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POLICY REVIEW

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How environmental regulation can drive innovation: Lessons learned from a systematic review

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Abstract

Regulation is often seen as a barrier to innovation. However, if done properly, it can actually serve as a driver of innovation. To understand how environmental regulation can be designed to stimulate innovation, we scrutinise the scientific literature related to regulation, innovation and the environment. Fifty one carefully selected studies are examined with regard to their scope, results and geographical affiliation, and their findings were distilled into ten lessons on how to design environmental regulation to stimulate innovation. Subsequently, we discuss the validity and implications of the lessons. We find that the lessons are overarching concepts of principal nature that are applicable for most regulatory settings. We also find that recent EU regulations on plastics, nanomaterials and waste support many of the lessons learned, while some are completely neglected. The lessons offer important guidance and can be seen as a checklist of what regulators must consider when designing new regulation.

KEYWORDS
environmental regulation, innovation, nano-specific REACH revisions, porter hypothesis, single-use plastic directive, waste framework directive

1 | INTRODUCTION

Regulation is often seen as a barrier to innovation and creative solutions, and new regulatory initiatives are frequently met with apprehension or even animosity by industries (AISE and CEFIC, 2015; SCI, 2020), who fear for their business practices and the economic and administrative burden imposed on them by the new regulation.

In the past few years, the EU has recognised that measures are needed to secure innovation within its regulatory framework (EC, 2021a; European Council, 2016). This requirement became blatant following the support of the 'innovation principle' (IP), which, in short, aims to: improve existing and future EU regulations by assessing their impact on beneficial innovation, steer the development of innovative solutions to embed EU values and protect Europeans and secure adaptability for scientific and technological progress as well as the predictability of the regulatory environment (EC, 2019a).

According to Garnett et al., the IP was proposed to the European Union (EU) in 2013. It was originally set up as a lobbying tool by industry, but it has since enjoyed increased popularity and is now recognised in the EU (European Council, 2016; Garnett et al., 2018). However, the IP is not implemented in either primary or secondary EU legislation, and it has been criticised as a compromise to the well-established precautionary principle (PP; Garnett et al., 2018)—and as a Trojan horse (Leroux, 2018). Nevertheless, the IP is still increasing in popularity with the European Council and the Commission (EC, 2019a). Recently, the European Commission (EC) initiated an independent expert evaluation of the IP and its current implementation in the EU (Renda & Simonelli, 2019). This expert evaluation was published in a report dated November 2019 and concluded, among

others, that the IP lacks: a clear legal basis, clarity between the PP and the IP, an acknowledged definition, sufficient awareness from EU officials and other stakeholders and enough capabilities in research and innovation (R&I) for better regulation initiatives (Renda & Simonelli, 2019). Nevertheless, the report does merit the IP holds as a successful tool for securing the quality and future-proof nature of EU policy.

Scientific literature published within the field of regulation and innovation is vast. A search on 'Regulation' and 'Innovation' yields more than 8000 hits on Web of Science (WoS) and more than 2.3 million hits on Google Scholar; many suggestions on how to improve regulation to stimulate innovation have been published over the years. The scope of the present paper is to collect data on how environmental regulation can be successfully compiled and implemented to drive green innovation. This is achieved by scrutinising the scientific literature and then assembling a set of lessons learned to support future regulators when designing environmental principles. Further, the implications of the lessons learned for future regulations are discussed with a glance at how the lessons learned are supported by three recent EU environmental regulations.

1.1 | The Porter hypothesis and the triple helix of regulatory driven innovation

The early and mid-1980s saw an increased awareness of how regulation affects industrial innovation (Ashford & Heaton, 1983; Stewart, 1981). Ashford et al. published a key paper describing responses in innovation to regulation, setting the scene for how regulation can be utilised to drive the market for innovation (Ashford et al., 1985). Building upon the work of Ashford et al. and others, Porter formulated the conceptual paradigm that environmental regulation is not just another economic and administrative obstacle for the industry to overcome but is rather a measure to support and steer innovation, if constructed properly (Porter, 1991). In his paper, Porter refers to how countries with strict environmental regulation often lead the market, claiming that 'tough standards trigger innovation and upgrading' (Porter, 1991). Within environmental management and regulation, this paradigm has become known as the 'Porter hypothesis' (Ambec et al., 2013; Kriechel & Ziesemer, 2009; Wagner, 2003), which has both a weak and a strong version. The weak version postulates a positive correlation between environmental regulation and innovation, while the strong version establishes a positive causal relationship between environmental regulation, innovation and a firm's productivity (Dechezleprêtre et al., 2019).

The Porter hypothesis has been at the epicentre of a long and heavy debate on regulatory eligibility as a driver of market innovation and competitiveness (Ambec et al., 2013; Kriechel & Ziesemer, 2009; Palmer et al., 1995; Wagner, 2003; Xepapadeas & de Zeeuw, 1999), and to date, it has been vehement challenged—especially by economists and business managers. One example of this criticism is the publication of Palmer et al., who claim that the hypothesis completely denies the validity of established environmental decision-support tools, leading to a fundamental misrepresentation of the problems surrounding environmental regulation (Palmer et al., 1995). Several studies have scrutinised the theoretical foundations of and empirical evidence for and against the Porter hypothesis (Ambec et al., 2013; Petroni et al., 2019; Xepapadeas & de Zeeuw, 1999; Xu, 2016), and although the findings are not unequivocal, most studies tend to favour the hypothesis—or at least its weak version. Thus, it remains controversial, but many of the thoughts behind it still stand tall, and it seems broadly accepted that environmental regulation can—and should—be designed to stimulate creativity and innovation while protecting human health and the environment. To illustrate this, the conceptual model of the innovation triple helix was developed in the late 1990 s and early 2000 s (Leydesdorff & Etzkowitz, 1998). Figure 1 depicts the conceptual model of the triple helix with the basic elements; industry, regulating authorities and academia/researchers, and the processes of regulatory driven innovation. The question left to answer is, how are such environmental regulations best designed to facilitate innovation?

2 | METHOD

2.1 | Literature review

For the systematic review in this study, WoS was utilised to analyse the scientific literature for peer-reviewed reviews published before August 2021 in recognised ISI journals within the field of regulation and innovation. The key search terms used were: Innovation, Regulation and Environment* in combination. In total, the searches yielded 223 reviews. However, 46 of these evolved around the regulation of biological processes and were thus disregarded. After careful inspection of the abstracts of the remaining 177 reviews, 32 were deemed relevant for innovation related to regulation and the purpose of this study. Through the reviews identified, relevant studies were backtracked. A brief historical biography of the 177 reviews was conducted to illustrate the increasing attention on regulation and innovation in the scientific literature, including an analysis of the geographical affiliation of the first authors (Africa, Asia, Europe, Middle East, North America, Oceania or South America), thereby helping to understand where the research is anchored. Also, a few studies evolving around regulatory measures were included in the review, together with EU regulatory documents, including reports and communications. Based on the reviews, studies identified through them and the hand-picked studies, this review encompasses a total of 51 carefully selected studies based on their relevance in terms of innovation related to regulation. A list of the studies included herein is provided in Appendix S1A. From the literature, information on how environmental regulation might be structured, assembled and implemented, in order to stimulate innovation, was compiled into 10 lessons learned.

3 | RESULTS AND DISCUSSION

To provide an overview of the historic development of the scientific papers published within the fields of innovation, regulation and environment* (the three key search terms), data on the numbers of review publications per year were extracted from WoS, as shown in Figure 2a. From the figure, it is evident that approximately 50% of all

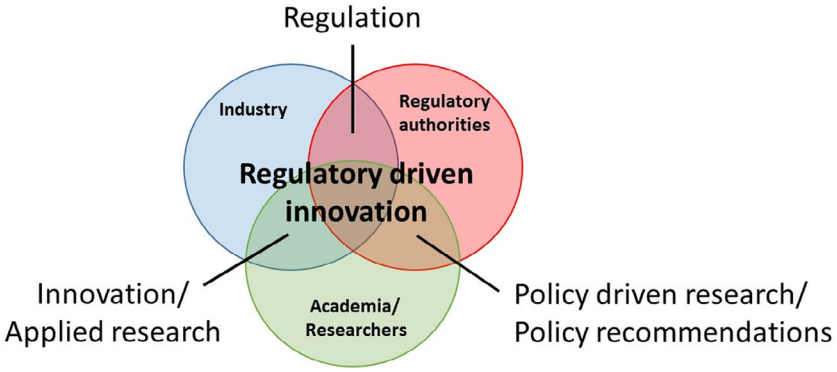

FIGURE 1 The innovation triple helix depicting the processes of regulatory driven innovation. Modified from Zhou and Etzkowitz (2021) [Color figure can be viewed at wileyonlinelibrary.com]

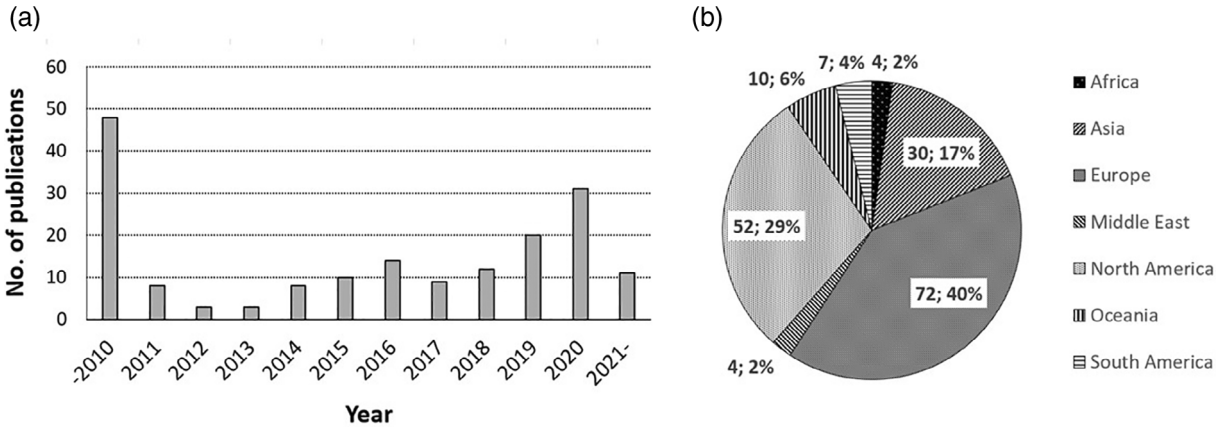

FIGURE 2 (a) Historical bibliography overview of the 177 published scientific review papers matching the search terms 'innovation', 'regulation' and 'environmental*' in WoS. (b) Geographical affiliation of the first authors of the identified papers. The numbers provided are numbers of studies from the respective geographical area followed by the percentage of the total studies identified. Note that the sum of papers is greater than 177, as some first authors were affiliated with more than one geographical area

reviews published in the field have been released over the past 5 years, with approximately 35% of the papers published in the past 2–3 years, that is, from 2019 to August 2021. It is noteworthy that a substantial amount of the literature (48 papers, or more than 25%) is relatively old, in that it was published in 2010 or before. Despite their age, however, many of the observations and conclusions might still be valid, and thus they are still included in our review.

From the analysis of the geographical affiliation of the first authors, as illustrated in Figure 2b, it is obvious that the majority of the research within the field has taken place in Europe and North America, constituting 69% (124 studies) of the studies identified. A quite substantial contribution is also provided by Asia (17%; 30 studies), whilst much less represented are Oceania (6%; 10 studies), South America (4%; 7 studies), Africa (2%; 4 studies) and the Middle East (2%; 4 studies).

3.1 | Lessons learned in terms of how environmental regulation can stimulate innovation

From the literature scrutinised, 10 lessons learned in terms of how environmental regulation can and should stimulate innovation was extracted. The lessons learned, the rationale and corresponding arguments behind the inclusion of the lessons, as well as the references for the supporting literature are provided in Table 1.

4 | DISCUSSION

4.1 | Lessons learned about the tripple helix of regulatory driven innovation

The concept of regulatory driven innovation is not a new invention. In fact, it has been around for decades—if not centuries without being termed as such. The triple helix of regulatory driven innovation, Figure 1, depicts how industry, regulators and researchers must come together to find solutions on how regulation can be designed to stimulate innovation. The 'pure' form of command-and-control regulation taking place between industry and regulators has little or nothing to do with facilitating innovation. This type of regulation only provides, what is often perceived as constricting, frameworks within which innovation has to take place. This is the reasoning behind much of criticism of command-and-control environmental regulation, for example, Palmer et al. (1995). On the other hand, there is a risk that

TABLE 1 The 10 lessons learned on how environmental regulation can stimulate innovation, the rationale and arguments for the inclusion of the specific lessons learned and, the references for the studies backing the specific lessons

Lesson learned	Rationale and arguments the inclusion of the lessons	References
Lesson 1: Environmental regulation should guide innovation	A great deal has been said about the Porter hypothesis, but there seems to be consensus that environmental regulation is positively correlated to innovation—as supported by the weak version of the hypothesis (Ambec et al., 2013; Borsatto & Bazani, 2020; de Vries & Verhagen, 2016; Dechezleprêtre et al., 2019; Lähteenmäki-Uutela et al., 2017; Magat, 1979; Wang & Shen, 2016). Importantly, there seems to be little evidence that strict environmental regulation lessens innovation. Even though the study is somewhat old, Rothwell (1992) scrutinised two major reports commissioned by the Six Countries Programme and the Environmental Directorate of the Organisation for Economic Co-operation and Development (OECD), uncovering the impacts of environmental regulation on innovation and highlighting that negative impacts are mainly associated with bad implementation. In fact, some studies point at low innovation as a result of overly lenient regulation (Ashford et al., 1985; de Vries & Verhagen, 2016; Porter & Van der Linde, 1995), and a recent study by Borsatto and Bazani on green innovation and environmental regulations, in which they reviewed 96 academic papers to identify trends and patterns, established that environmental regulation is one of the strongest drivers of innovation (Borsatto & Bazani, 2020). Likewise, Galera-Quiles et al. (2021) reviewed the influence of export and eco-innovation on the regional and national level by assessing 60 scientific papers. The authors ultimately made a call for more stringent environmental regulation, in order to stimulate eco-innovation. Also, Acar et al. (2019) reviewed 145 scientific papers evolving around regulation and innovation and identified and categorised constraints to creativity and innovation. They synthesised their observations into a taxonomy of constraints and mediation mechanisms, concluding that innovation induced by regulation is often coupled with a desire to lower the costs and expenses induced by compliance requirements, which may or may not be correlated to increased productivity—as proposed by the strong Porter hypothesis. With this in mind, environmental regulation should be used as a starting point from which to guide and steer innovation in a desired direction (e.g., green innovation) by setting the boundary conditions for which the innovation has to take place. de Vries and Verhagen (2016) investigated the impact of standardisation on innovation within the construction sector in the Netherlands. Not only did they find strong evidence for the weak version of the Porter hypothesis, they also observed how regulation triggers different types of innovation, making regulation a powerful tool to guide innovation.	Acar et al., 2019; Ambec et al., 2013; Ashford et al., 1985; Borsatto & Bazani, 2020; de Vries & Verhagen, 2016; Dechezleprêtre et al., 2019; Galera-Quiles et al., 2021; Lähteenmäki-Uutela et al., 2017; Magat, 1979; Porter & Van der Linde, 1995; Rothwell, 1992; Wang & Shen, 2016.
Lesson 2: The transition period is vital for industry if it wishes to adapt and find innovative solutions	In theory, new regulation may dramatically change the business landscape and potentially shut down old markets and/or open up new ones. Even if changes introduced by the regulation are less dramatic, companies have to adapt to the new regulatory landscape. As pointed out several decades ago by Ashford et al., this adaptation process requires time. The authors in this instance reviewed innovation waivers under three major environmental regulatory measures in the United States of America (USA): the Clean Air Act, the Clean Water Act and the Resource Conservation and Recovery Act. They highlighted that the mere anticipation of regulation is a strong driver of innovation, and thus, by setting a sunset date, that is, an expiry date for a Bill or an Act, innovation can be stimulated (Ashford et al., 1985). Much in line with Ashford et al. (1985), Hansen and Tickner (2007) analysed past experiences of voluntary environmental programmes (VEPs) in the United States and proposed a three-year transition period for new regulation. They suggested that regulatory initiatives should be introduced as 3-year VEPs that are subsequently made mandatory. By providing benefits for those engaging in these VEPs, early movers are rewarded for their efforts. Moreover, the three-year transition period allows the industry to prepare for upcoming obligations and invent innovative solutions. As noted by Acar et al. (2019), time pressure has a positive impact on creativity and innovation; however, they stress that innovation and creativity are 'reverse U-shaped' correlated to constraints, meaning that firms facing unachievable time pressures will make 'last resort solutions' and put innovation on the backburner, while a too long transition period will make firms hesitant. Thus, it is important to have a short transition phase that still allows sufficient time for adoption.	Acar et al., 2019; Ashford et al., 1985; Hansen & Tickner, 2007.
Lesson 3: Clear and concise regulations	In relation to innovation, it was recognised by Ashford et al. back in 1985 that regulation should be clear and concise and that regulating authorities should provide clear guidelines (Ashford et al., 1985). Many studies have addressed this issue. For instance, in 2015, de Miranda and Kruglianskas examined three institutional initiatives for 'regulatory renew', namely 'the recognition, during the decade of 1990, of the need to incorporate economic concerns within environmental regulation; the OECD programme for good practices in regulatory management; and the European Union 'better regulation' effort', and established 13 principles for good environmental regulatory quality. Among these, they highlighted that regulation must be clear and concise (de Miranda Ribeiro & Kruglianskas, 2015). Some other examples of studies raising the issue of clarity in regulation are Banks (2004), Brown et al. (2018), Rothwell (1992), Gouldson and Murphy (1998) and Ashford (1999). Brown et al. reviewed international policy issues and innovations and stressed that insufficiently clear rules and regulations hamper innovation and lead to confusion and uncertainty (Brown et al., 2018). Companies need to know what they are facing, in order to derive innovative solutions. Uncertainty about regulatory requirements, deadlines and the means accepted to meet them are bound to provoke inaction. Moreover, resources are often scarce, and firms might not have the surplus to deal with unduly expenses (Pacheco, 2020).	Ashford, 1999; Ashford et al., 1985; Banks, 2004; Brown et al., 2018; de Miranda Ribeiro & Kruglianskas, 2015; Gouldson & Murphy, 1998; Rothwell, 1992.

TABLE 1 (Continued)

Lesson learned	Rationale and arguments the inclusion of the lessons	References
Lesson 4: Flexible regulation and compliance deadlines	The industry consists of many different types of firms, companies, supply chains, etc., each of which has a very different environmental orientation, level of expertise and the opportunity and capacity to meet regulatory requirements. Regulations must be flexible to meet their individual capabilities and to facilitate creative and innovative solutions (Ambec et al., 2013; Brown et al., 2018; Dechezleprêtre et al., 2019; Lähteenmäki-Uutela et al., 2017; Remmen, 2001). In general, the scientific literature recognises that more prescriptive regulation tends to hamper innovative initiatives—in contrast to more flexible measures (Acar et al., 2019; Ashford et al., 1985; Banks, 2004; Pelkmans & Renda, 2014; Porter & Van der Linde, 1995). For instance, Lähteenmäki-Uutela et al. (2017) dissected the scientific literature on the economic impacts of environmental regulation, taking their point of reference from sulphur emission control, and described how regulation can slow down innovation when forcing the use of a particular technology. Thus, it is important that regulations allow maximum flexibility with respect to the means to achieve them (Ashford, 1999; de Miranda Ribeiro & Kruglianskas, 2015). Not only should the means to achieve regulatory requirements be flexible, but also the deadlines for complying with them. Ashford et al. (1985) argued that regulatory requirements and complying dates could be negotiated on a firm-by-firm basis. As such, they suggested that firms should develop environmental action plans, which are evaluated annually by regulating authorities. This is not necessarily in contradiction with the three-year transition period proposed by Hansen and Tickner (2007), as the latter should be seen as a rule of thumb. The idea of negotiable compliance in terms of dates seems intriguing but might be challenging to implement for all regulatory measures, due to the administrative burden. However, the concept that deadlines and requirements can be postponed or relieved under the right conditions is valid, for example, in the form of waivers. In addition, regulation should consider various reasons for non-compliance. Innovation entails a certain amount of uncertainty, and thus a higher risk of failure. If failing, due to taking an innovative approach in good faith, there should be possibilities for postponing compliance dates so that companies are not penalised for making creative and innovative choices. Furthermore, waivers could be endorsed with requirements of commercial availability (Ashford et al., 1985).	Acar et al., 2019; Ambec et al., 2013; Ashford, 1999; Ashford et al., 1985; Banks, 2004; Brown et al., 2018; de Miranda Ribeiro & Kruglianskas, 2015; Dechezleprêtre et al., 2019; Hansen & Tickner, 2007; Lähteenmäki-Uutela et al., 2017; Pelkmans & Renda, 2014; Porter & Van der Linde, 1995; Remmen, 2001.
Lesson 5: Provide economic incentives and other benefits for (doing more than) complying	Traditional regulatory measures such as command and control are efficient for regulating firms with a reactive environmental strategy (Remmen, 2001). However, these types of measures do not provide any incentive to go beyond simple compliance, and thus they are not well-suited for firms with a proactive environmental strategy (Banks, 2004; Remmen, 2001). In order to provide such an incentive, and to foster proactive and innovative firms, several measures have been proposed in the literature. For instance, Dechezleprêtre et al. (2019) reviewed 60 papers presenting empirical evidence on the correlation between the environmental and economic performance of firms, concluding that environmental taxes and market-based mechanisms hold the potential to promote these factors. Examples from the literature of measures to provide motivation include environmental taxes, emission pricing and trading programmes (Dechezleprêtre et al., 2019; Malloy, 2001; Wang & Shen, 2016), sanctions (Ashford et al., 1985), market-based incentives (Ambec et al., 2013, Banks, 2004, Dechezleprêtre et al., 2019), voluntary environmental programmes (Gouldson & Murphy, 1998; Hansen & Tickner, 2007), information-based incentives (Bowen & Panagiotopoulos, 2020), self- and co-regulation (Banks, 2004; Remmen, 2001) and performance-based incentives (Banks, 2004; de Miranda Ribeiro & Kruglianskas, 2015). Important for all of the measures is that they are not bound by a fixed endpoint and that they keep providing benefits for the firms if they optimise continuously. This provides the motivation to keep pressing the limits and think of new and innovative solutions.	Ambec et al., 2013; Ashford et al., 1985; Banks, 2004; Bowen & Panagiotopoulos, 2020; de Miranda Ribeiro & Kruglianskas, 2015; Dechezleprêtre et al., 2019; Gouldson & Murphy, 1998; Hansen & Tickner, 2007; Malloy, 2001; Remmen, 2001; Wang & Shen, 2016.
Lesson 6: A regulatory process where all voices are heard	In the 'Better regulation' report of 15 April 2019, issued by the EC, it is evident that stakeholder involvement is a key element of EU policy and one of the responses envisioned to secure regulatory-driven innovation (EC, 2019b). Also, in December 2019, the EC's Expert Group (EG) on Regulatory Obstacles to Financial Innovation (ROFIEG) published a report introducing 30 recommendations on regulation, innovation and finance. These were based on a review of the application and suitability of the EU's legal and regulatory framework in relation to technology-enabled innovation within the financial sector. A main finding of their work is expressed in the 26th recommendation, stating that regulatory dialogue should 'enhance knowledge-sharing[…]', 'share experiences[…]' and 'provide, where appropriate, clarification of or guidance on relevant EU legislation[…]' to facilitate innovation (FSFSCMU, 2019). Further, in the scientific literature on regulation and innovation, there is consensus that stakeholders should be actively included in regulatory processes (Ashford & Hall, 2011; Banks, 2004; Brown et al., 2018; Garnett et al., 2018; Taylor et al., 2012). If regulators are to make tailored regulations capable of guiding innovation while still accomplishing adequate environmental standards, they have to know whom they are regulating, recognise their interests and values and understand their specific needs. Also, gaining their input will help remove obstacles to innovation and map potential issues. None of the studies identified in this review describes the interaction between environmental regulation, innovation and stakeholder involvement. However, in 2002, Beierle reviewed 239 case studies of stakeholder involvement in decision-making and tested the hypothesis that it results in lower-quality decisions. His explicit conclusion was that stakeholder inclusion and intense stakeholder processes result in higher-quality decisions,	Ashford & Hall, 2011; Banks, 2004; Beierle, 2002; Brown et al., 2018; de Medeiros et al., 2014; EC, 2019b; FSFSCMU, 2019; Garnett et al., 2018; Steiner et al., 2019; Taylor et al., 2012.

(Continues)

TABLE 1 (Continued)

Lesson learned	Rationale and arguments the inclusion of the lessons	References
	as stakeholders bring in new information, ideas and analysis (Beierle, 2002)—in other words, the basis for innovative solutions. Moreover, stakeholder inclusion will lead to increased responsibility at all societal levels (Steiner et al., 2019) and may hold the key to successful regulation, as these stakeholders possess important knowledge and understand the subtle nuances of the 'real world' (Taylor et al., 2012). Furthermore, de Medeiros et al. reviewed 67 papers with the aim of mapping critical success factors driving the success of product innovation. They found that the diffusion of innovative solutions and technologies in society is driven by stakeholders, thus making them pivotal in the success of environmental regulation, both from an environmental and an innovation perspective (de Medeiros et al., 2014).	
Lesson 7: Evaluation of effects on innovation	In a study commissioned by the EC, Pelkmans and Renda (2014) reviewed trends within EU regulation over the past 30 years in relation to impacts on innovation. They scrutinised seven case studies of EU regulation obstructing and encouraging innovation. As part of their conclusion, they called for ex ante and ex post impact assessments (IAs) of EU legislation much in line with the IP. Also, they stressed that innovation can be stimulated by reassessing the comprehensive regulations of the Union. This point was also emphasised by Dechezleprêtre et al. (2019) and Banks (2004), both of whom called for policy and regulatory solutions that allow better evaluation of the effectiveness of regulations in general. In the EU, all regulations are subject to an IA (EC, 2021a), which explicitly requires an assessment of impacts on innovation (EC, 2021b). With this in mind, and with the increased EU focus on innovation, and to some extent the implementation of the IP, assessing new and old regulations according to their impact on innovation seems obvious.	Banks, 2004; Dechezleprêtre et al., 2019; EC, 2021a, 2021b; Pelkmans & Renda, 2014.
Lesson 8: Secure support and capacity-building	Administration and compliance with regulatory requirements poses an economic burden for the regulated (Banks, 2004). Weiss et al. scrutinised 57 papers within the field of material adequacy and innovation, looking into how resources or a lack thereof affects innovation. They concluded that financial resources are important for innovation (Weiss et al., 2017). Several studies highlight that some regulated groups are more vulnerable to administrative and economic burdens than others (Acar et al., 2019; Banks, 2004; del Brìo & Junquera, 2003). Especially small and medium-sized enterprises (SMEs) lack excess resources and have limited capacity. Therefore, regulations sometimes favour large companies (Ashford & Heaton, 1983; del Brìo & Junquera, 2003; Pacheco, 2020). Further, regulations that introduce high costs or constrain flexibility promote evasive behaviour (Banks, 2004). For these reasons, it is paramount to secure proper support for those who are challenged with respect to resources (economic, knowledge and expertise or other) and to support capacity-building. Also, the administrative burdens of regulation risk drawing resources away from innovation. For example, a study by the EC assessed the impacts of REACH on innovation from 2010 to 2013 (EC, 2015). It comprised a telephone interview survey with firms (1076 replies), an online business survey (566 replies), stakeholder interviews (104 interviews), in-depth interviews with selected firms (56) and an examination of five case studies. Among others, the report concluded that approximately half of the firms surveyed had transferred resources from innovation (research and development—R&D) to compliance activities. Also, Acar et al. (2019) pointed out that if excess resources are limited, firms are more creative and innovative in their use of them. However, they also noted that excess resources encourage higher risk-taking that might stimulate innovation. Thus, resources available to firms should be sufficient while still being limited. As a result, all regulations should be assessed according to their imposed burdens. In the EU, this is implemented through the IA (EC, 2021a, 2021b). Furthermore, firms of all sizes can apply for financial support in the form of business loans, microfinance, guarantees and venture capital (European Union, 2021).	Acar et al., 2019; Ashford & Heaton, 1983; Banks, 2004; del Brìo & Junquera, 2003; EC, 2015; EC, 2021a, 2021b; European Union, 2021; Pacheco, 2020; Weiss et al., 2017.
Lesson 9: Multiple regulatory measures are needed	Parker et al. (2009) reviewed 49 peer-reviewed scientific studies reporting empirical results on how SMEs, and to some extent larger companies, react to regulatory interventions. They emphasised that SMEs and industry in general represent a wide variety of firms with very different motivations, resources, expertise, capabilities and visions, and that regulatory measures must embrace this diversity. As a consequence, they stressed that a 'holistic mixture' of measures is needed to make companies engage properly and to improve their environmental performance while still allowing operating space for innovation. This viewpoint is supported by Iraldo et al. (2011), who reviewed the literature on links between environmental regulation and competitiveness. They established that no regulatory instruments can stand alone to make firms more environmentally proactive and innovative, noting that 'the key question is not "which instrument is best", but "which mix of instruments is best"' (Iraldo et al., 2011). This is further supported by Remmen (2001). In his study, scrutinising several Danish governmental support schemes, he identified the challenges involved in designing and implementing tailored, differentiated and dynamic regulatory solutions that take into account firms' motivation, resources, expertise, capabilities and visions. Nevertheless, this is the challenge that regulators must succeed in to produce effective environmental regulations that simultaneously foster green innovation.	Iraldo et al., 2011; Parker et al., 2009; Remmen, 2001.

TABLE 1 (Continued)

Lesson learned	Rationale and arguments the inclusion of the lessons	References
Lesson 10: Minimise the costs of compliance: the proportionality principle	Regulation inevitably introduces costs for the regulated and the regulating authority alike (Acar et al., 2019; Banks, 2004; Gouldson & Murphy, 1998). Banks (2004) examined the existing scope and role of regulations in Australia, focusing specifically on costs. Overall, he found that costs associated with regulation are high from both an administrative and a compliance perspective. He stressed that these costs are often underestimated, due to the complexity of estimating 'true costs'. As mentioned, it is evident that firms compensate for the economic and administrative burdens imposed by regulations, taking resources from R&D activities, thus hampering innovation (EC, 2015). With this, it is important to keep regulatory burdens at a minimum, without compromising the intentions of the regulatory initiative. After all, the purpose of the regulation must be the first priority, as stressed by Banks (2004); otherwise, it will be obsolete. In the EU, this is addressed through the proportionality principle of Article 5, which in theory stresses that actions taken by the EU must be necessary and kept to a minimum, in order to 'achieve the objectives of the Treaties' (EUR-Lex, 2019). From the perspectives of economic burdens introduced by regulation, this is more formerly addressed in the EU IAs, which are to be carried out if 'initiatives [are] expected to have significant economic, social or environmental impacts' (EC, 2021a).	Acar et al., 2019; Banks, 2004; EC, 2015; EC, 2021a; EUR-Lex, 2019; Gouldson & Murphy, 1998.

innovation taking place in the intersection between industry and academia/research can get 'out of hand'. Consequently, it is generally recognised that regulation should put in place restrictions or guidance of research to avoid, for example, the violation of ethical issues. Contrary the 'free' innovative research at the industry-academia/research intersection, policy driven research risk being locked to specific means, methodologies or paradigms and might not be considered truly free and innovative and might not be relevant for the industry either. Thus, it is not sufficient for regulators, industry and researchers to work two-and-two but rather, all three have to work together to promote the regulatory driven innovation. The 10 lessons learned established in this study aims at facilitating this collaboration, which must be much more than simple collaboration. It should be a partnership with the common goal of making innovation thrive within the regulatory settings.

4.2 | Validity of the lessons learned

The lessons learned extracted from the literature are overarching concepts of principal nature that are applicable for most regulatory settings and that we believe should be relevant for all who wishes to accelerate green environmental innovation by the use of regulation. The lessons compiled are based on literature and experiences from around the globe. Though, it is noteworthy that a substantial amount of the data gathered in this study, originates from Europe and the United States of America, potentially favouring those regulatory settings. We do believe that the lessons learned provides a universal frame for what to consider when designing regulation with respect to fostering innovation.

The 10 lessons learned in themselves fail to provide guidance on how to implement them. For instance, lesson number three states that regulations should promote innovation by being clear and concise. However, it is not within the scope of this study to gather empirical evidence on how to establish clear and concise regulation that minimise ambiguity and misunderstandings. This would be an entire field of research of its own, for each of the lessons established, and how to do so might be very dependant of the specific pieces of legislation (e.g., environmental field such as waste, chemical or other type of regulation), type of legislation (e.g., command and control, directive or other) and cultural setting, and must be carefully designed and tailored for each case.

The next step in the process of validation of the lessons learned will be to gather empirical data on how regulation affects innovation. Some studies for example, de Vries and Verhagen (2016) have collected data for specific sectors, which might or might not be representative for other cases. Indeed, more research is needed in order to confirm the validity of the lessons learned and to gather the empirical data required to support it.

4.3 | Implications of the lessons learned on future regulation

A valid question to raise is to what extend the lessons learned established in this study, are supported by current legislation. A brief

scrutiny of three recent EU regulations, namely the nano-specific Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) annex revisions, the Single-Use-Plastic (SUP) Directive and the Waste Framework Directive (WFD), indicates that the regulations—to a large extent—do support the lessons learned as the EU system has integrated several measures to address and account for many of them (see Appendix S1B). An example is the impact assessment, which specifically mentions impacts on innovation and economic consequences. This could indicate that the implications of adopting the lessons learned might not be so voluminous. However, there are lessons learned that are clearly not implemented yet or only supported to a very limited degree. For instance, lesson 5 that is, calls for providing economic incentives and other benefits for (doing more than) complying, however such incentives are lacking in for example, nano-specific REACH annex revisions, the SUP Directive and the WFD. Adhering to lesson 5, would require regulators to substantially rethink the regulatory means and instruments to avoid the risk of stalling innovation—or even ceasing innovation—as soon as the regulatory requirements are met. Similarly, lesson 2 calls for transition period of no longer than 3 year, allowing industry to prepare for upcoming obligations and invent innovative solutions. Longer transition periods tend to make firms hesitant (Hansen & Tickner, 2007). In the EU, the implications of following lesson 2 would in many cases mean that the transition period would be shorter than it currently is. For instance, the period for out phasing the use of intentionally added microplastics is between 4 years for rinse-off cosmetic products and 12 years for cosmetic lip, nail and certain make-up products (EC, 2022). Shorter transitions periods would force industry to avoid procrastinate while still providing sufficient time to prepare for the upcoming obligations, invent innovative solutions and reward early movers for their efforts.

The three regulations scrutinised in Appendix S1B are all examples of recent European regulations. However, they do illustrate how some lessons learned already are accounted for in current regulation and some not. This of course varies from regulation to regulation and from country to country. Despite this, we believe that they depict well how regulators have to change mind-set to accommodate all of the lessons learned.

Lastly, the 10 lessons learned on how environmental regulation can foster innovation offers important guidance and can be seen as a checklist of what regulators have to consider when designing new environmental regulation.

5 | CONCLUSIONS

A great deal has been said in the scientific literature about environmental regulation and its impacts on innovation. Of the 177 reviews identified, approximately half were published within the past 5 years, thus demonstrating the recent focus on the area. More than two-thirds of the publications originate from North America or Europe, while Asia accounts for almost one-third of the publications, thus indicating a broad worldwide interest.

Often, available conceptions and interpretations of the data are contradictory. Nevertheless, there are also many issues where, to a certain extent, there seems to be some form of consensus. This paper scrutinised 51 scientific peer-reviewed papers in the field of environmental regulation and innovation and deduced 10 lessons learned on how to design future environmental regulation to stimulate innovation, namely (1) Environmental regulation should set the frame for innovation; (2) A transition period is vital for industry to adapt and find innovative solutions; (3) Clear and concise regulations should be provided; (4) Flexible regulation and compliance deadlines should be made available; (5) Economic incentives and other benefits for (doing more than) complying should be in place; (6) A regulatory process should ensure all voices are heard; (7) The effects on innovation should be evaluated; (8) Secure support and capacity-building should be provided; (9) Multiple regulatory measures are needed and (10) The costs of compliance, that is, proportionality principle, need to be considered. The 10 lessons learned on how regulation can support innovation are overarching concepts of principal nature that are applicable for most regulatory settings. As most of the literature on the topic originates from Europe and the United States of America, they might have a bias towards those regulatory settings. A brief analysis of three European regulations (nano-specific REACH annex; SUP Directive and the WFD) indicates that many of the lessons learned are already accounted for under the European regulatory settings. However, some of them are not, requiring a substantial effort to change the regulatory mind-set to truly allow the regulation to spark innovation. More research is needed in order to confirm the validity of the lessons learned and to gather the empirical data required to support it. Despite, the lessons learned offers important guidance and can be seen as a checklist of what regulators have to consider when designing new regulation.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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