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The protection of the natural environment in armed conflicts and agent-based modelling

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Abstract

This article seeks to demonstrate the nexus between agent-related technology and the protection of the environment in armed conflicts, looking at how agent-based modelling and simulation (ABMS) can be used as a tool to protect the environment in armed conflicts. It further analyzes the precautionary principle and due regard, as relevant rules, and explains the legal benefits of deploying ABMS to protect and preserve the natural environment. The article argues that the deployment of ABMS helps States to better understand the environmental effects of conflicts, reassess their military activities and comply with the relevant applicable rules and norms.

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Keywords: agent-based modelling and simulation, computational design, autonomous agents, environmental protection, armed conflicts.

Introduction

Damages to the environment in warfare are inescapable,[1] and they claim a high toll, not only on humans but also on nature. Armed conflicts destroy the ecosystem, impair natural resources and harm biodiversity on land and in water. They cause deforestation and soil contamination, wildlife depletion and habitat destruction. Water pollution, degraded landscapes, climate change and harm to wildlife are the most common direct environmental effects of an armed conflict.[2] This impact further fuels and lengthens conflicts, deepens disparities and intensifies the scale of human suffering. The harm does not recognize boundaries and lasts beyond the period of conflict. This vicious cycle of destruction threatens the existence of all species, but despite this, the protection of the natural environment is often discussed from a human-centred approach.[3]

In international humanitarian law (IHL), the natural environment was not explicitly protected until 1977. In fact, understanding the protection of the environment is still an evolving and contemporary issue in IHL. In general, targeted attacks on the environment as such and using the environment as an instrument of warfare are prohibited.[4] Care and due regard to the protection and preservation of the natural environment must be taken.[5] In connection with this particular legal protection, technology can be immensely destructive to the environment, on the one hand, when deployed in the use of destructive weapons and military machinery. On the other hand, new technology can play an important role in protecting the environment, reducing the risk of environmental harm due to military activities and improving IHL compliance.

1 David Jensen and Silja Halle (eds), *Protecting the Environment during Armed Conflict: An Inventory and Analysis of International Law*, United Nations Environment Programme (UNEP), Nairobi, 2009.

2 Michael J. Lawrence, Holly L. J. Stemberger, Aaron J. Zolderdo, Daniel P. Struthers and Steven J. Cooke, "The Effects of Modern War and Military Activities on Biodiversity and the Environment", *Environmental Reviews*, Vol. 23, No. 4, 2015.

3 David Leary and Balakrishna Pisupati (eds), *The Future of International Environmental Law*, United Nations University Press, Tokyo, 2010; Donald Anton and Dinah Shelton, *Environmental Protection and Human Rights*, Cambridge University Press, Cambridge, 2011; Jonas Ebbesson and Phoebe Okowa (eds), *Environmental Law and Justice in Context*, Cambridge University Press, Cambridge, 2009.

4 Jean-Marie Henckaerts and Louise Doswald-Beck (eds), *Customary International Humanitarian Law*, Vol. 1: *Rules*, Cambridge University Press, Cambridge, 2005 (ICRC Customary Law Study), Rules 43–45, available at: https://ihl-databases.icrc.org/en/customary-ihl/rules (all internet references were accessed in November 2023).

5 *Ibid.*, Rule 44; see also Protocol Additional (I) to the Geneva Conventions of 12 August 1949, and relating to the Protection of Victims of International Armed Conflicts, 1125 UNTS 3, 8 June 1977 (entered into force 7 December 1978) (AP I), Arts 35, 55.

Agent-related technologies, especially agent-based modelling and simulation (ABMS), can help to analyze environmental conditions[6] before, during and after an attack and can help to provide assessment and information on the damages done (or that could be done) to the ecosystem, law compliance and the possibility of remediation. ABMS has recently been widely used to assess and inform decisions about a variety of complex socio-ecological systems,[7] but has not yet been employed as a legal tool.[8] These models have been increasingly used as a tool in environmental studies[9] to examine the impact of human activities on natural resources and ecosystems, and have been widely used in social sciences[10] to make predictions and assessments for building theories and understanding social phenomena. A model for the application of agent-based simulations, in both academic and industrial projects, has been proposed and studied in the financial markets,[11] and the utility of agent-based systems has been suggested to answer public health questions.[12] In legal studies, however, very few legal scholars have benefited from using ABMS as a tool to build legal theories, analyze legal implications and enhance law compliance.[13] Interestingly, the US Department of Defense uses simulation models in decision-making processes to enhance military training.[14] These models are proclaimed to help "test war plans against adversaries, influence force structure decisions, determine what equipment to acquire, decide the best combination and use of weapons, and explore potential changes in doctrine or tactics".[15] This is precisely how ABMS can help to protect the natural environment when computationally designed to assess military attacks and operations and their environmental impact.

Identifying gaps in the regulatory frameworks normally happens through real-world experiments – for example, when regulations are put into practice, depending on the outcomes and legal analysis, and new regulations and

6 Noelia Sánchez-Maroño *et al.*, "How Agent-Based Modeling Can Help to Foster Sustainability Projects", *Procedia Computer Science*, Vol. 207, 2022.
7 Wenhui Fan, Peiyu Chen, Daiming Shi, Xudong Guo and Li Kou, "Multi-Agent Modeling and Simulation in the AI Age", *Tsinghua Science and Technology*, Vol. 26, No. 5, 2021.
8 Sebastian Benthall and Katherine Strandburg, "Agent-Based Modeling as a Legal Theory Tool", *Frontiers in Physics*, Vol. 9, 2021.
9 N. Sánchez-Maroño *et al.*, above note 6; Patrick Bitterman and Christopher Koliba, "Modeling Alternative Collaborative Governance Network Designs: An Agent-Based Model of Water Governance in the Lake Champlain Basin, Vermont", *Journal of Public Administration Research and Theory*, Vol. 30, No. 4, 2020; Adam McLane, Christina Semeniuk, Gregory J. McDermid and Danielle J. Marceau, "The Role of Agent-Based Models in Wildlife Ecology and Management", *Ecological Modelling*, Vol. 222, No. 8, 2011.
10 Nigel Gilbert and Pietro Terna, "How to Build and Use Agent-Based Models in Social Science", *Mind and Society*, Vol. 1, No. 1, 2000.
11 Marco Raberto, Silvano Cincotti, Sergio M. Focardi and Michele Marchesi, "Agent-Based Simulation of a Financial Market", *Physica A: Statistical Mechanics and Its Applications*, Vol. 299, No. 1–2, 2001.
12 Douglas Luke and Katherine Stamatakis, "Systems Science Methods in Public Health: Dynamics, Networks, and Agents", *Annual Review of Public Health*, Vol. 33, 2012.
13 S. Benthall and K. Strandburg, above note 8.
14 Lloyd Brown, Thomas Cioppa and Thomas Lucas, "Agent-Based Simulations Supporting Military Analysis", *Phalanx*, Vol. 37, No. 3, 2004.
15 Thomas Cioppa, Thomas Lucas and Susan Sanchez, "Military Application of Agent-Based Simulations", in R. G. Ingalls, M. D. Rossetti, J. S. Smith, and B. A. Peters (eds), *Proceedings of the 2004 Winter Simulation Conference*, Vol. 1, IEEE, 2004, p. 1.

amendments are introduced. The cost of assessing environmental effects and the laws related to environmental protection in armed conflicts, in real-world cases, is immense. Therefore, ABMS are valuable and significant tools in this setting because they provide great opportunities for systematic computational experimentations with a wide range of scenarios.

Specific to the context of armed conflict and the natural environment, this article seeks to answer the following question: can ABMS be used as a tool to help protect the natural environment in armed conflict, and if so, how? For the purpose of answering this question, the article seeks to demonstrate the nexus between agent-based technology and the protection of the environment in armed conflicts, considering ABMS as a tool for legal theory. In order to create a clear nexus, the article studies how ABMS technology can be used as a tool to ensure the protection of the environment in armed conflicts. After providing a brief description of ABMS, the article further sets the legal framework and analyzes the precautionary principle as a relevant rule. Finally, it explains the legal benefits of deploying ABMS to protect and preserve the natural environment in armed conflict. The article concludes by arguing that the deployment of such computational technology allows States to better understand the potential environmental effects of a conflict and to reassess their military activities to comply with the applicable rules and norms, particularly the precautionary principle.

Agent-based modelling and simulation technology: Nature and role

What is ABMS technology?

Since ABMS is not well known to the legal field and is rarely found in its scholarship, this section provides a brief summary of its definition and nature. ABMS has been studied for decades in computer and engineering sciences, where it has been systematically introduced and analyzed.[16] In order to break down the concept, the terms "modelling" and "simulation" can be defined separately. Modelling is "the development of a model as a representative of a system, [whereas] [s]imulation can be defined as experimenting or executing a model".[17] With regard to the term "agent-based", "active components or decision makers are conceptualized as agents, being modeled and implemented using agent-related concepts and technologies".[18] Importantly, agents are autonomous, self-directed, unpredictable and social.[19]

16 Averill Law, *Simulation Modeling and Analysis*, 4th ed., McGraw-Hill, New York, 2007; Nigel Gilbert and Klaus Troitzsch, *Simulation for the Social Scientist*, 2nd ed., Open University Press, UK, 2005.
17 Franziska Klügl and Ana Bazzan, "Agent-Based Modeling and Simulation", *AI Magazine*, Vol. 33, No. 3, 2012, p. 30.
18 *Ibid.*, p. 30.
19 Charles Macal and Michael North, "Agent-Based Modeling and Simulation", in M. D. Rossetti, R. R. Hill, B. Johansson, A. Dunkin and R. G. Ingalls (eds), *Proceedings of the 2009 Winter Simulation Conference*, IEEE, 2009.

Literature on ABMS offers a number of definitions of the concept, but it is predominantly defined as:

> [a] set of techniques … [where] relations and descriptions of global variables are replaced by an explicit representation of the microscopic features of the system, typically in the form of microscopic entities ("agents") that interact with each other and their environment according to (often very simple) rules in a discrete space-time.[20]

Once the agents are located within their environment and assigned certain attributes, they

> will need 'sensors' to perceive their … environment. Usually, communication between agents is routed through the environment, which forwards messages on to the appropriate recipient. [A]gents will also need to be able to 'hear' [and] send messages to the environment for onward transmission.[21]

Simply put, agent-based models and simulations are computational tools that simulate the behaviour of individual agents within a system in order to understand how they interact with one another within their given environment and affect the overall outcomes of the system. They are models where multiple entities or actors (agents) "sense and stochastically respond to conditions in their local environments, mimicking complex large-scale system behavior".[22] The idea behind ABMS is to run experimental conduct by actors in a given system instead of merely describing a phenomenon in theory.[23] Such experimental conduct is used to study interactions between people, the environment and things in a given situation. ABMS can be particularly useful when experiments in the real world are not possible to conduct or come at a high cost. There are several types of modelling that would allow for the "investigation of specific real-world systems with highly idealized agents, and the practice of studying models that may not map on to any particular system in the world".[24]

For agent-based models and simulations, the computational agents, their behaviour, their interaction and their environment play an important role, because the simulated system is the result of the complex interaction between these individual simulated agents.[25] Such systems will need to identify the environment in which the agents interact and specify rules and regulations for these actors, before letting the system run to generate scenarios and behavioural outcomes and to make decisions. In the context of law, for instance, ABMS can

20 Dominique Gross and Roger Strand, "*Can Agent-Based Models Assist Decisions on Large-Scale Practical Problems? A Philosophical Analysis" Complexity*, Vol. 5, No. 6, 2000, p. 27.
21 N. Gilbert and K. Troitzsch, above note 16, p. 181.
22 S. M. Sanchez and T. W. Lucas, "Exploring the World of Agent-Based Simulations: Simple Models, Complex Analysis", in E. Yücesan, C. Chen, J. Snowdon and J. Charnes (eds), *Proceedings of the 2002 Winter Simulation Conference*, IEEE, 2002, p. 116.
23 F. Klügl and A. Bazzan, above note 17, p. 30.
24 Michael Weisberg, *Simulation and Similarity: Using Models to Understand the World*, Oxford University Press, Oxford, 2013, p. 4.
25 S. M. Sanchez and T. W. Lucas, above note 22, p. 116.

be a tool for generating patterns and outcomes of normative rules and for understanding of the consequences when certain rules are not followed and when they are.[26] The agents' interaction creates unforeseen outcomes such as legal, social and environmental implications. After the agents have created an outcome within their environment, analysis and assessments are conducted to confirm or refute the validity of scenarios – not mere assumptions – that are produced by the interaction between agents and their environment.[27] Validity, therefore, is an important component of ABSM. Validation techniques are used to lead to reliable and accurate results.[28] Validation and verification are conducted in order to ensure both that the simulations are a good model and that the computational programme is doing what it is expected to do.[29] Finally, the outcomes generated by the agents' interaction are analyzed,[30] and patterns and implications are drawn. Specific to the context of the natural environment in armed conflicts, these processes will depend on the data provided to and expectations of the simulation models and the agents' interactions. The role of ABMS in this context, hence, needs to be discussed.

The role of ABMS in helping to protect the natural environment in armed conflicts

In theory and practice, the role and ability of ABMS to address environmental implications of various specifications of agents have been established. The complexity lies in the given environment – that is, the conduct of armed conflicts. The agents can be modelled as decision-makers in armed conflicts in order to explore their interaction with other agents, the legal norms and their environment. As agent-related technologies, ABMS applications are capable of modelling the behaviour of individual agents or entities within a system and the interactions between them.[31] In complex situations of armed conflict, the modelled system can handle massive amounts of data on all relevant and applicable laws and principles and known environmental implications of military operations and weapons – data on specific contexts as well as psychological and social factors can be provided if necessary – in order to generate scenarios and interaction outcomes. These models can be used to explore the complex interactions between environmental factors, including animals, military operations and attacks, civilians, military commanders and decision-makers. This helps to develop strategies for mitigating the environmental impact of conflicts

26 Randal Picker, *Simple Games in a Complex World: A Generative Approach to the Adoption of Norms*, Working Paper No. 48, Coase-Sandor Institute for Law and Economics, 1997.
27 S. M. Sanchez and T. W. Lucas, above note 22, p. 119.
28 F. Klügl and A. Bazzan, above note 17, p. 38.
29 N. Gilbert and K. Troitzsch, above note 16, pp. 22–23.
30 *Ibid.*, p. 25.
31 See, generally, Paul Davidsson, Johan Holmgren, Hans Kyhlbäck, Dawit Mengistu and Marie Persson, "Applications of Agent Based Simulation", in Luis Antunes and Keiki Takadama (eds), *Multi-Agent-Based Simulation VII*, Springer, Berlin, 2007.

through proper legal understanding and analysis of such conduct. This also means that preventing through predicting is possible.

An ABMS model in the context of law is a model which seeks to replicate, through simulation, the decisions made by agents in a certain environment or context.[32] The model aims to map all relevant elements that underlie and influence the decisions and behaviours made by the agents. The agents, in turn, are those actors that possess some level of autonomy in a complex institutional system (such as subjects of law). Autonomy means here that the actors may intentionally decide to ignore given rules, changing the explicitly represented environment – which is populated by other agents as well – in ways that may also impact their own future decisions. Modelling is conducted in an interdisciplinary fashion, ideally involving tight cooperation between lawyers, environmentalists, economists and computer scientists who can produce a complex and complete dynamic description or portrayal of how actors interact with and in the context of law. Such a portrayal provides an approach to the study of law that is able to capture non-compliance and multi-level feedback loops connecting the behaviour of individual agents to their institutional and environmental context.[33]

Methodologically, ABMS can be beneficial when used as a legal theory[34] whose role lies in the interconnected relationship between legal thinking and computational thinking. The use of ABMS as a legal theory could assist in creating a "methodological portfolio or toolkit containing a range of distinct but complementary modes of analysis [that employs] multiple methods whenever possible".[35] In fact, this is seen as research that "uses more than one research technique or strategy to study one or several closely related phenomena".[36] This approach allows users (legal advisers, environmentalists, military commanders, computer scientists etc.) to carry out a dynamic analysis and achieve more nuanced "results that are more reliable and contribute more to the theoretical development of our understanding of law and society".[37] Developing an agent-based simulation as a method-tool is important. For legal questions related to the protection of the environment in armed conflict, the model development and usage form elements of a scientific method that allows users to address unsolved research questions related to the expressivity of a modelling framework, its validation and interpretation of simulation models in legal studies. Thus, the computational model development and usage provide a framework that facilitates the application of ABMS in legal studies and forms an element of a scientific method. This article envisages that ABMS, when designed and implemented in

32 S. Benthall and K. Strandburg, above note 8.
33 *Ibid.*
34 *Ibid.*
35 Oran Young, "Effectiveness of International Environmental Regimes: Existing Knowledge, Cutting-Edge Themes, and Research Strategies", *Proceedings of the National Academy of Sciences*, Vol. 108, No. 50, 2011, p. 19858.
36 Laura Nielsen, "The Need for Multi-Method Approaches in Empirical Legal Research", in Peter Cane and Herbert Kritzer (eds), *Oxford Handbook of Empirical Legal Studies*, Oxford University Press, Oxford, 2010, p. 953.
37 *Ibid.*, p. 953.

the context of the protection of the environment in armed conflict, is able to significantly contribute to (1) widening the set of available instruments for research in legal science by integrating agent-based modelling, (2) providing specific models of scenarios involving the protection of the natural environment in armed conflict situations and fostering an understanding of these situations as well as an analysis of the consequences, and (3) advancing research in ABMS by developing a new framework for identifying an appropriate level of model legal complexity.

Notably, the forms of complexity are an issue, as models that are too simplified are limited in their supporting insights, while models that are too complex do not allow for the proper validation, verification and analysis which form the basic prerequisites for the reliability and accountability of results. Thus, the levels of detail and abstraction of the model are important to allow the interaction between agents and their environment. Although the examples of the protection of the environment in armed conflict can be very complex, a certain balance should be taken into account in order to reach reliable validation and verification. For example, by modelling the behaviour of military forces and their impact on natural resources, ABMS can help identify areas where resource conservation efforts could be targeted to protect vital environmental resources during armed conflicts. ABMS can also be used to assess the potential consequences of environmental degradation and resource depletion caused by armed conflicts and the methods and means of warfare. For instance, modelling the impact of armed conflict on critical ecosystems can help to identify how environmental damage impacts/affects local communities, as well as the long-term consequences for ecosystem recovery and restoration.[38] Thus, the known environmental implications after the conduct of a military attack or operation can be suitably addressed.

At the legal level, the modelling can help to show to what extent relevant principles have been assessed and on what basis. If no legal basis exists, entirely or partially, then accountability questions should be addressed. Furthermore, ABMS can be used to support laws and policy decisions related to the protection of the environment during armed conflicts. This comes at the law- and policy-making stage. By simulating the outcomes of different legal and policy interventions, such as the application of the law, the use of alternative energy

38 This can be used as an analogy by using previous relevant ABSM studies: see, for example, Moira Zellner, "Embracing Complexity and Uncertainty: The Potential of Agent-Based Modeling for Environmental Planning and Policy", *Planning Theory and Practice*, Vol. 9, No. 4, 2008; Thomas Berger and Christian Troost, "Agent-Based Modelling of Climate Adaptation and Mitigation Options in Agriculture", *Journal of Agricultural Economics*, Vol. 65, No. 2, 2014; L. Brown, T. Cioppa and T. Lucas, above note 14; T. Cioppa, T. Lucas and S. Sanchez, above note 15; Patrick Bitterman and Christopher Koliba, "Modeling Alternative Collaborative Governance Network Designs: An Agent-Based Model of Water Governance in the Lake Champlain Basin, Vermont", *Journal of Public Administration Research and Theory*, Vol. 30, No. 4, 2020; Michael D. Gerst, P. Wang, Andrea Roventini and Giorgio Fagiolo, "Agent-Based Modeling of Climate Policy: An Introduction to the ENGAGE Multi-Level Model Framework", *Environmental Modelling and Software*, Vol. 44, 2013; Pepijn Schreinemachers and Thomas Berger, "An Agent-Based Simulation Model of Humane Environment Interactions in Agricultural Systems", *Environmental Modelling and Software* Vol. 26, No. 7, 2011.

sources or the enforcement of environmental laws, ABMS can help law- and policy-makers to assess the potential effectiveness of different interventions and make informed decisions about how to protect the environment during conflicts. Additionally, ABMS can help in assessing and predicting the legal and environmental implications resulting from a military attack, whether an attack may cause widespread, long-lasting and/or severe damage and whether an attack is in compliance with existing rules and principles. It must be emphasized that agent-based models and simulations are tools aimed at helping actors to make well-assessed and properly explained legal and military decisions.

Setting the legal principles on the environment for agent-based models

The international legal rules and principles that protect the natural environment in armed conflicts can be specific or general.[39] Legal scholars have criticized the legal framework protecting the environment in armed conflicts for its inefficiency and have proposed, *inter alia*, the application of international environmental law provisions to armed conflict.[40] Because of the way in which the role of the natural environment has evolved in armed conflicts, it is continually re-drawing the boundaries within which decision-makers and law-makers can operate; nonetheless, "[d]ecision makers and stakeholders often claim definitiveness in terms of what the law can and cannot accomplish, and the legal questions are often presented as well settled and resolved".[41] The question of the natural environment and the harm it suffers in armed conflicts is not a settled or resolved one, and it thus requires an innovative way of addressing such harm, one that is an analytical-mathematical calculation allowing software computational design to offer decision-making strategies, assess law compliance and show unpredicted interaction between actors and their environment. For this purpose and specific to the context of the protection of the environment in armed conflicts, ABMS can be used to "produce actionable theoretical insights"[42] in order to advance the legal field. As established earlier, agent-based models are strong and influential tools for illustrating the behaviours of different systems and

39 ICRC, *Guidelines on the Protection of the Natural Environment in Armed Conflict: Rules and Recommendations Relating to the Protection of the Natural Environment under International Humanitarian Law, with Commentary*, Geneva, 2020 (ICRC Guidelines).

40 Carl Bruch, Cymie Payne and Britta Sjöstedt, "Armed Conflict and the Environment", in Lavanya Rajamani and Jacqueline Peel (eds), *The Oxford Handbook of International Environmental Law*, 2nd ed., Oxford University Press, Oxford, 2021; Michael Bothe, "Precaution in International Environmental Law and Precautions in the Law of Armed Conflict", *Goettingen Journal of International Law*, Vol. 10, No. 1, 2020; Karen Hulme, "Using International Environmental Law to Enhance Biodiversity and Nature Conservation during Armed Conflict", *Journal of International Criminal Justice*, Vol. 20, No. 5, 2022.

41 Adell Louise Amos, "Developing the Law of the River: The Integration of Law and Policy into Hydrologic and Socio-Economic Modeling Efforts in the Willamette River Basin", *Kansas Law Review*, Vol. 62, 2014, p. 1091.

42 S. Benthall and K. Strandburg, above note 8, p. 1.

producing actionable theoretical insights, but although they have proven to be valuable for social sciences,[43] they are rarely used in the legal framework or legal scholarship.[44] In order to establish the nexus between the protection of the environment in armed conflicts and ABMS, a clarification of the nature of the legal principles in question is necessary. This is precisely because ABMS systems are based on data available to agents and other factors such as legal rules, military commanders, practices and environmental harm.

In order to demonstrate the connection between ABMS and the legal rules protecting the environment in armed conflicts, the precautionary principle and due regard will be analyzed as relevant legal rules. Throughout the legal analysis, this section adopts the normativity of law within the framework of legal positivism[45] for the purpose of deploying ABMS systems. In other words, this section does not intend to evaluate or assess these legal provisions or their efficiency, nor to deeply engage in the debate on these legal issues; rather, it describes the framework in order to establish the nexus between ABMS and the legal protection of the environment in armed conflicts – setting up the legal basis for an agent-based model design – as well as to show the practical characteristics of such a nexus. In other words, this article is not about debating the contours of the applicable legal framework, but rather aims to showcase the potential of ABMS in strengthening the protection of the natural environment in armed conflicts against the background of taking precautions and the due regard principle as a point of departure.

Additional Protocol I to the four Geneva Conventions (AP I) includes certain provisions that protect the environment in armed conflict under Articles 35 and 55. Article 35(3) generally limits the employment of methods of warfare which are intended or expected to cause "widespread, long-term and severe damage to the natural environment". Considering the precautionary principle, which is the focus of this section, there are two main provisions that are relevant to the context of the protection of the environment in armed conflict: Article 55 (1) of AP I, and Rule 44 of the International Committee of the Red Cross (ICRC) Customary Law Study. Each provision will be discussed in turn below.

Article 55(1) of AP I stipulates:

> Care shall be taken in warfare to protect the natural environment against widespread, long-term and severe damage. This protection includes a prohibition of the use of methods or means of warfare which are intended or may be expected to cause such damage to the natural environment and thereby to prejudice the health or survival of the population.

In order to ensure that the outcome of an attack does minimal environmental harm, care to the natural environment shall be taken in warfare and military operations.

43 N. Sánchez-Maroño *et al.*, above note 6, p. 2546.
44 S. Benthall and K. Strandburg, above note 8.
45 Brian Bix, "The Normativity of Law", in Torben Spaak and Patricia Mindus (eds), *The Cambridge Companion to Legal Positivism*, Cambridge University Press, Cambridge, 2021.

The duty of care becomes a responsibility of the individual attackers/military commanders in armed conflict.[46] Taking such care of the environment is translated into the outcome of an attack, a considerably high threshold of damage.[47] Specific to this context, widespread, long-lasting and severe environmental damage is prohibited. It is important to note that the United Nations Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques (ENMOD Convention) requires the fulfilment of one element: widespread, long-lasting *or* severe.[48] Hence, the ENMOD Convention lowers the threshold of environmental damage. More precisely, defining the scope of each element is important. The definitions of the Committee on Disarmament, for example, can be adopted; these are explained as:

(a) "widespread": encompassing an area on the scale of several hundred square kilometres;
(b) "long-lasting": lasting for a period of months, or approximately a season;
(c) "severe": involving serious or significant disruption or harm to human life, natural and economic resources or other assets.[49]

Although these provisions have certain identified gaps in scope and application,[50] they serve as a basic rule for the primary data – setting the threshold of environmental damage – for agent-based models and simulations. The description of widespread, long-lasting and severe provides leeway for the ABMS software designers. In fact, it allows the individual simulated agents to be "aware of (and interact with) their local environment through simple internal rules for decision-making, movement, and action".[51] These agents can comprise a large number of heterogeneous individuals on the battlefield,[52] representing belligerents, civilians, machines and the natural environment.

Another principle that influences decision-making regarding the natural environment is the precautionary principle. Customary IHL describes the obligation to take all feasible precautions to avoid or minimize damage to the environment (the precautionary principle).[53] Rule 44 ("Due Regard for the Natural Environment in Military Operations") of the ICRC Customary Law Study reads:

46 Janina Dill, "Do Attackers Have a Legal Duty of Care? Limits to the 'Individualization of War'", *International Theory*, Vol. 11, No. 1, 2019.
47 Karen Hulme, "Taking Care to Protect the Environment against Damage: A Meaningless Obligation?", *International Review of the Red Cross*, Vol. 92, No. 879, 2010.
48 Convention on the Prohibition of Military or Any Other Hostile Use of Environmental Modification Techniques, UNGA Res. 31/72, 10 December 1976 (entered into force 5 October 1978), Art. 1.
49 *Report of the Conference of the Committee on Disarmament*, UN Doc. A/31/27, 29 November 1976, p. 91.
50 Mais Qandeel and Jamie Sommer, "Syria Conflict and Its Impact: A Legal and Environmental Perspective", *International Journal of Humanitarian Legal Studies*, Vol. 13, No. 2, 2022; Michael Bothe, Carl Bruch, Jordan Diamond and David Jensen, "International Law Protecting the Environment during Armed Conflict: Gaps and Opportunities", *International Review of the Red Cross*, Vol. 92, No. 879, 2010.
51 S. M. Sanchez and T. W. Lucas, above note 22, p. 116.
52 *Ibid.*
53 ICRC Customary Law Study, above note 4, p. 147.

> Methods and means of warfare must be employed with due regard to the protection and preservation of the natural environment. In the conduct of military operations, all feasible precautions must be taken to avoid, and in any event to minimize, incidental damage to the environment. Lack of scientific certainty as to the effects on the environment of certain military operations does not absolve a party to the conflict from taking such precautions.[54]

The principle of precaution, embodied in Rule 44, recognizes the importance of the protection of the environment, not only for human survival but also for the natural environment itself.[55] According to Rule 8 of the *ICRC Guidelines on the Protection of the Natural Environment in Armed Conflict* (ICRC Guidelines), precautionary measures must be taken to prevent undue damage. The rule provides:

> In the conduct of military operations, constant care must be taken to spare the civilian population, civilians and civilian objects, including the natural environment. All feasible precautions must be taken to avoid, and in any event to minimize, incidental loss of civilian life, injury to civilians and damage to civilian objects, including the natural environment.[56]

The commentary on this rule explains how parties must fulfil their obligations to take necessary precautions in the conduct of military operations, even when lacking scientific certainty, noting that international environmental law is of significant relevance.[57] It must be emphasized that the natural environment is protected not only by the rules of IHL but also under other rules of international treaty and customary law, including international environmental law, international human rights law, the law of the sea and international criminal law.[58] More specifically, the prominence of the precautionary principle is centred at the heart of international environmental law,[59] as much of the consideration of the principle of precaution in international law has been in the context of environmental obligations under international environmental law. The core content of the principle in international environmental law has attained the status of a customary norm,[60] and is thus legally binding. For the purpose of this article, building a case for the use of ABMS also requires the inclusion of all relevant laws, rules, doctrines and commentaries providing for protection.

In practical terms, this protection is useful for developing a comprehensive computational design for ABMS systems. Designing practical steps for the conduct of military operations, defining feasible measures and outlining precautions are all

54 *Ibid.*
55 *Ibid.*
56 ICRC Guidelines, above note 39, p. 56.
57 *Ibid.*
58 *Ibid*, p. 20.
59 Aline L. Jaeckel, *The International Seabed Authority and the Precautionary Principle*, Brill, Leiden, 2017, pp. 27–69.
60 Arie Trouwborst, *Evolution and Status of the Precautionary Principle in International Law*, Kluwer Law International, 2002, pp. 7–31.

essential considerations of an ABMS design. Certainly, the precautionary principle is read in conjunction with other IHL principles, such as those of proportionality and distinction, as well as other existing IHL treaties and norms.[61] The application of these principles has been established in Principle 14 of the 2022 Draft Principles on Protection of the Environment in Relation to Armed Conflicts.[62] Additionally, understanding the complexity of the protection of the environment in armed conflicts also involves understanding certain principles originating from international environmental law and their effectiveness in "restraining environmental damage being caused by military activities".[63]

These legal obligations compel participating parties in military operations to assess and identify the environmental implications and possible environmental harm of military attacks, and are thus "relevant for military leaders responsible for operational planning".[64] Such planning is carried out before an attack and includes, *inter alia*, the type of weapons used and their direct and indirect impact on the environment. Chemical weapons, for instance, have an extreme negative environmental footprint and thus should not be used in warfare by default.[65] In addition, military leaders carry the responsibility of ensuring that such planning is conducted and that the negative environmental impact of a launched attack is minimized or prevented. This "will be judged according to [the] relative standards of measurement [of each Belligerent Party]", bearing in mind that "the required standard of conduct applies at all operational levels".[66] For the purpose of ABMS, military leaders are seen as independent agents that interact with the existing regulations and principles, the natural environment, and all other agents, including belligerents. The outcome of such interaction in ABMS computational design helps to examine how an assessment was done before and after a military attack. The ABMS outcome comes in connection with the obligation to take precautions in attack and helps to provide an assessment and analysis of the environmental impact of an attack. The assessment and analysis show the (un) lawfulness of an attack, considering the damage done to the natural environment.

The inventory of potential legal interpretations is of utmost importance. Transforming legal norms into modal logic for agent reasoning will provide the foundation for informing the development and implementation of the ABMS through data on relevant legal norms. Thus, defining the applicable legal principles that protect the natural environment in armed conflicts is vital for the computational design of agent-based models and simulations. Some elementary steps should be considered carefully, including:

61 Cordula Droege and Marie-Louise Tougas, "The Protection of the Natural Environment in Armed Conflict – Existing Rules and Need for Further Legal Protection", *Nordic Journal of International Law*, Vol. 82, No. 1, 2013.

62 *Draft Principles on Protection of the Environment in Relation to Armed Conflicts*, in *Yearbook of the International Law Commission*, Vol. 2, Part 2, 2022; see also UNGA Res. 77/104, 19 December 2022.

63 M. Bothe, above note 40, p. 268.

64 ICRC Guidelines, above note 39, p. 28.

65 *Ibid.*, Rule 21; see also M. Qandeel and J. Sommer, above note 50.

66 Jean-François Quéguiner, "Precautions Under the Law Governing the Conduct of Hostilities", *International Review of the Red Cross*, Vol. 88, No. 864, 2006, pp. 802–803.

1. Clarifying the scope, where the legal principles are defined in their scale and application to enable the agent-based models and simulations to function. Some rules can be ignored to create a wider-ranging set of agent behaviour.
2. Establishing standards for the use of agent-based models, including issues such as transparency in decision-making and accountability for violations.
3. Ensuring scientific validity in order to enable agent-based models to interact in an environment based on sound scientific principles.
4. Ensuring that the data used in agent-based models are accurate, transparent and verifiable. This includes data on the behaviour of individual agents, as well as the environmental conditions in which they operate, to produce a complex and complete picture on their interaction.

It is important to note that the computational system must be designed in accordance with the relevant rules and good practice for the agents concerned and their environment in order to generate the expected outcomes. Furthermore, the suitable scenarios for an analysis of the effects of the compliant and non-compliant decision-making of agents that considers the environmental impact depend on the legal framework and the practices and behaviour of the agents. The results of how these agents behave independently and unpredictably might influence decision-making in situations of armed conflict by illustrating potential environmental harm before the actual attack and, in the event of an attack, by showing the actual environmental damage. Thus, ABMS systems have the potential to create a practical pre-assessment and to enrich the understanding of the complexity of harm against the natural environment before, during and after an armed attack.

The nexus between ABMS and the environment in armed conflicts

Technology can be both a threat to and a tool for protecting the environment in times of armed conflict. On the one hand, it can be immensely destructive to the environment when using advanced war technologies such as armed drones, chemical weapons, weapons of mass destruction and military machinery.[67] For example, the use of weapons that release toxic chemicals or radiation can have long-lasting environmental effects,[68] while the destruction of infrastructure and the release of hazardous materials can also pollute the environment and harm

67 A. Thanikodi and P. Kanagaraj, "Military Technologies and Environmental Rights: A Study of Deleterious Consequences and Remedial Measures", *Indian Journal of Political Science*, Vol. 70, No. 2, 2009; UNEP, "Environmental Assessment of the Areas Disengaged by Israel in the Gaza Strip", 10 April 2006, available at: www.unep.org/resources/report/environmental-assessment-areas-disengaged-israel-gaza-strip; Organisation for Economic Co-operation and Development, "Environmental Impacts of the War in Ukraine and Prospects for a Green Reconstruction', 1 July 2022, available at: www.oecd.org/ukraine-hub/policy-responses/environmental-impacts-of-the-war-in-ukraine-and-prospects-for-a-green-reconstruction-9e86d691/.

68 Robert Coppock and Margitta Dziwenka, "Threats to Wildlife by Chemical Warfare Agents", in Ramesh Gupta (ed.), *Handbook of Toxicology of Chemical Warfare Agents*, 3rd ed., Academic Press, London, 2020.

wildlife. Additionally, the use of technology in military operations can result in the destruction of natural habitats and ecosystems. On the other hand, technology tools such as agent-related technologies can play an important role in protecting the environment, reducing the risk of environmental harm due to military activities and improving IHL compliance.

Modelling and simulations are well-known tools for theorizing and organizing knowledge.[69] ABMS is an individual-based approach derived from complex adaptive systems[70] and multi-agent systems,[71] whose general approach is described as generative social science.[72] This approach is particularly apt for dealing with situations in which interactions between heterogeneous (intelligent) actors must be explicitly considered. Those interactions may be context-dependent and change over (simulated) time. International law provisions, specifically those related to the natural environment, can be viewed as complex adaptive systems.[73] The natural environment is a complex system containing highly interactive components, with non-linear dynamics and feedback loops continuously emerging in them. The problems that emerge in such a system are complex for international law because of both the endogenous non-linear dynamics of the natural environment and the exogenous complexities associated with multiple stakeholders and actors involved and their often conflicting goals.[74] In the case of IHL, agent-based models and simulations have great potential to be used to (1) analyse the conceivable effects of military activities on the environment and determine their legality, (2) evaluate the effectiveness of monitoring and assessment systems for compliance and accountability, and (3) design effective policies to assess, monitor and investigate military activities through high-tech evidence- and data-gathering tools. This significant role necessitates the creation of a clear nexus between technology and the protection of the environment in armed conflicts. The connection between ABMS and the protection of the environment in armed conflicts is strong. This connection is described below.

During war and armed conflicts, each military attack or operation must be assessed individually in accordance with a set of rules and principles on military

69 M. Weisberg, above note 24.

70 Complex adaptive systems are "systems that involve many components that adapt or learn as they interact": John Holland, "Studying Complex Adaptive Systems", *Journal of Systems Science and Complexity*, Vol. 19, 2006, p. 1.

71 Multi-agent systems are forms of artificial intelligence which "form a system that comprises two or more agents, which cooperate with each other while achieving local goals": Jing Xie and Chen-Ching Liu, "Multi-Agent Systems and Their Applications", *Journal of International Council on Electrical Engineering*, Vol. 7, No. 1, 2017, p. 189.

72 Joshua Epstein, *Generative Social Science: Studies in Agent-Based Computational Modeling*, Princeton University Press, Princeton, NJ, 2012.

73 Jutta Brunnée, "The Rule of International (Environmental) Law and Complex Problems", in Heike Krieger, Georg Nolte and Andreas Zimmermann (eds), *The International Rule of Law: Rise or Decline?*, Oxford University Press, Oxford, 2019; Rakhyun Kim and Brendan Mackey, "International Environmental Law as a Complex Adaptive System", *International Environmental Agreements: Politics, Law and Economics*, Vol. 14, 2013.

74 Tomer Broude, "Complexity Rules (or: Ruling Complexity): Comment on Jutta Brunnée", in H. Krieger, G. Nolte and A. Zimmermann (eds), above note 73.

necessity, proportionality, the precautionary principle and due regard.[75] As modern weaponry has become capable of inflicting extreme destruction on an ever-increasing scale, the assessment of military attacks and operations requires a very rigid analysis. When military commanders decide to launch an attack or conduct a military operation, the environmental harm should be substantially calculated and considered. As discussed previously, the rules regarding the natural environment can be broken down into two categories: rules that aim to minimize the incidental effects on the natural environment caused by attacks on military objectives, and rules that restrict attacks on the natural environment as a target.[76] If these rules are not respected during the assessment or in outcomes, a violation can be established. With the use of ABMS, it becomes possible to provide for a framework in which tractable techniques can be implemented that meet various requirements of environmental protection modelling. The deployment of ABMS helps to predict human decision-making, which can be modelled and studied in attacks where there are environmental concerns. This means shaping the interactions between different scales of decision-makers, as well as the investigation of the emergence of responses to spare the environment from harm.[77]

Deployment of ABMS as a computational tool can be centred around enhancing environmental protection and compliance during armed conflicts by predicting implications and impact. This deployment can further enrich the understanding of the complexity of damage against the environment. The formulation and formalization of the models will support the clarification of the underlying real-world situations and the understanding of factors and ingredients relevant for such scenarios for law- and decision-makers. Thus, instead of dealing with severe, long-lasting and/or widespread environmental damage after the fact, ABMS can help to predict and avoid such damage. The purpose is to dissect the complex phenomenon as a way "to decompose a complex totality into its constituent entities and activities and then to bring into focus what is believed to be its most essential elements".[78] With this method, it is possible to improve the understanding of and explanations for how agents (States and combatants) that are involved make decisions in this regard and in the context of what particular elements such conduct occurs, as well as its impact on other agents (civilians and the natural environment). The models developed can be implemented as simulations providing a tool to use within the defined scenario and to make an in-depth analysis of alternative settings and resulting dynamics. As such, the modelling effort can help to provide a means to understand different sub-projects and support a comprehensive international legal framework on the protection of the environment in and during armed conflicts.

75 See, generally, ICRC, *Handbook on International Rules Governing Military Operations*, Geneva, December 2013.

76 ICRC Guidelines, above note 39.

77 M. Hare and P. Deadman, "Further Towards a Taxonomy of Agent-Based Simulation Models in Environmental Management", *Mathematics and Computers in Simulation*, Vol. 64, No. 1, 2004.

78 Peter Hedström, *Dissecting the Social: On the Principles of Analytical Sociology*, Cambridge University Press, Cambridge, 2005, p. 2.

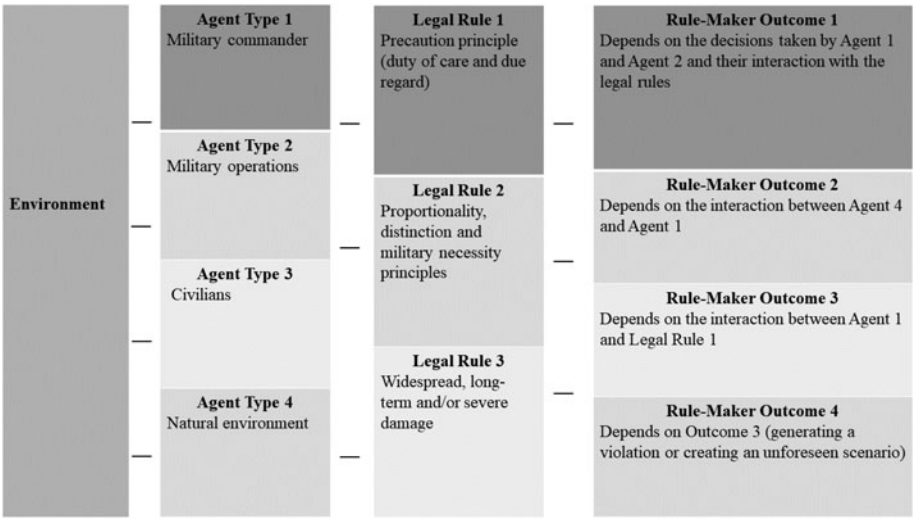

Figure 1. ABMS system: Protection of the natural environment in armed conflicts.

With the help of ABMS, and in connection with the precautionary principle as a relevant rule, parties to a conflict can thus predict environmental harm and implications, and decision-makers and law-makers can root out weaknesses in law and compliance mechanisms and identify gaps. With more specificity, a military commander can minimize the environmental footprint of a military attack, while law-makers and legal scholars can identify additional possibilities for future legal efforts to protect the environment and its constituents, including human beings. In other words, ABMS can help ensure greater scientific accuracy for predicting environmental harm and determining gaps in the law as well as the need for new rules if required. ABMS can be considered as a tool with which the precautionary principle is fulfilled. Simply put, as parties have the obligation to take all feasible precautions to avoid or minimize damage to the environment, deploying ABMS reflects an incentive of taking measures to avoid environmental harm.

In order to visualize the concept, Figure 1 shows how the deployment of an ABMS system is envisaged to be designed in relation to the protection of the environment in armed conflicts. The figure illustrates very limited examples and does not cover all the possible data input in terms of legal rules, actors, decisions etc.; as such, it only provides a limited picture of what an ABMS environment might look like. The figure is based on the "Environment-Rules-Agent Framework" for building agent-based computational models established by Gilbert and Terna.[79]

79 N. Gilbert and P. Terna, above note 10, p. 68.

Concluding remarks and policy recommendations

This article has attempted to offer a novel approach to enhancing the protection of the natural environment in warfare and armed conflicts. It has argued that the use of agent-based models and simulations, given their computational designs, provides for a balanced representation of actors and has a strong potential to help improve the understanding of and compliance with international legal rules. This article has further discussed that the deployment of such agent-related technology allows States to better understand the potential environmental effects of conflicts and to reassess their military activities and operations so that they comply with the applicable rules and norms, particularly the precautionary principle as a relevant rule. The article by no means claims that ABMS will solve all problems in the legal field, particularly those pertaining to the protection of the environment in armed conflicts; rather, it suggests that ABMS can be a significantly beneficial tool for advancing the understanding of law provisions and their interactions with States and non-State actors in the given environment and context. ABMS can also be a tool that helps to predict the environmental impact of military operations and attacks, and to assess military activities in line with the relevant principles.

For such agent-based models and simulations to come to life, a large amount of data input is needed on what exactly the laws are, how military commanders and States think of and interpret them, the kind of decisions that should be made by them and the features of the context of armed conflict (the area, the natural environment, the type of this environment, the type of attack, the means and methods of war etc.). Moreover, legal theories are a very important part of such computational systems to help those who deploy ABMS as a tool, including legal scholars, military commanders, law-makers, decision-makers, computer scientists and environmentalists, with the analysis and assessment of the modelling and simulation scenarios. The overall approach can be better understood when it is formulated in terms of the law and the issues that exist; ABMS can then be a tool that helps new and novel insights to emerge.

Finally, this article suggests that States should incorporate such agent-based technology in their policies and invest in the application of ABMS in order to improve the provisions of and compliance with the law. The article also suggests a dialogue among legal scholars, computer scientists, environmentalists, military actors and legal and environmental advisers to ensure that the natural environment is at the centre of protection and to deploy ABMS as a tool to help predict environmental effects, make sound decisions and assess environmental and legal implications. Within the complex peculiarities of international law, particularly IHL, ABMS may in all probability contribute to the progress of important legal issues at the national and international levels. ABMS systems can subsequently be deployed throughout the lifecycle of legal norms, starting with the evaluation and design of law proposals and ending with implementation, effectiveness and compliance. Theoretically and practically, the deployment of ABMS in the legal field is feasible.

The ultimate purpose of this article is to highlight the deployment of an innovative tool, namely ABMS, in international law. When ABMS is used in policy-making, law-making and implementation, it offers the possibility of making more informed decisions by analysing vast amounts of data and providing valuable insights. As a tool, ABMS can greatly contribute to proper law-making and decision-making in situations of armed conflict with a view to decreasing environmental damage, by helping to assess and predict future environmental harm and potential legal implications. The broader implication of the deployment of such a tool is to encourage legal reasoning through decision trees and sets of rules for computational designs. In many ways, the legal thinking of legal scholars is very similar to the computational thinking of computer scientists; a dialogue between the two can therefore bring many constructive results.