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Reconstructing Maritime Governance for the Age of
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Sustainable Autonomy under the Law of the Sea: Reconstructing Maritime Governance for the Age of Autonomous Ships

Autonomia Sustentável no Âmbito do Direito do Mar: Reconfigurando a Governança Marítima na Era dos Navios Autónomos

Cuong Viet DO¹

ABSTRACT

This article examines Maritime Autonomous Surface Ships (MASS) as a constitutional stress test for the legitimacy of contemporary maritime governance under conditions of ecological transition and technological autonomy. It argues that the convergence of technological autonomy and sustainability challenges the legitimacy of maritime governance frameworks still grounded in anthropocentric assumptions of command, control, and responsibility. Moving beyond sectoral analyses of safety or liability, the article situates MASS within a public law perspective, questioning whether international maritime law can preserve its constitutional coherence in the Anthropocene. Building on the progressive constitutionalization of sustainability in international and European Union law, sustainability is conceptualized as a structural principle conditioning legality rather than a discretionary policy objective. Through a doctrinal and teleological analysis of UNCLOS, MARPOL Annex VI, and the evolving regulatory practice of the International Maritime Organization, the article demonstrates that environmental protection and climate responsibility increasingly operate as criteria of legitimacy. It proposes a Sustainable MASS Governance Model grounded in green regulatory integration, multilevel coordination, distributed accountability, and ethical oversight, concluding that the future legitimacy of the law of the sea depends on its capacity to integrate ecological and algorithmic rationalities into a coherent legal order oriented toward intergenerational justice.

KEYWORDS: Maritime Autonomous Surface Ships (MASS); sustainability; law of the sea; maritime governance; constitutional legitimacy; algorithmic accountability; intergenerational justice

RESUMO

Este artigo examina os Navios de Superfície Marítimos Autónomos (Maritime Autonomous Surface Ships – MASS) como um teste de resistência constitucional à legitimidade da governação marítima contemporânea, em contextos de transição ecológica e de autonomia tecnológica. Sustenta-se que a convergência entre autonomia tecnológica e sustentabilidade desafia a legitimidade dos quadros de governação marítima ainda ancorados em pressupostos antropocêntricos de comando, controlo e responsabilidade. Ultrapassando análises setoriais centradas na segurança ou na responsabilidade civil, o artigo enquadra os MASS a partir de uma perspetiva de direito público, questionando se o direito marítimo internacional pode preservar a sua coerência constitucional no Antropoceno. Com base no processo progressivo de constitucionalização da sustentabilidade no direito internacional e no direito da União Europeia, a sustentabilidade é conceptualizada como um princípio estrutural

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que condiciona a legalidade, e não como um objetivo discricionário de política pública. Através de uma análise doutrinal e teleológica da CNUDM, do Anexo VI da MARPOL e da prática regulatória evolutiva da Organização Marítima Internacional, o artigo demonstra que a proteção ambiental e a responsabilidade climática operam cada vez mais como critérios de legitimidade. Propõe-se um Modelo de Governança Sustentável dos MASS, assente na integração regulatória verde, na coordenação multinível, na responsabilidade distribuída e na supervisão ética, concluindo-se que a legitimidade futura do direito do mar depende da sua capacidade de integrar racionalidades ecológicas e algorítmicas num ordenamento jurídico coerente orientado para a justiça intergeracional.

PALAVRAS-CHAVE: Navios de Superfície Marítimos Autónomos (MASS); sustentabilidade; direito do mar; governação marítima; legitimidade constitucional; responsabilidade algorítmica; justiça intergeracional

1. Introduction

The twenty-first century marks a transformative juncture in the evolution of maritime governance, defined by the convergence of two structural trajectories, namely the constitutionalization of sustainability and the advent of technological autonomy. These forces are reshaping the normative and institutional architecture of the law of the sea, compelling it to confront the limits of its anthropocentric foundations. On one side, sustainability has evolved from a policy aspiration into a constitutional principle that conditions the legitimacy of all governance under ecological constraint.² On the other, the rise of Maritime Autonomous Surface Ships (MASS), which are defined by the International Maritime Organization (IMO) as ships that “to a varying degree, can operate independent of human interaction”,³ is redefining the ontological premise of maritime legality itself, displacing the assumption that lawful navigation presupposes direct human command.⁴ Together, they expose a fundamental question for international law as to whether the law of the sea can sustain its constitutional integrity in an era when ecological and algorithmic rationalities co-govern the oceans?

² See VOIGT, Christina. *Sustainable Development as a Principle of International Law: Resolving Conflicts between Climate Measures and WTO Law*. In series *Legal Aspects of Sustainable Development*. Volume 2. Brill Nijhoff, 2008. ISBN 978-90-04-16697-4; BOSSELMANN, Klaus. Global Environmental Constitutionalism: Mapping the Terrain. *Widener Law Review*, 2015, vol. 21, nº 2, pp. 171-185; KOTZÉ, Louis. A Global Environmental Constitution for the Anthropocene?. *Transnational Environmental Law*, 2019, vol. 8, nº. 1, pp. 11-33. DOI: <https://doi.org/10.1017/S2047102518000274>.

³ IMO. *Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS)*. MSC.1/Circ.1638 (June 3, 2021), Annex, page 3.

⁴ See RINGBOM, Henrik, et al., eds., *Autonomous Ships and the Law*. 1st edition Routledge, 2020. ISBN 9780367692049; KLEIN, Natalie, et al., eds., *Maritime Autonomous Vehicles and International Law: Maritime Security Perspectives*. Routledge, 2025. ISBN 9781032675596; CHAE, Chong-Ju and BAUMLER, Raphael, eds., *Maritime Autonomous Surface Ships (MASS) - Regulation, Technology, and Policy: Three Dimensions of Effective Implementation*, vol. 11, WMU Studies in Maritime Affairs. Springer Nature Switzerland, 2024. DOI: <https://doi.org/10.1007/978-3-031-69437-0>.

The United Nations Convention on the Law of the Sea (UNCLOS), often hailed as the “Constitution for the Oceans”,⁵ was conceived in a world where maritime operations were human-directed and state-centric. Its architecture presumes control, accountability, and responsibility as attributes of human agency exercised under the flag of sovereign States.⁶ Yet, the accelerating degradation of marine ecosystems,⁷ the urgent need for decarbonization,⁸ and the rapid deployment of autonomous technologies⁹ now strain this architecture beyond its original assumptions. The ecological crisis demands that the law internalize sustainability as a structural principle, while technological autonomy demands that it redefine the subjects of responsibility and control. These dual pressures converge to test not only the adaptability of maritime regulation but the legitimacy of maritime legality under the Democratic Rule of Law.

Despite abundant scholarship on environmental protection and regulatory adaptation,¹⁰ the existing literature remains compartmentalized. Studies on sustainability within the law of the sea focus largely on environmental duties under Part XII of UNCLOS and the operational evolution of the International Convention for the Prevention of Pollution from Ships (MARPOL) under the IMO framework.¹¹ Meanwhile, analyses of MASS are predominantly technical or sectoral, emphasizing safety,

⁵ As Ambassador Tommy Koh, President of the Third United Nations Conference on the Law of the Sea, declared, UNCLOS serves as “a constitution for the oceans which will stand the test of time”. See KOH, Tommy. *A Constitution for the Oceans*. Third United Nations Conference on the Law of the Sea, Montego Bay, 11 December 1982. Available from:

https://www.un.org/depts/los/convention_agreements/texts/koh_english.pdf.

⁶ See TANAKA, Yoshifumi. *The International Law of the Sea*. Cambridge University Press, 2012. DOI: <https://doi.org/10.1017/CBO9780511844478>.

⁷ HALPERN, Benjamin S., et al., Cumulative Impacts to Global Marine Ecosystems Projected to More than Double by Mid-Century. *Science* 389, no. 6766 (2025): pp. 1216–19,

DOI: <https://doi.org/10.1126/science.adv2906>.

⁸ FENNEL, Katja. The Verification Challenge of Marine Carbon Dioxide Removal, *Annual Review Marine Science*. January 2026, vol. 18, pp. 141-164.

DOI: <https://doi.org/10.1146/annurev-marine-032123-025717>.

⁹ XU, Haitong and SOARES, C. Guedes. Challenges for the Development of Maritime Autonomous Surface Ships. *Autonomous Transportation Research*, January 8, 2026.

DOI: <https://doi.org/10.1016/j.atres.2026.01.001>.

¹⁰ For example, see HARRISON, James *Saving the Oceans Through Law: The International Legal Framework for the Protection of the Marine Environment*. Oxford University Press, 2017; NORDQUIST, Myron H., et al., eds., *The Marine Environment and United Nations Sustainable Development Goal 14: Life below Water*. Brill Nijhoff, 2018.

¹¹ IMO, History of MARPOL.

Available from: <https://www.imo.org/en/knowledgecentre/conferencesmeetings/pages/marpol.aspx>

liability, and compliance.¹² What remains missing is an integrated framework that situates automation within the broader constitutional transformation of maritime law – one that recognizes autonomy not merely as a technological challenge but as a constitutional experiment for the legitimacy of ocean governance. This gap is both doctrinal and normative: (i) doctrinal, because existing rules lack conceptual tools to attribute responsibility in distributed, algorithmic decision-making; and (ii) normative, because the law has yet to reconcile human accountability with ecological sustainability as co-equal foundations of legitimacy.

Against this background, this study advances a central argument that the governance of MASS represents a constitutional test for the law of the sea. MASS are not merely mechanical innovations; they are catalysts that force a re-examination of the constitutional logic underpinning maritime legality as to how sovereignty, accountability, and ecological stewardship can coexist under conditions of automation. The question is no longer how to regulate autonomous ships within existing frameworks, but how the law itself must be reconstructed to remain legitimate when agency becomes distributed between humans, institutions, and intelligent systems. The future of maritime governance thus depends less on the adaptation of norms and more on the constitutional coherence of law in sustaining both ecological integrity and technological rationality.

However, it should be noted that this article adopts a constitutional lens not in order to constitutionalize UNCLOS as such, nor to import domestic constitutional categories into international maritime law. Rather, it employs constitutional reasoning as an analytical framework for assessing legitimacy in public law. In this sense, the article understands sustainability as a structural principle conditioning the legality of governance, and MASS as a stress test revealing whether existing maritime institutions remain capable of allocating authority, responsibility, and accountability under

¹² See RINGBOM, Henrik. Regulating Autonomous Ships: Concepts, Challenges and Precedents. *Ocean Development & International Law* 50, nos. 2–3 (2019): pp. 141–69. DOI: <https://doi.org/10.1080/00908320.2019.1582593>; VEAL, Robert, et al.. The Legal Status and Operation of Unmanned Maritime Vehicles. *Ocean Development & International Law* 50, no. 1 (2019): pp. 23–48. DOI: <https://doi.org/10.1080/00908320.2018.1502500>; COITO, Joel. Maritime Autonomous Surface Ships: New Possibilities and Challenges in Ocean Law and Policy. *International Law Studies* 97, no. 1 (2021). Available from: <https://digital-commons.usnwc.edu/ils/vol97/iss1/19/>; KOIMTZOGLU, Alexandros, et al. Risk Analysis on Autonomous Vessels Based on Systems Theory – Application of NET-HARMS Method. *Journal of Physics: Conference Series* 2867, no. 1 (2024): 012046, DOI: <https://doi.org/10.1088/1742-6596/2867/1/012046>; ALAMOUSH, Anas S. and OLCER, Aykut I. Maritime Autonomous Surface Ships: Architecture for Autonomous Navigation Systems. *Journal of Marine Science and Engineering* 13, no. 1 (2025): 1, DOI: <https://doi.org/10.3390/jmse13010122>.

conditions of ecological constraint and algorithmic decision-making. The constitutional perspective is thus invoked not as a claim about formal hierarchy, but as a method for evaluating whether the law of the sea can preserve coherence and legitimacy in the Anthropocene.

Methodologically, the article adopts a doctrinal and teleological approach, interpreting UNCLOS and related IMO instruments in light of their evolving object and purpose under ecological constraint. It combines normative legal analysis with constitutional theory to demonstrate how principles of sustainability and accountability can be reconstructed for algorithmic governance. The inquiry is structured across five interconnected parts. Section 2 traces the evolution of sustainability from an ethical aspiration to a constitutional principle, examining its institutional expression across UNCLOS, the IMO framework, and the European Union (EU). Section 3 analyses how autonomy challenges this constitutional architecture, exposing gaps in responsibility and legitimacy, and proposes the Sustainable MASS Governance Model as a normative framework for reconciling automation with ecological stewardship. It is followed by Section 4 which develops the notion of maritime legitimacy in the Anthropocene, showing how legality must evolve from command-based control to coherence-based accountability. Section 5 concludes by situating these findings within the broader project of reconstructing the law of the sea as a living constitution which is capable of learning, adapting, and preserving its legitimacy in an era of sustainable autonomy.

In doing so, the study argues that the future of ocean governance will not be determined by technology alone but by law's capacity to integrate ecological and digital rationalities into a unified constitutional order. The age of MASS thus heralds not the decline of maritime legality but its renewal, transforming the oceans from spaces of command into arenas of constitutional responsibility.

2. The constitutionalization of sustainability in maritime law

The legitimacy of maritime governance in the Anthropocene increasingly depends on its ability to integrate ecological rationality into the constitutional logic of the law of the sea. The environmental degradation of marine ecosystems, coupled with the global imperative of decarbonization, has transformed sustainability from a moral aspiration into a structural condition of legality. This shift marks not merely a new policy agenda but a redefinition of what it means for law to be legitimate under ecological

constraint. Understanding this transformation is essential to the present inquiry, for the governance of MASS can only be evaluated within a constitutional order already reshaped by sustainability. Before autonomy can test the law's coherence, sustainability must first be understood as the principle that confers legitimacy upon it.

2.1. From ethical aspiration to constitutional principle

The modern concept of sustainability entered international law as an ethical commitment and policy deal rather than a legal norm, guiding cooperation but lacking juridical precision.¹³ Emerging from the 1987 Brundtland Report¹⁴ and the 1992 Rio Declaration¹⁵ (Principle 4), sustainable development was framed as a pragmatic balance between economic growth and environmental protection, guided by the ideal of intergenerational equity.¹⁶ Yet, as planetary degradation accelerated, this balancing model proved conceptually and normatively inadequate. Merely reconciling competing goals could not ensure the continuity of the ecological systems upon which legality itself depends.¹⁷ The question thus arose whether sustainability could evolve from an external policy value into a constitutional principle that determines the legitimacy of governance?

Legal theorists such as Klaus Bosselmann and Christina Voigt provided the intellectual foundation for this transformation. Bosselmann's theory of ecological constitutionalism argues that modern legality must internalize ecological limits as constitutional imperatives, placing the preservation of the Earth's life-support systems

¹³ FRANCONI, Francesco. Revisiting Sustainable Development in Light of General Principles of International Environmental Law. in *Reflections on the Constitutionalisation of International Economic Law*. Brill Nijhoff, 2014, pp. 473-492. DOI: https://doi.org/10.1163/9789004228832_031.

¹⁴ United Nations General Assembly, Forty-second session, Development and International Economic Cooperation: Environment, *Report of the World Commission on Environment and Development*, A/42/427, 4 August 1987. Available from: <https://digitallibrary.un.org/record/139811?ln=en>

¹⁵ United Nations General Assembly, Report of the United Nations Conference on Environment and Development, Annex I: Rio Declaration on Environment and Development, A/CONF.151/26 (Vol. I), Rio de Janeiro, 3-14 June 1992. Available from:

https://www.un.org/en/development/desa/population/migration/generalassembly/docs/globalcompact/A_CONF.151_26_Vol.I_Declaration.pdf

¹⁶ MENSAH, Justice. Sustainable Development: Meaning, History, Principles, Pillars, and Implications for Human Action: Literature Review. *Cogent Social Sciences* 5, no. 1 (2019): 1653531, DOI: <https://doi.org/10.1080/23311886.2019.1653531>.

¹⁷ See KOTZE, Louis J. Earth System Law for the Anthropocene: Rethinking Environmental Law alongside the Earth System Metaphor. *Transnational Legal Theory* 11, nos. 1-2 (2020): pp. 75-104, DOI: <https://doi.org/10.1080/20414005.2020.1776556>; BELLVER, Vicente. Ecological Justice in the Anthropocene: A Proposal. In *Global Changes: Ethics, Politics and Environment in the Contemporary Technological World*, ed. VALERA, Luca and CASTILLA, Juan Carlos. Springer Verlag, 2020.

alongside democracy and human dignity as structural pillars of legitimacy.¹⁸ He conceptualizes sustainability as a meta-principle which is not one value among others, but the condition that unites all legal reasoning under ecological constraint.¹⁹ In parallel, Voigt advances the idea of sustainability as a general principle of international law, capable of harmonizing fragmented treaty regimes through an interpretive duty of coherence.²⁰ Together, these perspectives reconceptualize sustainability as the connective tissue that binds the plural orders of international law into a single normative system grounded in ecological responsibility.

This constitutional turn has since materialized institutionally. Within the EU, Article 3(3) of the Treaty on European Union and Article 11 of the Treaty on the Functioning of the European Union elevate sustainable development to a constitutional objective and integration clause, requiring that all policies respect environmental limits.²¹ Globally, instruments such as the 2015 Paris Agreement²² embed sustainability in a legal form through intergenerational equity, precaution, and differentiated responsibility.²³ The principle of common but differentiated responsibilities (CBDR) embodies this constitutional pluralism, reconciling universality with fairness, unity with diversity, and environmental necessity with distributive justice.

¹⁸ KLAUS, Bosselmann. *The Principle of Sustainability: Transforming Law and Governance*. 2nd ed. Routledge, 2017. See also TRENESKA-DESKOSKA, Renata, TRAJKOVSKA-HRISTOVSKA, Jelena. The Interplay of Sustainability, Constitutionalism and Legitimacy: Examining the “Political Ecotopia” as a manifestation of Social Sustainability and a Pillar of Constitutionalism. *Juridical Tribune – Review of Comparative and International Law*, December 2024, vol. 14, no. 4, pp. 670-687.

DOI: <https://doi.org/10.62768/tbj/2024/14/4/09>.

¹⁹ See also LOWE, Vaughan. Sustainable Development and Unsustainable Arguments. In *International Law and Sustainable Development: Past Achievements and Future Challenges*, ed. BOYLE, Alan and FREESTONE, David. Oxford University Press, 1999, pp. 19-37. DOI: <https://doi.org/10.1093/acprof:oso/9780198298076.003.0002>; BARRAL, Virginie. Sustainable Development in International Law: Nature and Operation of an Evolutive Legal Norm. *European Journal of International Law* 23, no. 2 (2012): pp. 377–400, DOI: <https://doi.org/10.1093/ejil/chs016>.

²⁰ VOIGT, Christina. *Sustainable Development as a Principle of International Law: Resolving Conflicts between Climate Measures and WTO Law*. In series *Legal Aspects of Sustainable Development*, Volume 2. Brill Nijhoff, 2008. ISBN 978-90-04-16697-4.

²¹ Official Journal of the European Union, Consolidated versions of the Treaty on European Union and the Treaty on the Functioning of the European Union, 2016/C 202/01, 7 June 2016. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex%3A12016ME%2FTXT>

²² United Nations. The Paris Agreement. 12 December 2015.

Available from: <https://www.un.org/en/climatechange/paris-agreement>

²³ WILL, Ulrike and MANGER-NESTLER, Cornelia. Fairness, Equity, and Justice in the Paris Agreement: Terms and Operationalization of Differentiation. *Leiden Journal of International Law* 34, no. 2 (2021), pp.397–420. DOI: <https://doi.org/10.1017/S0922156521000078>. See also BONDANSKY, Daniel et al. Paris Agreement. In *International Climate Change Law*, ed. BONDANSKY, Daniel et al. Oxford University Press, 2017, pp. 209-257. DOI: <https://doi.org/10.1093/law/9780199664290.003.0007>; KLEIN, Daniel et al., eds., *The Paris Agreement on Climate Change: Analysis and Commentary*. Oxford University Press, 2017, DOI: <https://doi.org/10.1093/law/9780198789338.001.0001>.

The implications of this evolution for the law of the sea are profound. UNCLOS, adopted in 1982, predates the rise of sustainability as a constitutional principle. Its structure reflects an instrument organized around sovereign entitlements and freedom of navigation. Nonetheless, the Convention's open-textured provisions, particularly Articles 192 to 194, created interpretative space for the progressive internalization of sustainability.²⁴ These provisions can now be read as embryonic constitutional clauses. They are not self-contained technical norms, but framework obligations enabling the integration of ecological rationality into the maritime legal order. As the ecological crisis of the oceans intensifies, these clauses acquire renewed constitutional significance. They invite a reinterpretation of UNCLOS through the prism of sustainability as the structural criterion of lawful authority at sea.²⁵ The following section explores how this principle has begun to materialize in practice through the progressive greening of UNCLOS and the IMO framework, setting the stage for a truly constitutional ecology of the seas.

2.2. UNCLOS and MARPOL: from sovereignty to stewardship

If sustainability has evolved into a constitutional principle, then the law of the sea represents its first and most consequential field of application. The UNCLOS, adopted in 1982 before the concept of sustainability had acquired legal force, remains the structural foundation of maritime governance. UNCLOS's constitutional quality lies not in its codification of sovereignty, but in its capacity to transform sovereignty into stewardship. It provides an open-textured legal framework that balances sovereign rights with universal obligations, enabling the progressive internalization of ecological responsibility as a condition of legitimacy.

At the core of this transformation is Part XII of UNCLOS, particularly Articles 192 to 194, which articulate the customary obligation to protect and preserve the marine environment.²⁶ This duty, while framed in general terms, carries a

²⁴ KLERL, Bastiaan Ewoud. Protecting the Marine Environment from the Impacts of Climate Change: A Regime Interaction Study. *Review of European, Comparative & International Environmental Law* 32, no. 1 (2023): pp. 44–56, DOI: <https://doi.org/10.1111/reel.12487>.

²⁵ TESTA, David. Controlling GHG Emissions from Shipping: The Role, Relevance and Fitness for Purpose of UNCLOS. In *The Environmental Rule of Law for Oceans: Designing Legal Solutions*, ed. POZDNAKOVA, Alla and PLATJOUW, Froukje Maria. Cambridge University Press, 2023, pp. 31-45. DOI: <https://doi.org/10.1017/9781009253741.007>.

²⁶ See KOJMA, Chie. Integration of General Principles of International Environmental Law into the Law of the Sea: Assessment and Challenges. *Marine Policy* March 2023, vol. 149, 105497, DOI:

transformative potential. It redefines the ocean not merely as a resource frontier but as a legal commons of shared responsibility. Part XII of UNCLOS also establishes a hierarchy of legitimacy in which sovereign rights, such as exploration, exploitation, and navigation, are qualified by environmental responsibility. For instance, Article 193 affirms States' sovereign right to exploit their natural resources, but expressly subjects that right to the environmental duties enshrined in the Convention. This "subject-to" formulation marks a constitutional reordering of legality. One may argue that sovereignty is no longer absolute but ecologically conditioned. It signals a shift from jurisdictional entitlement toward environmental accountability, placing stewardship – not exploitation – at the normative center of maritime authority. In this respect, Part XII of UNCLOS operates in a manner comparable to a framework convention, establishing general obligations of conduct and due diligence while relying on cross-regime interaction, most notably with MARPOL and subsequent IMO instruments, for substantive elaboration. This structural openness is not a weakness, but a defining feature of the Convention's constitutional architecture, leaving interpretative space for normative evolution through subsequent instruments, judicial interpretation, and institutional practice.²⁷

The framework nature is what allows UNCLOS to remain living law. This interpretive approach has been expressly endorsed by the International Tribunal for the Law of the Sea (ITLOS). The 2011 ITLOS Advisory Opinion on responsibilities and obligations of States with respect to activities in the Area articulated due diligence as a dynamic standard, adaptable to evolving scientific knowledge.²⁸ In its 2024 Advisory Opinion requested by the Commission of Small Island States on Climate Change and

<https://doi.org/10.1016/j.marpol.2023.105497>; SERSIC, Maja. Environmental Law of the Sea and Part XII of the UN Convention on the Law of the Sea. In *40 Years of the United Nations Convention on the Law of the Sea*. Routledge, 2025; PLATJOUW, Froukje Maria and POZDANKOVA, Alla. eds., *The Environmental Rule of Law for Oceans: Designing Legal Solutions*. Cambridge University Press, 2023, DOI: <https://doi.org/10.1017/9781009253741>; TREVISANUT, Seline. The Future of the Oceans: The Role of Human Rights Law and International Environmental Law in Shaping the Law of the Sea. In *The Many Paths of Change in International Law*, ed. KRISCH, Nico and YILDIZ Ezgi. Oxford University Press, 2023. DOI: <https://doi.org/10.1093/oso/9780198877844.003.0009>.

²⁷ See PROELSS, Alexander. Fragmentation and Coherence in the Legal Framework for the Protection of the Marine Environment. In *Research Handbook on International Marine Environmental Law*. Edward Elgar Publishing, 2023; NGUYEN, Lan Ngoc ed. Protection of the Marine Environment. In *The Development of the Law of the Sea by UNCLOS Dispute Settlement Bodies*. Cambridge University Press, 2023. DOI: <https://doi.org/10.1017/9781108980296.007>.

²⁸ Responsibilities and obligations of States with respect to activities in the Area, Advisory Opinion, 1 February 2011, ITLOS Reports 2011. Available from:

https://www.itlos.org/fileadmin/itlos/documents/cases/case_no_17/17_adv_op_010211_en.pdf

International Law (COSIS) on climate change and international law, ITLOS affirmed that the obligation under Article 192 of UNCLOS to protect and preserve the marine environment encompasses harm arising from greenhouse gas (GHG) emissions contributing to climate change.²⁹ Crucially, the Tribunal relied on Article 31(3)(c) of the 1969 Vienna Convention on the Law of Treaties (VCLT) to interpret UNCLOS in light of relevant climate law instruments and scientific consensus. The Advisory Opinion thus confirms that sustainability and climate responsibility are not external policy considerations, but integral elements of the legal content of UNCLOS obligations as interpreted within an integrated international legal system. Further, when read together with this ITLOS Advisory Opinion, the environmental obligations of UNCLOS acquire direct relevance for the governance of autonomous maritime technologies, insofar as algorithmic decision-making increasingly determines vessels' emissions profiles, energy efficiency, and environmental risk management.

Yet UNCLOS, by design, is a deliberately framework-oriented and open-textured legal order. Its constitutional quality lies precisely in its capacity to articulate general principles such as the obligation to protect and preserve the marine environment under Articles 192 to 194, while delegating operational specification to subsequent regulatory instruments, institutional practice, and interpretive development. This design has enabled UNCLOS to accommodate evolving environmental concerns through dynamic interpretation, without requiring formal amendment. At the same time, the framework nature of the Convention inevitably generates zones of structural indeterminacy, particularly when confronted with novel forms of governance such as algorithmic decision-making in maritime operations. The challenge posed by MASS therefore does not reveal a deficiency of UNCLOS, but rather exposes the limits of a framework constitution when authority and responsibility are increasingly mediated by autonomous systems rather than human command.

It appears that UNCLOS defines duties but delegates operational detail. Its general clauses require institutional mechanisms capable of translating constitutional principles into measurable practice. This is the role performed by MARPOL which is considered the procedural hinge of maritime constitutionalism. MARPOL converts the

²⁹ Request for an advisory opinion submitted by the Commission of Small Island States on climate change and international law, Advisory Opinion, 21 May 2024, ITLOS Reports 2024. Available from: https://www.itlos.org/fileadmin/itlos/documents/cases/31/Advisory_Opinion/C31_Adv_Op_21.05.2024_corr.pdf

normative aspirations of UNCLOS into enforceable performance standards, thereby embodying the functional dimension of sustainability. Originally a technocratic regime focused on pollution control, MARPOL has progressively evolved into an ecological governance system. The adoption of Annex VI in 1997 regulating air pollution from ships reorients the Convention from preventing discrete discharges to promoting ecological performance.³⁰ Mechanisms such as the Energy Efficiency Design Index (EEDI) and the Ship Energy Efficiency Management Plan (SEEMP) link vessel operation to global emission-reduction goals, transforming compliance from a technical obligation into a criterion of legitimacy.³¹ MARPOL thereby operationalizes sustainability as a continuous performance duty, integrating technological innovation into the normative architecture of the law of the sea.

However, MARPOL's effectiveness remains limited by its reliance on flag-state implementation and port-state control, leading to disparities in enforcement.³² The convention's monitoring and verification processes operate largely through administrative reporting rather than adjudicative accountability.³³ Its procedural design reflects that sustainability is recognized as a guiding norm but not yet as a self-executing legal principle. Nevertheless, its iterative mechanisms, including reporting, auditing, and technological adaptation, generate the feedback loops through which maritime law learns and evolves. In this way, MARPOL sustains the dynamic relationship between principle and practice, ensuring that the constitutional duty of environmental protection articulated in UNCLOS becomes tangible in the governance of daily maritime operations.

³⁰ EHLERS, Peter. A Success Story? Fifty Years of MARPOL. *The International Journal of Marine and Coastal Law* 40, no. 1 (2024): pp. 57–112. DOI: <https://doi.org/10.1163/15718085-bja10194>.

³¹ See IMO. *MARPOL Annex VI and NTC 2008 with Guidelines for Implementation* (IMO e-Publications, 2023). DOI: <https://doi.org/10.62454/KD664E>; YEREMENKO, Kristina Yeremenko. International Maritime Organization and Decarbonization of Maritime Industry: Mandate and Instruments. *Lex Portus*, 2022, vol. 8(3), pp. 30–57. DOI: <https://doi.org/10.26886/2524-101X.8.3.2022.2>; FAKHRY, Aref and BULUT, Belma. MARPOL Energy Efficiency: Verging on Legal Inefficiency?. In *Trends and Challenges in Maritime Energy Management*, ed. OLCER, Aykut I. et al. Springer International Publishing, 2018, DOI: https://doi.org/10.1007/978-3-319-74576-3_2.

³² HONNIBALL, Arron N. and COELHO, Nelson F. The MARPOL Port State Jurisdiction Regime. In *The International Convention for the Prevention of Pollution from Ships*. Edward Elgar Publishing, 2025.

³³ See MENSAH, Thomas A. Compliance Control In International Conventions On The Protection Of The Marine Environment Against Oil Pollution. In *Ensuring Compliance with Multilateral Environmental Agreements*. Brill Nijhoff, 2006; TAN, Alan Khee-Jin. *Vessel-Source Marine Pollution: The Law and Politics of International Regulation*. Cambridge Studies in International and Comparative Law. Cambridge University Press, 2005.

Together, UNCLOS and MARPOL form a constitutional continuum. UNCLOS defines the normative foundation of stewardship, MARPOL translates it into procedural accountability. The former provides legitimacy, the latter functionality. Their interaction demonstrates how the law of the sea internalizes sustainability not as an external policy but as a structural element of legality. This dialectic – between framework principle and procedural execution – constitutes the juridical essence of the law’s constitutional evolution, bridging the abstract duty of environmental protection and the emergent architecture of ecological legitimacy.

2.3. From the IMO GHG Strategy to Net-Zero Framework: constitutionalizing sustainability in global maritime law

The IMO’s 2023 Revised Strategy on the Reduction of Greenhouse Gas Emissions from Ships,³⁴ firstly initiated in 2018,³⁵ represents the most explicit attempt to embed sustainability as a structural norm within global maritime governance. Building upon the technical legacy of MARPOL Annex VI, the Strategy articulates for the first time a comprehensive vision of ecological legitimacy in the maritime sector – one that connects technological innovation, distributive equity, and institutional transparency.³⁶ The Strategy’s commitment to achieve net-zero GHG emissions by or around 2050 is not merely a regulatory target;³⁷ it signals a shift in the source of maritime legality itself. The authority of the IMO, traditionally grounded in technical expertise and state consent, now increasingly derives from its alignment with global climate imperatives.³⁸ This reflects a transformation in the very grammar of legitimacy that compliance with international maritime law is no longer measured only by

³⁴ IMO, 2023 IMO Strategy on Reduction of GHG Emissions from Ships, Resolution MEPC.377(80) adopted on 7 July 2023. Available from:

<https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/annex/MEPC%2080/Annex%2015.pdf>

³⁵ IMO, Initial IMO Strategy on Reduction of GHG Emissions from Ships, Resolution MEPC.304(72) adopted on 13 April 2018. Available from:

https://unfccc.int/sites/default/files/resource/250_IMO%20submission_Talanoa%20Dialogue_April%202018.pdf

³⁶ BILGILI, Levent and OLCER, Aykut I. IMO 2023 Strategy-Where Are We and What’s next?. *Marine Policy*, February, 2024, vol 160 (105953). DOI: <https://doi.org/10.1016/j.marpol.2023.105953>.

³⁷ FRIEDMAN, Andrew. The International Maritime Organization’s Revised Greenhouse Gas Strategy: A Political Signal of Shipping’s Regulatory Future. *The International Journal of Marine and Coastal Law* 39, no. 4 (2024): pp. 685–711, DOI: <https://doi.org/10.1163/15718085-bja10162>.

³⁸ SAHIN, Ali Ulvi. IMO 2023 Revised Emission Reduction Strategy and Regulatory Challenges of Maritime Decarbonization. *European Journal of Commercial Contract Law* 16, no. 1 (2024): pp. 25–33, DOI: <https://doi.org/10.7590/187714624X17132716463900>.

adherence to procedural standards, but by conformity with the ecological thresholds defined by climate science. The Strategy, albeit initially non-binding, transforms decarbonization from a policy aspiration into a structured commitment, anticipating the eventual juridification of climate governance at sea.³⁹

That juridification materialized in 2025 with the IMO Net-zero Framework, approved at the Marine Environment Protection Committee's 83rd session.⁴⁰ The Framework introduces, through amendments to MARPOL Annex VI, a dual regulatory mechanism combining a global fuel standard for ships measured by well-to-wake GHG intensity and a sectoral carbon pricing regime for emissions. Together, these provisions constitute the first legally binding, industry-wide climate regime in international law, operationalizing the 2023 Strategy's programmatic commitments.

Doctrinally, this development signifies a constitutionalization of sustainability within maritime governance. The normative basis of compliance shifts from technical conformity to environmental performance, aligning the IMO's regulatory authority with the scientific and distributive principles underpinning the Paris Agreement 2015.⁴¹ The establishment of the IMO Net-Zero Fund, redistributing revenues from emissions pricing toward innovation, capacity-building, and just-transition initiatives in developing and vulnerable States, embeds a justice-oriented dimension in the maritime legal order. In doing so, the IMO implicitly integrates the principle of CBDR into a sectoral regulatory framework, transforming it from a principle of negotiation into one of implementation.⁴² Institutionally, the Net-Zero Framework enhances procedural

³⁹ GARCIA, Beatriz et al. Net Zero for the International Shipping Sector? An Analysis of the Implementation and Regulatory Challenges of the IMO Strategy on Reduction of GHG Emissions. *Journal of Environmental Law* 33, no. 1 (2021): pp. 85–112, DOI: <https://doi.org/10.1093/jel/eqaa014>. See also CHIRCOP, Aldo and SHAN, Desai. Governance of International Shipping in the Era of Decarbonisation: New Challenges for the IMO?. in *Maritime Law in Motion*, ed. MUKHERJEE, Proshanto K. et al. Springer International Publishing, 2020. DOI: https://doi.org/10.1007/978-3-030-31749-2_6.

⁴⁰ IMO, IMO approves net-zero regulations for global shipping. Available from:

<https://www.imo.org/en/mediacentre/pressbriefings/pages/imo-approves-netzero-regulations.aspx>

⁴¹ See BULLOCK, Simon et al. Beyond Fuel: The Case for a Wider Perspective on Shipping and Climate Change. *Climate Policy* 25, no. 8 (2025): pp. 1326–34, DOI: <https://doi.org/10.1080/14693062.2024.2447474>; BULLOCK, Simon et al. The Urgent Case for Stronger Climate Targets for International Shipping. *Climate Policy* 22, no. 3 (2022): pp. 301–9, DOI: <https://doi.org/10.1080/14693062.2021.1991876>.

⁴² See CHEN, Yuli. Reconciling Common but Differentiated Responsibilities Principle and No More Favourable Treatment Principle in Regulating Greenhouse Gas Emissions from International Shipping. *Marine Policy* 123 (January 2021): 104317, DOI: <https://doi.org/10.1016/j.marpol.2020.104317>. See also HALL, Catherine. Towards Minilateral Climate Governance? Analysing Climate Club Design Options through the Lens of Common but Differentiated Responsibilities and Respective Capabilities.

legitimacy through expanded participation, transparency, and technical cooperation.⁴³ Substantively, it consolidates environmental protection as a co-equal objective alongside safety and efficiency, thus reconstituting the internal hierarchy of maritime law.

In sum, the IMO's 2023–2025 developments mark a paradigmatic shift from consent-based coordination to principle-oriented constitutionalism. By converting sustainability into a foundational norm of maritime legality, the IMO has initiated the first genuine constitutional moment in the international regulation of shipping, aligning the law of the sea with the imperatives of planetary climate governance. The interaction between UNCLOS and adjacent environmental and climate regimes is not merely a matter of policy coherence, but is firmly grounded in the law of treaties. Article 31(3)(c) of the VCLT requires that treaty provisions be interpreted in light of any relevant rules of international law applicable in the relations between the parties. This principle of systemic integration provides the doctrinal basis for reading UNCLOS obligations, particularly Articles 192 to 194, together with evolving norms on climate change mitigation, environmental protection, and due diligence. Cross-regime interpretation therefore does not alter the normative hierarchy of UNCLOS, but clarifies its content and scope in response to changing legal and scientific contexts.

2.4. Regional consolidation: the EU as a constitutional laboratory

While the UNCLOS and IMO frameworks articulate the constitutional and procedural foundations of sustainability at the global level, the EU has emerged as the most advanced regional experiment in transforming sustainability from principle into binding constitutional practice. Within the EU legal order, environmental protection and climate neutrality are not only policy aspirations but also structural conditions of legality that shape legislative, administrative, and judicial action alike. The Union thus functions as a constitutional laboratory – a jurisdiction where sustainability has

Review of European, Comparative & International Environmental Law 33, no. 3 (2024): pp. 604–18, DOI: <https://doi.org/10.1111/reel.12582>.

⁴³ LIND, Mikael et al. Effective Partnerships to Support Maritime Decarbonization. In *Maritime Decarbonization: Practical Tools, Case Studies and Decarbonization Enablers*, ed. LIND, Mikael et al. Springer Nature Switzerland, 2023. DOI: https://doi.org/10.1007/978-3-031-39936-7_13. See also LEE, Jung-Yoon et al. A Study on the Comprehensive Impact of the 2023 IMO GHG Strategy on International Shipping. *대한조선학회 논문집* (Journal of the Society of naval Architects of Korea) Vol. 60, no. 6 (2023): pp. 397–405, DOI: <https://doi.org/10.3744/SNAK.2023.60.6.397>.

achieved full normative density and enforceability, offering a model for how ecological responsibility can be constitutionalized within maritime governance.

The EU's constitutional embedding of sustainability is explicit. Article 3(3) of the Treaty on European Union enshrines sustainable development as a foundational objective, while Article 11 of the Treaty on the Functioning of the European Union mandates the integration of environmental protection across all Union's policies and activities. These clauses elevate sustainability to the level of constitutional identity, reshaping the internal hierarchy of EU norms and the external legitimacy of its actions.⁴⁴ Unlike the open-textured provisions of UNCLOS, which rely on interpretive evolution, the EU's framework institutionalizes sustainability through positive legal obligations and judicial review, transforming ecological rationality into a justiciable standard of legality.

This constitutional commitment is concretized through an increasingly sophisticated body of secondary legislation. The 2019 European Green Deal⁴⁵ reframes sustainability as the Union's new growth paradigm, linking decarbonization, digital transformation, and social justice into a unified legal and political agenda.⁴⁶ In the maritime sector, the FuelEU Maritime (Regulation (EU) 2023/1805 entered into force on 1 January 2025)⁴⁷ translates these commitments into enforceable obligations. It establishes life-cycle GHG intensity limits for marine fuels, prescribes penalties for non-compliance, and integrates maritime transport into the EU's Emissions Trading System (ETS). Through these mechanisms, sustainability functions as both a normative foundation and a functional driver of legal integration, binding economic governance to ecological legitimacy.

Judicial interpretation by the Court of Justice of the European Union (CJEU) has

⁴⁴ SCHOLTES, Julian. Constitutional Identity in the European Union. In *The Abuse of Constitutional Identity in the European Union*, ed. SCHOLTES, Julian. Oxford University Press, 2023. DOI: <https://doi.org/10.1093/oso/9780198883173.003.0002>. See also ZILLER, Jacques. Acts of EU Law and Hierarchy of Norms. In *Advanced Introduction to European Union Law*. Edward Elgar Publishing, 2023.

⁴⁵ EUROPEAN COMMISSION. Communication from the Commission to the European Parliament, the European Council, the Council, the European Economic and Social Committee and the Committee of the Regions. The Green Deal. COM/2019/640 final. Brussels, 11.12.2019. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=celex:52019DC0640>.

⁴⁶ FILIPOVIC, Sanja et al. The Green Deal – Just Transition and Sustainable Development Goals *Nexus. Renewable and Sustainable Energy Reviews* 168 (October 2022): 112759, DOI: <https://doi.org/10.1016/j.rser.2022.112759>.

⁴⁷ Regulation (EU) 2023/1805 of the European Parliament and of the Council of 13 September 2023 on the use of renewable and low-carbon fuels in maritime transport, and amending Directive 2009/16/EC. Available from: <https://eur-lex.europa.eu/eli/reg/2023/1805/oj/eng>

reinforced this constitutionalization. In *Air Transport Association of America and Others v Secretary of State for Energy and Climate Change* (case C-366/10),⁴⁸ the Court upheld the inclusion of aviation in the ETS as consistent with international law, affirming the Union's competence to impose climate obligations on transboundary activities. By analogy, the CJEU's reasoning legitimizes the extraterritorial reach of EU maritime decarbonization measures as expressions of constitutional duty rather than protectionism. The Court thereby elevates environmental protection and climate neutrality to the level of a general principle of Union law, giving sustainability the same normative force as fundamental rights and proportionality.⁴⁹

Through this multi-level architecture, including constitutional clauses, regulatory instruments, and judicial enforcement, the EU demonstrates how sustainability can function as a comprehensive system of legality. Its model contrasts with the voluntary, consensus-based approach of the IMO, revealing how regional constitutionalism can supply normative precision where global governance remains indeterminate. The EU does not replace the international order; it deepens it by providing a template for the constitutional ecology of the seas – a system in which ecological responsibility, technological innovation, and distributive justice coexist as interdependent principles of maritime legality.

This emerging constitutional ecology marks the culmination of sustainability's evolution from ethical aspiration to structural norm. It transforms ocean governance from a regime of rights and duties into a reflexive legal ecosystem grounded in coherence, accountability, and adaptability. From this foundation, the next inquiry naturally arises whether the law of the sea, now constitutionally oriented toward ecological stewardship, can maintain its legitimacy when confronted with the disruptive rationality of automation embodied in MASS.

3. MASS and the constitutional transformation of ocean governance

The relevance of MASS does not lie primarily in their technological novelty, but in the transformation they introduce in the rationality of maritime governance. MASS

⁴⁸ JUDGEMENT OF THE COURT (Grand Chamber) of 21 December 2011 regarding Case C-366/10. Available from: <https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:62010CJ0366>

⁴⁹ See FAHEY, Elaine and HERLIN-KARNELL, Ester. EU Law qua Global Governance Law? Deciphering Regulatory and Constitutional Competence Between EU Environmental Law and Global Governance. *German Law Journal* 13, no. 11 (2012): pp. 1147–50, DOI: <https://doi.org/10.1017/S2071832200017788>.

institutionalize algorithmic decision-making in a domain historically governed by human judgment and command-based responsibility. At the same time, the Anthropocene imposes ecological constraints that redefine sustainability from a policy objective into a condition of legal legitimacy. It is the intersection of these two structural shifts, namely algorithmic governance and ecological limitation, that renders MASS a critical site for examining the future of the law of the sea. Autonomous vessels therefore operate not merely as technological artefacts, but as governance infrastructures through which environmental performance, risk allocation, and responsibility are increasingly mediated by code. In this context, sustainability, algorithms, and the Anthropocene are not parallel themes, but interdependent dimensions of a single transformation in maritime public law.

The constitutionalization of sustainability has redefined the legitimacy of maritime law through ecological responsibility. Yet this redefinition remains incomplete until it encounters the disruptive rationality of technological autonomy. The emergence of MASS constitutes not merely a regulatory innovation but a constitutional inflection point. On the one hand, their deployment promises gains in maritime safety and efficiency⁵⁰ while reducing GHG emissions⁵¹, enhancing real-time environmental monitoring,⁵² and contributing to the decarbonization goals embedded in the IMO frameworks. On the other hand, it compels the law of the sea to confront a question unprecedented in its history whether a legal system built upon human command and sovereign intention can remain legitimate when decision-making is delegated to

⁵⁰ See LIM, Do Hyeong and JOO, Hyogyong. Autonomous Navigation System. In *Maritime Autonomous Surface Ships (MASS) - Regulation, Technology, and Policy: Three Dimensions of Effective Implementation*, ed. CHAE, Chong-Ju and BAUMLER, Raphael. Cham: Springer Nature Switzerland, 2024, pp. 117–42. DOI: https://doi.org/10.1007/978-3-031-69437-0_7; ALAMOUSH, Anas S. and OLCER, Aykut I. Maritime Autonomous Surface Ships: Architecture for Autonomous Navigation Systems. *Journal of Marine Science and Engineering* 13, no. 1 (January 2025): 122, DOI: <https://doi.org/10.3390/jmse13010122>.

⁵¹ See PRIBYL, Sean. Autonomous Vessels in the Era of Global Environmental Change. In *Autonomous Vessels in Maritime Affairs: Law and Governance Implications*, ed. HOHANSSON, Tafsir Matin et al. Springer International Publishing, 2023. DOI: https://doi.org/10.1007/978-3-031-24740-8_9; KIM, Mingyu et al. Autonomous Shipping and Its Impact on Regulations, Technologies, and Industries. *Journal of International Maritime Safety, Environmental Affairs, and Shipping* 4, no. 2 (2020): pp. 17–25, DOI: <https://doi.org/10.1080/25725084.2020.1779427>.

⁵² TSVETKOVA, Anastasia et al. Steering towards Sustainability: The Impact of Autonomous Shipping on Achieving Sustainable Development Goals. *Journal of Physics: Conference Series* 2867, no. 1 (2024): 012014, DOI: <https://doi.org/10.1088/1742-6596/2867/1/012014>; ZANELLA, Tiago Vinicius. The Environmental Impacts of the Maritime Autonomous Surface Ships (MASS). *Veredas Do Direito* 17, no. 39 (2020), DOI: <https://doi.org/10.18623/rvd.v17i39.1803>; ABRAMOWICZ-GERIGK, Teresa and BURCIU, Zbigniew. Situational Awareness in Autonomous Shipping – Ship Domain in Remote MASS Operation. *TransNav, International Journal on Marine Navigation and Safety Od Sea Transportation* 18, no. 4 (2024): pp. 889–93. DOI: <https://doi.org/10.12716/1001.18.04.15>.

algorithmic systems that act, learn, and decide beyond continuous human control?

3.1. From human command to algorithmic governance

In legal terms, algorithms deployed in MASS should not be understood merely as technical tools, but as institutionalized decision-making mechanisms that allocate risk, prioritize objectives, and operationalize environmental standards without continuous human intervention.

The architecture of international maritime law was historically constructed upon the presumption of human agency. A number of conventions such as UNCLOS, the International Convention for the Safety of Life at Sea (SOLAS), and the Convention on the International Regulations for Preventing Collisions at Sea (COLREGs) presuppose that lawful navigation is exercised under the direct control of a human master, whose authority anchors accountability.⁵³ Articles such as UNCLOS Article 94(3), SOLAS Regulation V/14, and COLREG Rule 5 explicitly impose duties of continuous human oversight, situational awareness, and responsible command. These provisions embody a constitutional logic that responsibility follows command, and command presupposes human intention.

The emergence of MASS fundamentally destabilizes this anthropocentric paradigm. According to the IMO's Regulatory Scoping Exercise for the Use of MASS (2021) working ahead to the development of a non-mandatory MASS Code, autonomy may range from remote human supervision to full algorithmic self-governance. As the human operator recedes, command becomes distributed among programmers, system designers, and artificial intelligence routines, dissolving the singular chain of control that underpins the law's concept of lawful navigation. The result is a constitutional displacement that the "master" is no longer an individual but a system of interacting agents – human and non-human – operating across digital and geographic

⁵³ See KATSIVELA, Marel. Legal, Ethical and Industry Issues and Developments Regarding Maritime Autonomous Surface Ships. *Ocean Yearbook Online* 37, no. 1 (2023): pp. 506–41. DOI: <https://doi.org/10.1163/22116001-03701021>; CHOI, Junghwan and LEE, Sangil. Legal Status of the Remote Operator in Maritime Autonomous Surface Ships (MASS) Under Maritime Law. *Ocean Development & International Law* 52, no. 4 (2022): pp. 445–62. DOI: <https://doi.org/10.1080/00908320.2022.2036276>; GARCIA-LLAVE, Ruth et al. Autonomous Ships and Flag State: Challenges and Opportunities in International Maritime Law. *Journal of Transportation Security* 18, no. 1 (2025): 15. DOI: <https://doi.org/10.1007/s12198-025-00304-z>.

space.⁵⁴

This transformation challenges the foundational premise of maritime legality. Under UNCLOS, the flag State's jurisdiction and responsibility depend on effective control exercised over vessels flying its flag. Yet when control becomes algorithmic, effective exercise can no longer be measured solely by human decision-making. Instead, it must encompass systemic reliability, data integrity, and predictive capacity. Similarly, the due diligence standard articulated in the 2011 ITLOS Advisory Opinion and reaffirmed in the 2024 ITLOS Advisory Opinion must evolve beyond human foresight to include anticipatory governance over algorithmic design and operation. In this sense, due diligence transforms from a test of conduct into a test of system architecture.

From a constitutional perspective, MASS exposes the tension between state responsibility and technological agency. The law of the sea, long anchored in the unity of command and control, must now reconcile with distributed decision-making governed by artificial intelligence. The challenge is not only technical but constitutional in order to reinterpret existing obligations so that legitimacy no longer depends on physical human oversight but on the law's capacity to ensure accountable autonomy. In this new paradigm, command becomes algorithmic, yet the constitutional imperatives of transparency, responsibility, and ecological stewardship must remain intact.

3.2. Algorithmic accountability and legality

Under conditions of ecological transition, sustainability operates not as an external policy objective, but as a constraint shaping permissible forms of decision-making. In the context of autonomous vessels, this implies that environmental protection and climate responsibility are increasingly embedded within algorithmic processes that govern navigation, energy use, and operational efficiency. The legal question is therefore not whether autonomous ships can be regulated for environmental compliance, but whether algorithmic governance itself can be structured in a manner consistent with sustainability as a condition of legitimacy.

⁵⁴ IMO has recognized the institutional implications of the transformation with the emergence of MASS and required reinterpretation or amendment to accommodate autonomy at seas.

See IMO, *Outcome of the Regulatory Scoping Exercise for the Use of Maritime Autonomous Surface Ships (MASS)*, MSC.1/Circ.1638, 3 June 2021.

The displacement of human command by algorithmic systems does not merely disrupt maritime operations; it fractures the legal grammar of accountability that underpins the law of the sea. Traditional maritime law is premised on a direct causal chain that command entails control, and control entails responsibilities. Once this unity dissolves under conditions of automation, the law faces a structural indeterminacy: who, or what, can be held accountable when decisions at sea are executed by autonomous code rather than human will? This accountability gap represents not only a technical challenge but a constitutional one, for legitimacy in international maritime law depends on the continuous attribution of responsibility.

First, doctrinal gaps in the existing legal framework

The first level of inquiry reveals that the core conventions of maritime law, such as UNCLOS, MARPOL, SOLAS, and COLREGs implicitly presuppose human agency. Article 94 of UNCLOS obliges flag States to effectively exercise their jurisdiction and control over ships flying their flag. Yet, when control becomes algorithmic, effectiveness cannot be evaluated through human oversight alone. The provision lacks criteria for assessing systemic reliability, algorithmic transparency, or data integrity – elements that now define “control” in an autonomous context. Under Article 31(1) of the VCLT, the ordinary meaning of treaty terms must be interpreted in light of the instrument’s object and purpose.⁵⁵ Teleologically, this requires a reinterpretation of effective control as encompassing not only human supervision but functional equivalence in ensuring safe and environmentally responsible operations of autonomous systems.

Similarly, MARPOL Annex VI, which imposes duties on owners and operators to prevent pollution and reduce emissions, presumes intentional compliance managed by human decision-makers. In an automated environment, compliance becomes an algorithmic process, raising the question whether a line of code can violate Article 192 of UNCLOS or the due diligence standard articulated in the 2011 ITLOS Advisory Opinion on responsibilities and obligations of States with respect to activities in the Area. The Convention’s normative silence on this issue creates a void between human liability and machine action. In this context, the IMO’s Regulatory Scoping Exercise for the Use of MASS adopted in 2021 offers an embryonic response by introducing the

⁵⁵ See MCLACHLAN, Campbell. The Principle of Systemic Integration and Article 31(3)(c) of the Vienna Convention. *International & Comparative Law Quarterly* 54, no. 2 (2005): pp. 279–320, DOI: <https://doi.org/10.1093/iclq/lei001>.

principle of equivalent levels of safety, requiring that MASS achieve outcomes functionally comparable to those of manned vessels. However, it leaves unresolved who bears legal responsibility for ensuring equivalence – developers, operators, or flag States.⁵⁶ These ambiguities expose the doctrinal fragility of maritime law when confronted with distributed, non-human agency.

Second, reconstructing responsibility through distributed accountability

To bridge this gap, accountability must be reconceptualized not as a personal attribute but as a systemic condition embedded across the autonomous ecosystem. This implies a shift from hierarchical to distributed responsibility. At the design stage, software developers bear a duty of ethical coding, ensuring that algorithms comply with applicable safety and environmental norms, reflecting the principle of precaution in Article 194(2) of UNCLOS. During operation, shipowners and remote operators retain an *ex post* obligation to monitor algorithmic performance and intervene where necessary, fulfilling a modernized form of due diligence. Meanwhile, flag States, under Article 94 of UNCLOS, must extend their supervisory role to include certification and auditing of algorithmic systems as part of their effective control. Finally, port States reinforce this network through data-based inspections and environmental compliance verification, mirroring the cooperative structure envisioned in MARPOL Article 5. Together, these roles form a Climate Accountability Chain – a polycentric framework where each actor contributes to the law’s constitutional goal of transparency and sustainability.

Third, legality of algorithmic decision-making from law as command to law as code

Beyond attribution, automation compels a rethinking of legality itself. Under classical doctrine, legality arises from human interpretation of legal norms; under autonomy, it emerges through computational execution. This transition from *law as command* to *law as code* risks replacing juridical reasoning with technical optimization. The legitimacy of algorithmic governance thus depends on embedding procedural safeguards – transparency, explainability, and contestability – within the digital

⁵⁶ HONG, Sang-Yong and HAE-DONG Jeon. A Legal Study on the Collision Liability for Maritime Autonomous Surface Ships - Focusing on fully autonomous ships. *Maritime Law Review* 35, no. 3 (2023): pp. 35–73. DOI: <https://doi.org/10.14443/kimlaw.2023.35.3.2>; OSALONI, Oluwatosin S. and AYENI, Victor O. The Development of Maritime Autonomous Surface Ships: Regulatory Challenges and the Way Forward. *Beijing Law Review* 13, no. 3 (2022): pp. 544–54, DOI: <https://doi.org/10.4236/blr.2022.133035>.

decision-making process. These criteria operationalize the rule of law in an automated environment: a decision is lawful not merely if it achieves a compliant outcome, but if its rationale can be reconstructed, audited, and challenged.⁵⁷ Accordingly, the law of the sea must evolve toward algorithmic due process – a constitutional principle requiring that automated maritime systems remain intelligible to human and institutional oversight. In this new paradigm, legality no longer depends solely on human command but on the law’s capacity to ensure that algorithmic conduct remains accountable, transparent, and ecologically coherent.⁵⁸ Only through such a transformation can maritime autonomy coexist with the constitutional integrity of the oceans.

3.3. Polycentric governance and ecological subsidiarity

The Anthropocene constitutes not merely a descriptive context for maritime regulation, but a structural condition that exposes the inadequacy of governance models premised on linear causality and human-centered control. The reconstruction of accountability under automation cannot rely on a single sovereign locus of control. The complexity of MASS demands a governance model capable of managing distributed agency through institutional interdependence rather than hierarchical command. This requirement gives rise to a polycentric structure of maritime governance, in which multiple regulatory centers – global, regional, and private – interact dynamically to ensure that autonomy remains legally coherent and ecologically sustainable.

The concept of polycentric governance, as developed by Elinor Ostrom (2010) and adapted to environmental law, describes systems in which authority is dispersed among overlapping institutions that cooperate through mutual monitoring and adaptive feedback.⁵⁹ In the maritime context, this model translates constitutional sustainability into operational reality. The UNCLOS provides the normative foundation; the IMO develops functional standards such as MARPOL Annex VI and the MASS Code;

⁵⁷ SMUHA, Nathalie A. *Algorithmic Rule By Law: How Algorithmic Regulation in the Public Sector Erodes the Rule of Law*. Cambridge University Press, 2024. DOI: <https://doi.org/10.1017/9781009427500>.

⁵⁸ See LANGER, Charlotte. Decision-Making Power and Responsibility in an Automated Administration. *Discover Artificial Intelligence* 4, no. 1 (2024): 59, DOI: <https://doi.org/10.1007/s44163-024-00152-1>.

⁵⁹ OSTROM, Elinor. Polycentric Systems for Coping with Collective Action and Global Environmental Change. *Global Environmental Change*, 20th Anniversary Special Issue, vol. 20, no. 4 (2010): pp. 550–57. DOI: <https://doi.org/10.1016/j.gloenvcha.2010.07.004>.

regional organizations like the EU implement binding decarbonization measures through the FuelEU Maritime Regulation 2023/1805 and the ETS mechanism; and private actors such as classification societies, insurers, and technology providers codify technical norms and ethical standards. None of these nodes alone can ensure accountability, yet collectively they generate a web of legitimacy rooted in cooperation and transparency. As Black (2008) observes, legitimacy in multilevel governance derives not from unity of command but from reciprocal accountability among overlapping regimes.⁶⁰

This diffusion of authority reflects the principle of ecological subsidiarity – a constitutional logic whereby decisions are taken at the lowest competent level consistent with ecological coherence. At the operational tier, shipowners and operators apply adaptive technologies to meet environmental targets. At the regional tier, bodies such as the EU ensure enforceability through hard law instruments. At the global tier, the IMO harmonizes standards and facilitates capacity-building for developing States, thereby giving effect to the principle of CBDR. Polycentric governance thus transforms sustainability from a normative ideal into a juridical method in which legitimacy arises from coordination, not command; from mutual accountability, not unilateral control.

In constitutional terms, polycentricity represents the maturation of maritime legality in the Anthropocene. It mirrors the ecological reality of the oceans – complex, interconnected, and resilient through diversity. By embedding feedback, participation, and adaptive learning into the governance of autonomy, the law of the sea redefines itself as a constitutional ecosystem, capable of balancing technological innovation with environmental stewardship. This framework sets the stage for the next step about the articulation of a concrete institutional design that embodies these principles – the Sustainable MASS Governance Model.

3.4. The Sustainable MASS Governance Model

The constitutional challenges posed by automation demand not only conceptual adaptation but also institutional architecture. To preserve the legitimacy of the law of the sea in the age of algorithmic governance, sustainability must be operationalized through a coherent juridical framework. The proposed Sustainable MASS Governance

⁶⁰ BLACK, Julia. Constructing and Contesting Legitimacy and Accountability in Polycentric Regulatory Regimes. *Regulation & Governance* 2, no. 2 (2008): pp. 137–64. DOI: <https://doi.org/10.1111/j.1748-5991.2008.00034.x>.

Model (SMGM) offers such a framework. It systematizes the principles of constitutional sustainability and polycentric governance into four interdependent pillars designed to reconcile technological autonomy with ecological legality.

First, green regulatory integration

The first pillar ensures that existing treaty regimes, particularly Articles 94 and 192-194 of UNCLOS, MARPOL Annex VI, and the IMO MASS Code, are interpreted teleologically to encompass autonomous operations. As Kim and Bosselmann (2013) emphasizes, environmental treaties must evolve through purposive interpretation to maintain normative coherence in the face of technological change.⁶¹ Accordingly, duties of control, prevention, and due diligence apply not only to human activity but to algorithmic processes that affect the marine environment. Certification and compliance regimes should therefore assess algorithmic reliability, emission performance, and data transparency as conditions of lawful operation. This approach transforms sustainability from a sectoral obligation into a constitutional standard⁶² of maritime legality.

Second, multilevel coordination

The second pillar institutionalizes polycentric governance. The IMO defines global safety and sustainability thresholds; regional actors such as the EU implement binding decarbonization measures through instruments like FuelEU Maritime Regulation 2023/1805; and private entities such as classification societies, insurers, and technology providers develop and update technical standards. Through reciprocal monitoring and cross-validation, these levels create adaptive feedback loops that sustain ecological coherence across jurisdictions. By institutionalizing cooperation among international, regional, and private regimes, the SMGM constructs a relational legality capable of translating sustainability's abstract values into operative norms across governance scales.

While the EU is examined in this article as a constitutional laboratory for the juridification of sustainability, this approach necessarily raises concerns of EU-centric bias and normative overreach. The transposition of sustainability-driven maritime

⁶¹ KIM, Rakhyun E. and BOSSELMANN, Klaus. International Environmental Law in the Anthropocene: Towards a Purposive System of Multilateral Environmental Agreements. *Transnational Environmental Law* 2, no. 2 (2013): pp. 285–309. DOI: <https://doi.org/10.1017/S2047102513000149>.

⁶² See BIN, Zhao. Towards a Constitutionalization of International Climate Law?. *Opinio Juris*, October 6, 2025. Available from: <https://opiniojuris.org/2025/10/06/towards-a-constitutionalization-of-international-climate-law/>.

regulation into global governance cannot be assumed to be frictionless, particularly in light of structural capacity gaps affecting developing and least developed States. For many flag States in the Global South, the deployment and oversight of MASS intersect with constraints in technological infrastructure, regulatory expertise, and access to green maritime finance. These asymmetries render a purely performance-based model of compliance potentially exclusionary if not accompanied by redistributive mechanisms and capacity-building commitments. Accordingly, the constitutionalization of sustainability in maritime governance must remain attentive to the principle of common but differentiated responsibilities, not merely as a negotiating formula but as an operational condition of legitimacy. Any sustainable governance framework for MASS must therefore integrate flexibility, technical assistance, and institutional solidarity, ensuring that ecological ambition does not translate into structural inequity within the international law of the sea.

Third, distributed accountability

The third pillar consolidates the reconfigured notion of responsibility introduced in Section 3.2. Accountability is shared across the autonomous ecosystem: developers must adhere to ethical-by-design obligations; operators and owners ensure transparent oversight; flag States certify compliance under expanded due diligence duties; and port States conduct data-driven enforcement. Together, these actors form a Climate Accountability Chain, embedding responsibility as a structural – not merely personal – condition of legality. At the institutional level, open-access carbon ledgers and machine-verifiable emissions data can enable public scrutiny and inter-state verification. As Jafarzadeh (2019) argues, transparency is the procedural core of environmental accountability.⁶³ By embedding transparency into technological infrastructure, the SMGM transforms it from an ethical virtue into a constitutional function of legality itself.

Fourth, ethical oversight

Finally, the fourth pillar ensures moral legitimacy through the establishment of an IMO Maritime Technology Ethics Council (MTEC) – a multidisciplinary body tasked with issuing interpretative and ethical guidance on automation's environmental and social implications. Acting through soft-law authority, the MTEC would parallel the

⁶³ JAFARZADEH, Nafiseh. Global Assessment and Review: The Importance of a Transparency Turn in International Environmental Law. In *Charting Environmental Law Futures in the Anthropocene*, ed. LIM, Michelle. Springer, 2019, pp 139-148. DOI: https://doi.org/10.1007/978-981-13-9065-4_12.

function of human rights committees, fostering reflexivity and normative learning within the global maritime regime. Analogous to the European Data Protection Board,⁶⁴ the MTEC would issue non-binding recommendations that, through repetition and uptake, acquire the status of soft constitutional norms. Its authority would derive not from coercion but from epistemic legitimacy. Its capacity to bridge the moral foundations of sustainability and the procedural mechanisms of law. As Bosselmann and Taylor (2017) contends, the legitimacy of ecological law rests on its ability to translate ethical values into institutional form,⁶⁵ the MTEC would embody precisely that translation in the maritime digital sphere.

Collectively, these four pillars reconstruct maritime governance as a living constitution of sustainable autonomy. The SMGM translates constitutional theory into operational design, ensuring that innovation serves legality and that the oceans remain governed not merely by efficiency, but by the enduring principles of transparency, responsibility, and ecological stewardship.

4. Reconstructing maritime legitimacy in the Anthropocene

The age of automation and ecological crisis demands a redefinition of legitimacy within the law of the sea. Traditionally, legitimacy rested on command-based authority – the presumption that control exercised by States and human masters guaranteed accountability. Yet this paradigm collapses under the dual pressures of sustainability and autonomy. When human command gives way to distributed, algorithmic systems, the source of legitimacy can no longer be command; it must be coherence – the alignment of law, ecology, and technology within a unified constitutional logic.

Under Articles 192–194 of UNCLOS, the duty to protect and preserve the marine environment provides the normative anchor for this shift. Read teleologically, these provisions make environmental protection not a discretionary policy but a condition of lawful authority. Law becomes self-legitimizing when it sustains the ecological systems that sustain its validity. In parallel, MARPOL Annex VI, the IMO GHG Strategy and the IMO Net-zero Framework institutionalize this logic through

⁶⁴ Information about the European Data Protection Board, available from:

https://www.edpb.europa.eu/edpb_en

⁶⁵ BOSSELMANN, *Klaus and TAYLOR, Prue. Ecological Approaches to Environmental Law*. Edward Elgar Publishing Limited, 2017.

continuous performance obligations, requiring States and operators to adapt their conduct to scientific evidence and technological progress. Maritime law thus evolves into a reflexive system, learning from the consequences of its own regulation and adjusting through procedural innovation, interpretive evolution, and institutional feedback.

Automation further accelerates this reflexive turn. Properly regulated, algorithmic governance does not erode legality but deepens it. Under the SMGM, accountability is distributed across developers, operators, and States, transparency is ensured through digital traceability, and ethical oversight guarantees alignment with sustainability's constitutional core. These mechanisms transform autonomy into a constitutional test that reaffirms the rule of law by demanding clarity, auditability, and due diligence at every level of decision-making. In this sense, the legitimacy of maritime governance in the Anthropocene depends less on who commands than on how coherently human and non-human systems uphold accountability.

At its deepest level, this reconstruction transforms the very ontology of the sea. The ocean ceases to be a passive object of regulation and becomes a constitutional actor – a living component of legality whose integrity defines the legitimacy of maritime authority. The obligations codified in UNCLOS and MARPOL are therefore reciprocal that States protect the ocean not merely to preserve resources but to sustain the legal and moral order that depends on it. Maritime legitimacy today thus rests on three interlocking foundations, namely coherence, reflexivity, and interdependence. The law of the sea remains legitimate when it learns, adapts, and governs through these principles. In the Anthropocene, autonomy does not signal the erosion of maritime legality but its renewal in terms of a shift from command to coordination, from control to coherence, from rule over the ocean to rule with the ocean.

5. Conclusion

The inquiry has traced the constitutional evolution of maritime law from ecological obligation to technological transformation, revealing a single underlying truth that the legitimacy of the law of the sea in the twenty-first century depends on its capacity to live, learn, and adapt. Sustainability has redefined legality as a function of ecological coherence; autonomy now tests whether that coherence can survive when human control dissolves into distributed intelligence. The challenge is not to choose between human and machine, sovereignty and science, but to weave them into a

common constitutional fabric that sustains both legality and life at sea.

The analysis demonstrates that the relevance of constitutional reasoning in the law of the sea does not lie in formal claims of constitutional status, but in its capacity to articulate standards of legitimacy when sustainability functions as a structural principle and governance is increasingly mediated by autonomous systems. In this respect, MASS does not merely require regulatory adaptation, but expose the constitutional conditions under which maritime law can remain legitimate in the Anthropocene.

The trajectory from constitutional sustainability to autonomous governance shows that law's endurance no longer lies in rigidity but in reflexivity. The oceans, dynamic and interdependent, require a form of legality that mirrors their own resilience capable of adjusting to feedback, integrating innovation, and maintaining balance without losing normative orientation. This is the promise of a living constitution which is a juridical order that preserves legitimacy not through command, but through the perpetual renewal of coherence between human institutions, technological systems, and ecological realities.

Such a vision requires institutions to act as learners, not merely regulators. The international institutions such as IMO and ITLOS, and regional bodies such as the EU must embrace interpretive pluralism and procedural openness, allowing law to evolve through participation, transparency, and shared responsibility. The Sustainable MASS Governance Model embodies this orientation. It is not a fixed design, but a constitutional method, ensuring that maritime governance remains accountable while adaptive.

In the Anthropocene, where the boundaries between natural and artificial, human and algorithmic, have blurred, the law of the sea must stand as the moral and constitutional equilibrium of this new order. Its task is no longer to rule over the ocean, but to preserve the conditions under which the ocean – and the law itself – can continue to exist. The future of maritime governance, therefore, lies not in control, but in continuity: a legality that endures because it evolves.

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