act: Risk-based regulation of AI systems for navigation and control

The AI Act covers all AI systems used in or placed on the EU market.[87] For autonomous inland vessels,[88] AI systems used for functions like route planning, collision avoidance, perception, environment recognition and adaptive decision-making are likely to be

[80] Pelkmans and Renda, *Does EU Regulation Hinder or Stimulate Innovation?* (*supra*, note 15), 15, para. 3.2.

[81] Ibid.

[82] Ibid.

[83] Reg. (EU) 2024/1689.

[84] Reg. (EU) 2016/679 of the European Parliament and of the Council of 27 April 2016 on the protection of natural persons with regard to the processing of personal data and on the free movement of such data, and repealing Directive 95/46/EC (General Data Protection Regulation) [2016] OJ L 119/1.

[85] Reg. (EU) 2023/2854 of the European Parliament and of the Council of 13 December 2023 on harmonised rules on fair access to and use of data and amending Reg. (EU) 2017/2394 and Directive (EU) 2020/1828 (Data Act) PE/49/2023/REV/1 [2023] OJ L 2023/2854.

[86] Reg. (EU) 2022/868 of the European Parliament and of the Council of 30 May 2022 on European data governance and amending Reg. (EU) 2018/1724 (Data Governance Act) PE/85/2021/REV/1 [2022] OJ L 152/1.

[87] AI Act, Arts. 2(1), 3(1).

[88] With the exception of those used in regulatory sandboxes (Art. 2(6)).

high-risk AI systems, as defined in Article 3(1), if they meet one or both of the following characteristics:

First, if the operation of autonomous inland vessels does not seem to fall under "prohibited practices,"[89] it is likely to be classified as "high risk" under Article 6 because these vessels include AI for safety functionalities,[90] which probably require third-party conformity assessments.[91] Second, under Article 6(2) and Annex III, inland waterway vessels will operate in or interact with critical (digital) infrastructure as defined in Article 3(62).

The AI Act imposes stringent requirements on system providers and operators of high-risk systems, including in relation to risk management, transparency, robustness, human oversight, and conformity assessments; all of these aspects will also be subject to regulatory intervention in autonomous inland shipping. Additionally, the AI Act's scope covers the entire lifecycle of the AI system (Articles 9 and 15) and applies regardless of whether the system is embedded in a physical product, such as a ship, or delivered as a cloud-based service (Recital 12). As such, the AI Act provides, in essence, the foundational regulatory provisions for ensuring that autonomous vessels, as high-risk AI-driven systems, will operate in a safe, trustworthy and accountable manner.

b. GDPR: Regulation of personal data in inland waterway AI systems

The GDPR will apply to autonomous inland vessels when personal data is processed during the operation or its oversight. According to the GDPR, "personal data" is any data about an identified natural person or a person who could be identified based on various factors (Recital 26, Article 4(1)). Although autonomous vessels will be primarily operated by machines, they are likely to process personal data, even if this, given their uncrewed nature, is done indirectly. In this respect, it is foreseeable that there will be various types of personal data involved in autonomous inland shipping operations, in particular with regard to the exchange of operational or safety-related information.

Notably, the GDPR applies regardless of whether the data processing, as defined in Article 4(2), is carried out by a public or a private entity (Article 2(1)), which will have a considerable impact on the exchange of operational data between the public and the private sector. The core GDPR principles, as enshrined in Article 5(1), however, require that any personal data must be processed lawfully, transparently and only for clearly defined purposes related to safety, operational or regulatory compliance. Hence, only such data as is necessary can be collected, and the data must be accurate, kept up to date and stored securely for no longer than needed. Operators and system providers must also implement appropriate safeguards and demonstrate full accountability for their data processing practices across all stages of the vessel's operation.

Additionally, under Chapter IV, the "controller" and the "processor" of personal data – who can be natural persons, legal entities, public authorities or agencies – play key roles in complying with the GDPR. The controller holds primary responsibility, often through data processing agreements with processors such as AI providers or cloud service providers. Depending on the context, the controller and the processor could be vessel operators, shipping companies, AI system providers, port authorities, or waterway managers, depending on how the data is collected and processed. Accordingly, the GDPR establishes regulatory provisions related to personal data in the autonomous inland shipping context,

[89] Art. 5.

[90] As defined in Art. 3(14).

[91] In view of Reg. (EU) 2019/1020 of the European Parliament and of the Council of 20 June 2019 on market surveillance and compliance of products and amending Directive 2004/42/EC and Reg. (EC) No 765/2008 and (EU) No 305/2011 [2019] OJ L 169/1.

thereby determining the substantive obligations of private and public stakeholders to comply with EU data protection standards.

c. The Data Act and the DGA: Access to and reuse of data generated by a vessel

The Data Act and the DGA will play a role in shaping the regulation of autonomous inland shipping, as they include provisions covering accessing, sharing and reusing data, which is critical to ensuring safety, interoperability and accountability.

The Data Act regulates the fair access to and use of data from connected products and services, particularly in the industrial and mobility sectors; this includes autonomous inland vessels that will generate and rely on large volumes of data. Given Article 1, the Data Act is likely to apply to autonomous inland shipping operations because these systems qualify as "connected products" within the meaning of Article 2(5). Autonomous inland vessels are connected products because they generate real-time data, such as navigation, diagnostic and environmental inputs, using embedded software and sensors. Therefore, Article 1(1)(a) applies as data is produced during the use of the vessel and the related services, such as AI route planning or remote control. The Data Act covers access to data generated by these connected products and related services, setting out conditions for how the data is to be shared between businesses (B2B) and between businesses and government entities (B2G). From a public regulatory perspective, the Data Act is significant for two reasons.

First, it guarantees access to vessel-generated data for oversight and compliance purposes. It also offers legal certainty and clarifies roles within a multi-stakeholder environment.

More specifically, under the Data Act, public bodies can access data from connected products, such as inland vessels and AI systems, for public interest tasks (Articles 14–22). The data here will include data related to navigation, obstacle detection, system overrides and environmental aspects. This enables regulators to have oversight, to verify compliance and to respond to emergencies in real time. The Data Act will also prevent manufacturers from having data monopolies, allowing the authorities to verify system behaviour independently, supporting fairness and digital sovereignty in transport innovation.[92]

Furthermore, given that different stakeholders from the private and public sectors will be involved in autonomous inland shipping operations, the Data Act clarifies the roles of data holders and users, protecting access under transparent conditions (Articles 3–5, 8–12). This will, in particular, become important for cross-border inland waterway coordination, and necessitate transparent and interoperable data-sharing regulations. The Data Act will also protect trade secrets and personal data during access and sharing, aligning with the GDPR and promoting the fair use of AI and operational data amongst stakeholders.

In turn, the DGA establishes a regulatory framework for data sharing, covering the reuse of protected public-sector data, the governance of data intermediation services, and data altruism (Article 1). Pursuant to Article 2(1), data generated in the context of autonomous inland shipping operations will fall within the scope of the DGA. Consequently, the DGA will shape data sharing related to autonomous inland shipping, although more indirectly than the AI or Data Acts. Its application and impact will ultimately depend on whether and how public-sector data, sensitive industrial data, or data altruism schemes are involved in the broader governance ecosystem of inland waterways.

By establishing procedures for reusing protected public-sector data (Articles 3(1)(a)–(d)), such as infrastructure data or traffic forecasts that cannot easily be shared for personal data or confidentiality reasons, the DGA complements the Data Act by

[92] B Otto and others, *Industrial Data Space: Digital Sovereignty Over Data* (Fraunhofer 2016) p 13.

allowing the controlled reuse of such data for the public interest or commercial innovation through a regulated process (Articles 5–7). This will enable regulators to facilitate the access to and sharing of pertinent data with technology developers, researchers and public agencies (Articles 16–25). Based on these provisions, public inland waterway authorities could be given a legitimate way of sharing anonymised operational data to enhance the safety and regulatory oversight of autonomous shipping operations, without undermining aspects related to personal data or business confidentiality.

A further contribution of the DGA lies in its support for the establishment of trusted data intermediation services and sector-specific data spaces, offering neutral frameworks in which regulators can securely share and access data across institutions and Member States (Articles 10–15). For inland navigation, such coordination will be vital for regulatory consistency and interoperability along the European transnational corridors. Hence, the DGA extends regulators' data-driven oversight of autonomous operations across national borders whilst safeguarding confidentiality, intellectual property and personal data. Consequently, the Data Act, as much as the DGA, highlights the importance of voluntary data sharing for the public good. Both regulations formalise data altruism mechanisms, allowing authorities to support or oversee the pooling of anonymised or non-sensitive data by vessel operators, system providers and research institutions (Article 49(1)(a) Data Act and Articles 16–25 DGA).

d. Integrating EU horizontal digital regulation within the regulatory framework for autonomous inland shipping

The implications of EU horizontal digital regulation for establishing a regulatory framework for autonomous inland shipping are evident. Within this multilayered framework, two approaches towards possible interaction between these two spheres are possible. One possibility is that the regulatory framework for autonomous inland vessels explicitly references horizontal EU digital legislation, without directly addressing the data and AI-related aspects covered by the EU horizontal digital regulations discussed above. Whilst this would make the regulatory task for inland shipping regulators regarding data and AI-level issues less burdensome, as they would not need to establish specific rules compliant with existing EU horizontal data regulations, it could render the regulatory framework governing autonomous shipping less comprehensive and thus less predictable, thereby potentially increasing compliance costs for regulatees. Another way of integrating EU horizontal digital regulation into autonomous inland shipping regulation would be to incorporate the relevant provisions of the former directly into the regulatory framework for autonomous inland shipping, thereby establishing a more comprehensive, sector-specific regulatory framework.

Since EU legislation remains solely applicable within the EU, but Europe's inland waterways extend beyond EU borders, the issue of integrating horizontal regulation within vertical regulation is closely connected to questions of regulatory competence and the level of harmonisation that can be achieved within the European inland waterway transport sector. Therefore, it must be considered within a broader discussion.

III. Regulation of autonomous inland shipping in a multilevel governance system

The EU's competence within its Common Transport Policy, covering all modes of transport including inland waterway vessels (Article 90 TFEU), provides a strong legal basis for EU involvement in inland waterway rulemaking. However, this competence is shared with Member States and subject to specific limitations, especially in areas traditionally

governed by national authorities or, in the case of transnational rivers, by river commissions. Moreover, the division or sharing of these competences has direct implications for the degree of harmonisation of inland waterway regulations, which thus ultimately depends on the regulatory area.

1. Regulatory competences in Europe's inland waterways: a barrier to a harmonised regulatory framework

a. Shared competences and recent harmonisation efforts

In terms of competence to adopt binding regulations, the two most influential regulators in Europe's inland waterways, notably the EU and the Central Commission for the Navigation of the Rhine (CCNR), have very similar rule-making powers.[93] Under Article 91(1) TFEU, the EU can adopt rules on international transport, access for foreign carriers, transport safety and related matters.[94] However, under Article 4(2)(g) TFEU, transport is explicitly listed as a shared competence between the EU and its Member States. Accordingly, and in line with the principle of subsidiarity as enshrined in Article 5(3) TEU and its Protocol (No 2), Member States may legislate and adopt binding acts in the fields listed in Article 91(1) TFEU as long as the EU has not exercised its competence or where EU rules permit national measures. Similarly, the CCNR, under the 1868 Act of Mannheim, is authorised to regulate Rhine navigation, including safety standards, vessel and crew requirements, police regulations and broader measures to promote the prosperity of the Rhine navigation.[95] Moreover, the competence of the CCNR to establish rules that restrict the freedom of navigation is considered exclusive: the national authorities of the riparian states have no power to adopt national safety regulations that impose restrictions on the freedom of navigation.[96]

Based on these provisions, the EU and the CCNR, through the Member States, share responsibility for regulations on technical requirements and navigation personnel. Consequently, there used to be a significant overlap in their authority in these areas, as well as differences in their requirements.[97] The problem has been partially addressed today through the creation of an additional institution. There is now convergence between CCNR and EU standards via the European Committee for Drawing up Standards in the Field of Inland Navigation (CESNI), acting as an intermediary body, which has achieved significant harmonisation regarding these regulatory matters. More specifically, on the technical requirements, references to the CESNI standard ES-TRIN[98] are now integrated into the legal frameworks of the EU and the CCNR.[99] Similarly, regarding the qualifications of inland navigation personnel, the CESNI standard ES-QIN[100] has been developed as a common benchmark for both the EU and the CCNR regulations in this area. Consequently, a system of mutual recognition has been established, whereby professional qualifications

[93] C Tournaye, "What Prospects for the 200-year-old Rhine Legal Regime in the European Context?" (2015) 21 Journal of International Maritime Law 382, 385, note 22.

[94] Strategies to Promote Inland Navigation (SPIN) "The Integration of European Waterways" (2004) Working Paper, 28.

[95] Revised Rhine Navigation Act of 17 October 1868 (Act of Mannheim) Arts. 1, 23, 32, 45(b).

[96] SPIN (*supra*, note 92) 16.

[97] Ibid, 54–7.

[98] European Committee for Drawing up Standards in the Field of Inland Navigation (CESNI), "European Standard Laying Down Technical Requirements for Inland Navigation Vessels (ES-TRIN)".

[99] Directive (EU) 2016/1629 of the European Parliament and of the Council of 14 September 2016 laying down technical requirements for inland waterway vessels, amending Directive 2009/100/EC and repealing Directive 2006/87/EC [2016] OJ L 252/118; CCNR, "Rhine Vessel Inspection Regulations (RVIR)" (2024).

[100] CESNI, "European Standard for Qualifications in Inland Navigation (ES-QIN)" (2019).

issued under EU Directive (EU) 2017/2397[101] and those issued under the CCNR Regulations for Rhine navigation personnel[102] are now considered equivalent. As a result, a high level of harmonisation in areas related to technical requirements and navigation personnel has been achieved across the EU and CCNR Member States, covering the Rhine region and its tributaries and confluences.

Beyond EU borders, the Danube Commission, as the other most influential river commission, recommends CESNI standards in its international instruments. Notably, implementing these is mandatory for its riparian states that are also EU Member States, but not for those that are not.[103] However, it is important to note that all Danube Commission members are currently either EU Member States or candidate countries for EU membership. The latter countries therefore have a strong interest in adopting CESNI standards, which can influence the process of achieving harmonisation across the pan-European inland waterway network.

b. Exclusive competences: An obstacle to a harmonised framework for autonomous inland shipping

In contrast to the types of regulation mentioned above, there is little harmonisation concerning operational (police) navigation frameworks. This is mainly due to the EU's limited competence in this area.

As shown above, the EU's shared transport competence under Article 91(1) TFEU enables it to regulate aspects of international transport and safety, but it does not extend to internal law enforcement or operational navigation rules (police regulations); harmonisation thereof remains a matter of bilateral or multilateral agreements between states.[104] Moreover, police regulations encompass local rules of navigation, emergency procedures and public safety issues closely connected to territorial authority, as outlined in Article 4(2) TEU. Hence, operational regulations vary across EU Member States, and the EU, in accordance with Article 4(2) TEU, can only support interoperability and cross-border cooperation in this respect.[105]

The only national inland waterways that are actually subject to a common regime in the area of operational (police) regulations are those governed by river commissions. In addition to the exclusive competences mentioned above, the CCNR is further authorised to adopt binding police regulations.[106] Similarly, the Danube Commission has also adopted a standard regime for its riparian states, albeit not a binding one. Therefore, adopting operational (police) regulations remains a national competence, and, apart from the river regimes, no harmonisation has been achieved.

In the light of this fragmented regulatory landscape, the inadequate harmonisation in police navigation regulations across the EU and beyond, as well as the lack of harmonised frameworks for technical and navigation personnel requirements in the Danube region, present an essential obstacle to a pan-European implementation of autonomous inland vessels. Notwithstanding these considerations, full harmonisation of regulations in these specific areas of exclusive national competence may not be necessary for a functional cross-border deployment of autonomous inland vessels. What will be required instead is a sufficient level of interoperability amongst nationally and regionally adopted rules, especially concerning police regulations within the EU and beyond, as well as technical

[101] Directive (EU) 2017/2397 of the European Parliament and of the Council of 12 December 2017 on the recognition of professional qualifications in inland navigation and repealing Council Directives 91/672/EEC and 96/50/EC [2017] OJ L 345/53.

[102] CCNR, "Regulations for Rhine Navigation Personnel (RPN)" (2025).

[103] Implicitly referred to in the Belgrade Convention, Art. 8(f).

[104] M Kucler-Dolinar, "Multilevel Governance within the European Union" (2010) 9 European View 97, 98.

[105] TFEU, Art. 71.

[106] Act of Mannheim 1868, Art. 32.

compatibility between EU and non-EU states. Such interoperability could achieve a level of alignment adequate to support seamless and legally foreseeable cross-border operations, effectively placing these types of regulations at the lower end of the harmonisation spectrum. How the degree of operational interoperability amongst different regulatory regimes across European inland waterways can be realised is discussed in the following subsections.

2. *Possibilities for achieving a harmonised regulatory framework for autonomous inland shipping*

To explore methods for achieving the harmonisation of regulations, it is useful first to comprehend the concept of legal harmonisation in order to discern its various facets and identify effective strategies for European inland waterway transport. The concept of "harmonisation" refers to the process of making legal rules, standards and requirements homogeneous, or bringing them into closer alignment across various jurisdictions, to reduce legal disparities and promote consistency in cross-border cooperation.[107] Furthermore, within legal and regulatory contexts, harmonisation lies on a spectrum, so the extent to which legal rules, standards or regulatory frameworks are aligned may vary.[108] Along this spectrum, complete harmonisation means that regulatory provisions are entirely uniform across jurisdictions, and no harmonisation refers to rules being entirely independent in different jurisdictions.

Applying the concept of harmonisation to Europe's inland waterways reveals that some areas, like technical vessel standards and crew qualifications, have moved towards greater harmonisation, whereas other areas, like police regulations, remain fragmented outside common river regimes because of national competencies. Furthermore, rejecting the idea that harmonisation must be either complete or absent enables not only the assessment, on a spectrum, of how much regulatory alignment has taken place but also facilitates an exploration of the level of harmonisation required for autonomous inland vessels across the pan-European inland waterway network, and how this might be accomplished within a complex, multilayered system.

The underlying rationale is that complete harmonisation of regulations might not be necessary, and is anyway not feasible, at least for the time being, because of the allocation of competences explained above. As long as there is some level of alignment between national and regional regulations, ensuring that they are compatible with each other, this will allow the operation of autonomous inland vessels in a harmonised manner at a pan-European scale.

In the light of the above, it is therefore preferable to refer to a moderate level of harmonisation, or, to use another word, coherence. Coherence, in a given context, can be divided into two categories: "regulatory coherence," which refers to the process of establishing regulations that are consistent with each other, and "judicial coherence," which describes the mechanisms of coherence through the authoritative power of the courts.

a. Harmonisation through regulatory coherence

In contexts like that of Europe's inland waterways in which complete harmonisation is unattainable because of diverging competencies in regulation-making, regulatory coherence can ensure that regulations do not conflict with or undermine one another.

[107] P Craig and G De Búrca, EU *Law: Text, Cases, and Materials* (5th ed, Oxford, Oxford University Press 2011) pp. 92–3.

[108] OECD, International Regulatory Co-operation: Addressing Global Challenges (OECD Publishing 2013) p. 16.

Instead, they become complementary and interoperable.[109] Moreover, regulatory coherence can serve as a means by which national or regional regulators can preserve their sovereignty and local accountability, which is crucial for their participation in regulatory coherence.[110] Thus, the primary objective of regulatory coherence is to eliminate redundancies and discrepancies amongst regulations, before they are adopted, by enhancing integration amongst regulators, based on mechanisms that unify the different regulatory authorities involved.[111]

From a conceptual perspective, regulatory coherence can refer to "substantive regulatory harmonisation,"[112] on the one hand, and "a harmonisation process by which regulations are developed and adopted,"[113] on the other. Arguably, if the process of regulatory coherence is fruitful, the result will be a system of regulations that are consistent with one another, and thus coherent. Regarding the latter concept, regulatory coherence can be achieved by "the use of good regulatory practices in the process of planning, designing, issuing, implementing, and reviewing regulatory measures in order to facilitate achievement of domestic policy objectives, and in efforts across governments to enhance regulatory cooperation in order to further those objectives."[114] Possible actions to achieve coherence can range from "uncoordinated regulatory activities with some information sharing or transparency mechanisms to fully uniform regulatory homogeneity, fully harmonised regulations."[115] In this regard, regulatory coherence can be achieved through mutual recognition, deliberation or coordination mechanisms.[116] In other words, regulatory harmonisation encompasses various mechanisms aimed at minimising "substantive differences or divergences."[117] What might these mechanisms look like in the context of Europe's inland waterways?

From a governance perspective, the sector essentially presents a "shared, multilevel, multi-actor governance" system, in which regulation often occurs across disconnected levels of authority, leading to overlap, fragmentation, and, ultimately, regulatory uncertainty that undermines legal clarity.[118] Applying the concept of regulatory coherence within a multilevel governance system is particularly challenging. To explore potential modes of interaction amongst the various regulators, the abstract idea of "multilevel regulation" can help to identify new approaches to achieve regulatory coherence.

Within a multilevel governance system, multilevel regulation enables a shift from a single regulator (typically the state) as the sole actor to a more complex and dynamic regulatory space involving both public and private actors, even in the absence of a formal legal mandate, across different levels of governance.[119] Within this concept, the way in

[109] Ibid.

[110] TJ Bollyky, "Regulatory Coherence in the TPP Talks" in CL Lim, DK Elms and P Low (eds), *The Trans-Pacific Partnership: A Quest for a Twenty-First Century Trade Agreement* (Cambridge, Cambridge University Press 2012) p. 180.

[111] R Polanco, "The Trans-Pacific Partnership Agreement and Regulatory Coherence" in T Voon (ed), *Trade Liberalisation and International Co-operation, A Legal Analysis of the Trans-Pacific Partnership Agreement* (Cheltenham/Northampton, Edward Elgar Publishing 2013) pp. 232–3.

[112] Ibid, 231.

[113] Ibid.

[114] PXF Cai, "Horizontal Regulatory Coherence Aspects of the TPP" in JA Huerta-Goldman and DA Gantz (eds), *The Comprehensive and Progressive Trans-Pacific Partnership: Analysis and Commentary* (Cambridge, Cambridge University Press 2021) p. 651, citing the Trans-Pacific Partnership, Art. 25.2.

[115] Ibid, 651.

[116] OECD, International Regulatory Co-operation (*supra*, note 106) 54.

[117] Cai (*supra*, note 112) 653.

[118] N Chowdhury and RA Wessel, "Conceptualising Multilevel Regulation in the EU: A Legal Translation of Multilevel Governance?" (2012) 18(3) European Law Journal 18(3), 335, 339; M Maggetti and Christian Ewert, "Comparative Regulatory Regimes and Public Policy", in Edoardo Ongaro and Sandra van Thiel (eds), *The Palgrave Handbook of Public Administration and Management in Europe* (London, Palgrave Macmillan 2018) p. 637.

[119] Chowdhury and Wessel (*supra*, note 116) 339.

which responsibilities are divided in the regulatory system highlights how different functions are separated, rather than focusing solely on the authority to promulgate binding measures.[120] Subsequently, regulations are not just vertically segregated according to hierarchical frameworks; they may also be interconnected horizontally through institutions, and in this way the multilevel governance system may exhibit traits of both vertical and hierarchical structures.[121] Accordingly, functional differentiation in rule-making does not necessarily reflect normative powers,[122] and soft laws, like standards, become increasingly recognised within the regulatory system.[123] Within Europe's inland waterways, the CESNI standards, which are non-binding regulatory standards, only acquire normative power by being referenced in mandatory EU and CCNR instruments, thereby presenting an effective means of achieving coherence between horizontal governance levels.

These more flexible, inclusive, and inventive forms of regulation within multilevel governance are known as "new governance mechanisms."[124] More specifically, these mechanisms can foster multilevel integration by recognising the need for coordination across different vertical and horizontal governance levels through establishing institutional structures that facilitate dialogue and cooperation.[125] Considering how different actors interact at various levels, the possible regulatory outcome can be seen as a kind of "negotiated outcome."[126] In this regard, establishing a regulatory coherence committee to evaluate undefined cooperative activities could prove beneficial in ensuring the success of coherence oversight.[127] Applying this to Europe's inland waterways, CESNI may be considered to be such a platform on which stakeholders from diverse governance levels, including the European Union, the CCNR, and their respective member states, collaboratively develop and update standards. In alignment with the principle of multilevel governance and to ensure regulatory coherence of technical and crew-related requirements across Europe's entire inland waterway network, it would be advantageous to strengthen the cooperation between the EU and non-EU entities through CESNI.

First, non-EU countries could participate in CESNI's activities as observers through their affiliation with the Danube Commission.[128] In this way, non-EU experts could contribute to CESNI's working groups on professional qualifications or technical requirements. This would foster inclusiveness, capacity building and mutual understanding. CESNI could further serve as a platform for dialogue and for EU and non-EU cooperation on new regulatory requirements, such as for autonomous vessels.[129]

Second, non-EU countries could voluntarily incorporate CESNI standards into their national regulations, thereby aligning their regulatory frameworks with those of the EU and the CCNR.[130] These standards could then be used as a benchmark or model regulation

[120] Ibid, 348.
[121] Ibid, 342.
[122] Ibid, 342.
[123] Ibid, 340.
[124] J Scott and DM Trubek, "Mind the Gap: Law and New Approaches to Governance in the European Union" (2002) 8(1) European Law Journal 1, 5–6; this is also referred to as "reflexive governance" by KM Weber and H Rohracher, "Legitimizing Research, Technology and Innovation Policies for Transformative Change: Combining Insights from Innovation Systems and Multi-level Perspective in a Comprehensive "Failures" Framework" (2012) 41 Research Policy 1037, 1040–1, 1044.
[125] Scott and Trubek (*supra*, note 122) 5.
[126] Chowdhury and Wessel (*supra*, note 116) 337.
[127] Bollyky (*supra*, note 108) 182.
[128] OECD, International Regulatory Co-operation (*supra*, note 106) 61; OECD, Regulatory Policy and Governance (*supra*, note 29) 28.
[129] OECD, International Regulatory Co-operation (*supra*, note 106) 16.
[130] Ibid, 25; Chowdhury and Wessel (*supra*, note 116) 340, 347.

for national authorities, and, in this way, promote regulatory coherence without imposing supranational obligations.[131]

Third, and building upon the preceding points, EU and non-EU states could conclude mutual recognition agreements (MRAs) for certificates and qualifications based on CESNI standards.[132] In this way, mutual recognition would serve as a tool for functional harmonisation by ensuring alignment in practice. River commissions could act as essential intermediaries in recognising qualifications based on CESNI standards across jurisdictions, thereby enabling interoperability and cross-border workforce mobility.

Fourth, non-EU training institutes could be encouraged (or certified) to provide CESNI-compliant training, enabling graduates to access EU-recognised certification. This could motivate non-EU states to voluntarily adopt CESNI standards into their national regulations, thereby improving the quality and comparability of training and professional standards.

Regarding technical and crew-related regulations, these four regulatory coherence mechanisms, individually or in combination, offer the potential for a level of horizontal regulatory coherence to be established that is sufficient to enable the operation of autonomous vessels across Europe. However, the more complex challenge appears to be that of harmonising police regulations.

In this regard, it must be noted that many United Nations Economic Commission for Europe (UNECE) members that are not EU members currently base their national rules on the European Code for Inland Waterways (CEVNI)[133] or adopt it directly; the Danube Commission incorporates CEVNI provisions into its operational recommendations. This means that CEVNI, as a regulatory non-binding framework for police regulations, supports at least a basic level of regulatory consistency across the Danube region. Notwithstanding this harmonisation, the following avenues should be examined to attain regulatory coherence in police regulation across the European inland waterway network:

First, CEVNI recommendations could find broader (voluntary) adoption if states and river commissions formally adopted or updated their police regulations for navigation in line with the latest version of CEVNI. Notably, a model law could serve as a valuable resource for national legislators seeking to reform their domestic transport laws, to address legislative gaps, or to regulate areas not covered by existing uniform regulatory frameworks.[134] In this regard, UNECE would play a more prominent role in establishing operational requirements for vessels, including those used for autonomous operations. National authorities could thus integrate CEVNI provisions directly into their regulatory frameworks, thereby aligning national provisions.

Second, although CESNI does not currently legislate on police regulations, it could facilitate coordination by hosting national working groups to compare existing police regulations, identify key divergences and develop recommendations or guidelines for greater alignment.[135] Playing a similar role to that of UNECE in this regulatory area, this would eventually mean that CESNI had an expanded mandate. Police regulation would be left as a competence of states, by supporting bottom-up harmonisation whilst respecting national competences.

[131] The author does not support the view that distinguishes "regulatory coherence" from "regulatory standardisation", as put forward by Cai (*supra*, note 112) 653, but includes the latter within the former.

[132] OECD, International Regulatory Co-operation (*supra*, note 106) 33–4; OECD, Regulatory Policy and Governance (*supra*, note 29) 146; Cai (*supra*, note 112) 653.

[133] United Nations Economic Committee for Europe (UNECE), *European Code for Inland Waterways* (CEVNI) (6th edn, UNECE 2021).

[134] F Smeele, "Harmonising the Fragmented Law of Transport through Soft Law?" (2015) 7 European Journal of Commercial Contract Law 62, 66 para. 25.

[135] C Charbit, "Governance of Public Policies in Decentralised Contexts: The Multi-level Approach" (2011) OECD Regional Development Working Paper 2011/04, 15.

Third, it would be possible to enhance cooperation between river commissions. Based on this intergovernmental cooperation, the CCNR and the Danube Commission could work together to promote the interoperability of police regulations, develop joint interpretations of CEVNI rules, and issue harmonised guidance documents, in particular with regard to autonomous operations. This would eventually create cross-river coherence without requiring supranational regulation.

Another option would be to foster mutual recognition and equivalence mechanisms, with countries adopting MRAs in respect of each other's police regulations, based on mutual core principles. These principles could, for example, be based on CEVNI.

Fifth, it would be possible to integrate CEVNI provisions into training and examination. In this way, harmonisation could be supported by requiring knowledge of CEVNI, thereby making CEVNI a de facto standard, even if not formally binding.

Lastly, whereas police regulations fall under national competence, the EU could, on the basis of Article 71 TFEU, nevertheless promote soft law tools, such as by including CEVNI in guidance documents or best practices.

Admittedly, achieving harmonised police regulations across Europe's inland waterway transport presents a far greater challenge than aligning technical standards or crew qualification requirements, given the diversity of national legal traditions and enforcement practices. Nevertheless, it is worth exploring these pathways as they could, over time, promote greater regulatory coherence. Moreover, this could also establish a level of regulatory interoperability necessary to accommodate operational realities, especially in contexts where full harmonisation is difficult to achieve, thereby enabling the functional cross-border deployment of autonomous inland vessels across the pan-European inland waterway network.

b. Harmonisation through judicial coherence

In addition to regulatory coherence, which concerns the alignment of legal rules and standards across jurisdictions, judicial coherence emerges as a distinct but complementary concept. It refers to the consistent interpretation and application of rules by courts and adjudicatory bodies across the same, or even different, governance levels.[136] In Europe's inland waterways, the judicial and quasi-judicial system essentially consists of a multilevel structure.

At the supranational level, the Court of Justice of the European Union (CJEU) ensures the uniform interpretation and enforcement of EU legislation.[137] The national courts of the EU Member States play a complementary role by applying EU law domestically and referring interpretative questions to the CJEU.[138] Additionally, the CCNR operates as a quasi-judicial appellate body, competent to hear appeals in administrative matters arising from Rhine navigation enforcement decisions, thereby ensuring a uniform interpretation of CCNR regulations.[139] In parallel, the courts in non-EU Danube Commission Member States exercise judicial authority, although without recourse to the CJEU.

Consequently, as regards technical and crew-related regulations, EU national courts, as well as the CCNR, are competent to hear cases that essentially involve requirements under CESNI standards, as incorporated into national laws or CCNR instruments. In addition, non-EU national courts of Danubian states that have incorporated CESNI standards into their

[136] F Baldan and E van Zimmeren, "The Future Role of the Unified Patent Court in Safeguarding Coherence in the European Patent System" (2015) 52 Common Market Law Review 377, 400, 404.

[137] In the light of TFEU, Art. 91(1) and by virtue of TFEU, Arts. 258–60, 263.

[138] In accordance with TFEU, Art. 267.

[139] Act of Mannheim 1868, Art. 37; M Fischer, "Prozessuale Besonderheiten Schifffahrtsrechtlicher Verfahren in Deutschland" in *Festschrift Resi Hacksteiner, A Voyage Through the Law of Inland Navigation* (The Hague, Eleven International Publishing 2020) p. 89.

respective national regulations also interpret CESNI standards. As for police regulations, national courts, within the EU and beyond, are solely responsible for ruling on and interpreting their police regulations, with the possibility of appealing to the CCNR's Chamber of Appeals in the case of disputes involving Rhine regulations, as an alternative to the domestic courts.[140] The question, therefore, concerns the extent to which mechanisms of judicial coherence could contribute to a dialogue between these judicial and quasi-judicial bodies to enhance judicial coherence in the light of future regulations on autonomous inland shipping.

In the absence of a uniform definition,[141] the concept of "judicial coherence" refers to the extent to which substantive and procedural laws are interpreted and applied consistently across different legal systems or levels of governance.[142] Furthermore, the concept of judicial coherence may encompass distinctions between horizontal and vertical coherence, as well as local and global coherence.[143]

The concept of horizontal coherence can be applied to Europe's inland waterways when considering decisions made by actors situated at the same governance level, namely national courts.[144] National courts applying CESNI standards, whether in EU or non-EU states, can significantly enhance consistency regarding these standards by mutually influencing each other's interpretations, which has been described as "transnational borrowing."[145] In this regard, a form of horizontal coherence could be "transnational judicial dialogue," referring to exchanges and interactions between judges operating within different legal systems, including both judicial and quasi-judicial actors.[146] Presumably, horizontal judicial coherence will improve significantly as more non-EU member states adopt CESNI standards into their frameworks. The same applies to police regulations, provided that national regulations follow a new police regulation for autonomous inland vessels, issued by either CESNI or UNECE.

Apart from national judges influencing each other in their decision-making, it is also possible that national courts may follow CCNR rulings, provided their national frameworks are not significantly different from the Rhine regulations. This would represent a form of judicial vertical coherence, albeit voluntarily in the case of states that are not members of CCNR. True vertical judicial coherence would mean that, within Europe's inland waterways, the jurisprudence of each EU Member State's national courts would be bound by preliminary rulings of the CJEU. However, outside EU jurisdiction, this has limited significance.

In this regard, the possibility of a unified European inland waterway court, like the one set up in the context of patent law, is worth exploring.[147] Like patent regulation, inland waterway transport regulation is highly technical, cross-border in nature and requires uniform interpretation to function efficiently across multiple jurisdictions. In the same way as the Unified Patent Court, a unified inland waterway court would have exclusive jurisdiction over disputes relating to the interpretation and application of CESNI standards and EU Directives and Regulations relevant to inland waterway transport, as well as, potentially, international agreements, including CEVNI. Participation could be based on an

[140] Act of Mannheim 1868, Art. 37; T Waldstein and H Holland, *Binnenschifffahrtsrecht*, *Kommentar* (5th edn, Berlin, De Gruyter 2007).

[141] Baldan and van Zimmeren (*supra*, note 134) 381.

[142] Weisbrot (*supra*, note 75) 348.

[143] Baldan and van Zimmeren (*supra*, note 134) 381–3.

[144] Ibid, 382.

[145] E Mak, N Graaf and E Jackson, "The Framework for Judicial Cooperation in the European Union: Unpacking the Ethical, Legal and Institutional Dimensions of "Judicial Culture" (2018) 34(1) Utrecht Journal of International and European Law 34(1) 24, 25–6.

[146] Baldan and van Zimmeren (*supra*, note 134) 386.

[147] Ibid.

intergovernmental treaty open to both EU and non-EU states, and decisions could be subject to review by a higher chamber or, in EU-related matters, through a preliminary reference procedure to the CJEU, to preserve constitutional coherence. It is undeniable that establishing a uniform inland waterway court would significantly enhance judicial coherence by providing a single, authoritative body to interpret and apply inland navigation law uniformly across jurisdictions. Its creation, however, currently faces several notable challenges. Ensuring institutional legitimacy would require a fair and inclusive process for appointing judges from both EU and non-EU countries. The court's design would also need to address jurisdictional compatibility by clearly defining its relationship with existing national courts and quasi-judicial bodies, particularly the CCNR appellate body.

Besides horizontal and vertical judicial coherence, global coherence, within the European inland waterway context, would require courts to consider overarching values and fundamental principles drawn from various areas of law.[148] In this regard, overarching legal principles such as legal certainty, proportionality and mutual recognition could provide a crucial foundation for fostering judicial coherence, especially in the context of an evolving regulatory landscape for autonomous vessels.[149]

In turn, local coherence would ensure that inland waterway regulations are interpreted in a manner that supports principles akin to those of the sector. In the context of autonomous shipping, amongst the most important principles are those of freedom of navigation[150] and equal treatment.[151]

Judicial coherence could ensure consistent interpretation of inland waterway rules across Europe and reduce fragmentation where standards are in place, particularly in contexts of diverging risk categorisations or conflicting risk assessments. However, it is unlikely to achieve sufficient harmonisation alone without prior regulatory coherence mechanisms. Therefore, judicial coherence can support harmonisation by aligning interpretations of current and future regulations, reducing legal uncertainty and promoting consistency, especially regarding CESNI standards and CEVNI-inspired regulations within the EU and beyond.

IV. Conclusions

Although regulating autonomous inland shipping remains a challenging task for public regulators, selecting different regulatory approaches and referring to innovation-guiding principles can help to create a balanced and progressive framework. New governance mechanisms can further support harmonised regulation across the European inland waterway sector.

As for regulatory approaches, GBR should generally be preferred in the initial implementation phase; nonetheless, some issues are better addressed through RBR. The choice of regulatory approach is ultimately a question of the measurability of the intended regulatory aim and a balance of costs between the regulator and the regulatees.

When outcomes are measurable and the regulatees accept the costs, GBR should be used; if the regulatees do not accept the costs, hybrid GBR should be preferred. When outcomes are not measurable and the regulator accepts the costs, RBR should be considered; if the costs are too high for the regulator, a hybrid RBR approach should be selected. Whilst RBR will most probably govern issues that require clarity and predictability *ex ante*, such as accountability, authorisation, standards, data, enforcement,

[148] Ibid 382; Mak, Graaf and Jackson (*supra*, note 143) 29–30.
[149] Mak, Graaf and Jackson (*supra*, note 143) 39.
[150] SPIN (*supra*, note 92) 14.
[151] Ibid, 45.

and risk management, GBR will be most suited to aspects that will continue to undergo technological development, like safety, system reliability, and operational efficiency. However, the selection of regulatory approach is not final but must be refined over time.

Innovation-guiding principles will define and influence the regulatory approach and level of intervention. Adaptability will ensure that issues under GBR can transition into more predictable, clearer RBR. Regulatory sandboxes, in which hybrid GBR is adopted, can foster trust between regulators and regulatees. A risk-based regulation aligned with the proportionality principle creates a balanced framework in which the requirements match the risk levels, thereby making RBR more adaptable and GBR more predictable. Compliance with the principles of innovation, precaution and technological neutrality will further ensure that the interests of the regulator and the regulatees are balanced: GBR is more innovation-friendly, the precautionary principle justifies RBR, and if the two conflict, a compromise can be achieved following the principle of technological neutrality. Legal certainty will ensure a regulatory framework that is both legally sound and sustainable, despite the flexibility and exemptions that foster innovation under GBR. Considerations of harmonisation will influence predictability and legitimacy, addressing the jurisdictional fragmentation that can hamper uniform deployment.

Horizontal digital regulation on data and AI-related aspects will further influence and shape the regulatory provisions on autonomous inland shipping within the EU. The AI Act imposes stringent requirements for high-risk system providers and operators, including in relation to risk management, transparency, robustness, human oversight and conformity checks. The GDPR sets rules for personal data in inland shipping, requiring only necessary data to be collected and for data to be accurate and securely stored. Accordingly, operators and providers must implement safeguards and be accountable for data practices throughout their vessels' operations. The Data and Data Governance Acts will further shape the regulatory provisions for accessing, sharing and reusing operational data, which will be crucial for the safety, interoperability, and accountability of autonomous shipping operations.

Even if a regulatory framework can be established, the current division of regulatory competencies within the multilevel governance system will hinder the pan-European regulation of autonomous inland vessels. To overcome this, however, regulatory and judicial coherence mechanisms could achieve significant harmonisation.

Coherence in technical and qualifications regulations between EU and non-EU countries could be achieved through observer participation by non-EU countries in CESNI's working groups, and the voluntary adoption of CESNI standards in these countries. Mutual recognition agreements between EU and non-EU countries, and the offer of CESNI-compliant training by non-EU institutes, could further create coherence in regulations across Europe. In turn, coherence in police regulations could be achieved by strengthening UNECE's role and promoting wider adoption of CEVNI as a model regulation. Concluding MRAs based on CEVNI principles and integrating CEVNI into training across Europe's inland waterways could enhance this, and the EU could promote soft law tools that incorporate CEVNI standards. To achieve harmonisation through judicial coherence, an enhanced judicial dialogue between national judges as well as with the CCNR appellate body would be viable. Whilst a unified European inland waterway court could significantly improve uniform interpretation across the sector, its creation seems rather unlikely because of the interrelationships between the judicial authorities of the EU, the CCNR and countries within the EU and beyond.

Data availability statement. All data generated or analysed during this study are included in this published article and its supplementary information file.

Acknowledgment. The author would like to thank Prof. Wouter Verheyen, University of Antwerp, Prof. Frank Smeele, Erasmus University Rotterdam, as well as the anonymous reviewer(s) for their valuable comments on earlier versions of this article.

Author's contributions. The author confirms sole responsibility for the following: study conception and design, data collection, analysis and interpretation of results, and manuscript preparation.

Financial support. The research leading to the results presented in this article has received funding from the EU's Horizon 2020 research and innovation programme under the Marie Skłodowska–Curie Grant Agreement No. 955768 (MSCA ETN AUTOBarge).

Competing interests. The author declares that there are no competing interests or personal relationships that could have appeared to influence the work presented in this paper.

Author's information. The author is affiliated as Early-Stage Researcher to the European Training and Research Network on Autonomous Barges for Smart Inland Shipping (MSCA ETN AUTOBarge: https://etn-autobarge.eu/).

Cite this article: SC Orzechowski, "A Conceptual Framework for Regulating Autonomous Inland Shipping in Europe". *European Journal of Risk Regulation*. https://doi.org/10.1017/err.2026.10093