3 Regulatory governance and delivery in the energy transition

This chapter highlights existing work on the regulatory governance and delivery of hydrogen, with a specific focus on the energy transition. It first discusses key considerations for the regulation of innovations, focusing on the risks and agility, and the use of licensing for new energy applications. The chapter continues by discussing the application of precaution, highlighting the interaction with innovation as well as Responsible Research and Innovation and safety-by-design approaches.

Regulating innovation in the energy transition

Innovations drive the creation of renewable or low-carbon energy sources such as low-emission hydrogen. The deployment of low-emission hydrogen solutions can fundamentally change how societies and economies function, bringing potential benefits that increase overall welfare. However, to realise the full potential of any innovation, appropriate attention should be paid to its risks. This requires safeguards that ensure novel technologies are developed in a way that upholds fundamental rights, democratic values and the rule of law, while preserving the appropriate protections for citizens and the environment (OECD, 2021[1]).

Innovations often emerge more quickly than the regulations that govern them, giving rise to a “pacing problem” (OECD, 2021[2]). On the one hand, this can create regulatory gaps, where existing regulations do not sufficiently cover the new activities driven by the innovation. This may bring undesirable consequences from a societal point of view – for example when safety or environmental risks are not appropriately managed. On the other hand, the pacing problem may result in regulations that are inadequately tailored to the context of the hazard and associated risks, with unnecessarily high or inappropriate regulatory burdens for innovations and slow the speed of their rollout.

Technological innovations may require policymakers and regulators to change the way they work, including through the creation of new roles and tools. The energy landscape is changing, with new sources of energy such as solar and wind power, and the development of new hydrogen applications. Meanwhile, there is an increasing reliance on digital technologies and online platforms for many regulatory activities (OECD, 2019[3]). Such changes can affect the structures and operations of sectors overseen by regulators and may require them to oversee new activities that did not exist before. At the same time, innovations can support the effectiveness of regulators, in particular through the development of data-driven regulatory tools (OECD, 2020[4]).

Technological innovations may necessitate new or updated mandates, functions and powers for regulators. They may also require regulators to develop new knowledge and skills to supervise and guide new activities and make full use of data-driven approaches. These new demands could put pressure on the overall resources of the regulator (OECD, 2020[4]). Responding to new roles or activities could require regulators to adjust the resources in use: bringing in new staff with the appropriate competences, providing different training and guidance, as well as ensuring that appropriate support and tools are available. As such, appropriate governance can support the continued ability of regulators to both design objective and evidence-based regulatory decisions, and to stay abreast of market developments (OECD, 2022[5]).

Policymakers and regulators may have to consider if existing institutional frameworks and governance arrangements are still effective and efficient in supervising new technologies. This may be especially relevant where new technologies disrupt and cut across the traditional boundaries of markets (OECD, 2020[4]). In light of the foreseen or anticipated change, there may also be a need to develop new institutional co-ordination mechanisms to connect and align the work of different bodies.

Regulatory policy and governance

Sound regulatory policy and governance are crucial to driving the energy transition and enabling the development of renewable or low-carbon energy solutions such as low-emission hydrogen. In 2012, the OECD developed a recommendation to provide guidance to countries on the design, enforcement and review of their regulatory frameworks. The recommendation recognises regulation as one of the crucial factors for governments to promote prosperity, welfare and the public interest (OECD, 2012[6]). To achieve this potential, regulations need to be well designed, implemented and enforced. The recommendation provides governments with twelve key considerations to make sure this is the case (Box 3.1).

Box 3.1. OECD 2012 Recommendation on Regulatory Policy and Governance

To improve the quality of regulation as well as the tools and institutions for evidence-based decision making, the OECD Council adopted the *2012 Recommendation on Regulatory Policy and Governance*. This recommendation advises countries to:

1. commit at the highest political level to an explicit **whole-of-government policy** for regulatory quality.
2. adhere to principles of open government, including **transparency and participation** in the regulatory process.
3. establish mechanisms and institutions to actively provide **oversight of regulatory policy procedures and goals** to foster regulatory quality.
4. integrate **Regulatory Impact Assessment** (RIA) into the early stages of the policy process for the formulation of new regulatory proposals.
5. conduct systematic programme **reviews of the stock of significant regulation** against clearly defined policy goals, including consideration of costs and benefits.
6. regularly publish **reports on the performance** of regulatory policy and reform programmes and the public authorities applying the regulations.
7. develop a consistent policy covering the **role and functions of regulatory agencies** to provide greater confidence that regulatory decisions are objective, impartial and consistent.
8. ensure the effectiveness of **systems for the review of the legality and procedural fairness** of regulations and of decisions made by bodies empowered to issue regulatory sanctions.
9. as appropriate, apply **risk assessment, risk management and risk communication strategies** to the design and implementation of regulations.
10. where appropriate, promote **regulatory coherence** through co-ordination mechanisms between the supranational, national and sub-national levels of government.
11. foster the development of regulatory management **capacity and performance at sub-national levels** of government.
12. give consideration to all relevant **international standards and frameworks** for co-operation in the same field and, where appropriate, their likely effects.

Source: (OECD, 2012[6]), Recommendation of the Council on Regulatory Policy and Governance, https://doi.org/10.1787/9789264209022-en.

When innovations transform sectors or create new activities, as is the case with the development of low-emission hydrogen applications, governments should ensure sufficient role clarity among public actors. When an innovation emerges, it may not always be clear which regulatory agency should supervise or enforce activities, or which ministry may be in charge of policymaking. The 2012 recommendation advises governments to ensure that roles, functions, powers and objectives are therefore defined in legislation (OECD, 2012[6]). Clarifying roles and mandates in law can support an effective execution of regulatory tasks, and prevent overlaps or gaps in mandates.

While hydrogen has been around for a long time as a feedstock in industrial processes, its production process is changing and, most importantly, is expected to become less polluting. Moreover, the scale and scope at which its application is envisaged – beyond the industrial sectors in which it is currently applied – means that policymakers and regulators need to reconsider its regulatory governance. To support a smooth hydrogen transition while acknowledging and addressing its actual risks, more agile regulatory approaches will be required.

Risks in regulation

Innovations can introduce new risks and may reduce existing risks, giving rise to so-called "risk-risk" trade-offs. This context will require governments to define strategies on risk assessment, risk management and risk communication (OECD, 2012[6]). This is also relevant in the case of hydrogen, the properties of which differ from conventional fuels. To ensure regulation is targeted and effective, governments need to provide clear and consistent guidance on methodologies for risk assessment and an objective communication of those risks to the public. As the mitigation of one risk could come at the expense of another, strategies on risk management should communicate how the government expects to approach such "risk-risk" trade-offs (Graham, J. and Wiener, J., 1995[7]).

A risk-based and proportionate approach is not only necessary to the formulation of regulations, but also to their implementation and enforcement. This means that inspections and enforcement activities by regulatory bodies should be proportional and prioritised according to the actual risk level of activities (OECD, 2014[8]). In this context, it is important to emphasise that risks result from the combination of the likelihood of a hazard occurring with the magnitude of damage of such an event. An evidence-based approach to this assessment of risks can ensure an objective risk ranking and avoid a disproportionate focus on hypothetical (rather than actual) risks.

The formulation and communication of comprehensive and clear risk-based approaches to innovations can ensure consistent and predictable decision making. However, the mere existence of risk-based approaches may not be sufficient to achieve this (OECD, 2018[9]). A common understanding of the definition of risk and a common approach to risk management will allow for more harmonised and co-ordinated actions between different regulatory authorities at different levels of government, as well as between teams or units within a regulatory authority. Of course, this need would have to be balanced against any need for regulatory discretion in order to customise decisions based on circumstantial factors.

An important consideration in developing strategies for risk assessment, risk management and risk communication for new hydrogen technologies will be to ensure these are in proportion to the actual risks. This may require a comparative risk assessment with existing fuels, where differential regulatory treatments or stricter risk measures for hydrogen applications should be based on significant and defined additional risks as compared with these fuels. As there is a real momentum driving improvements in technologies and approaches, safety measures based on older data or outdated technologies may result in excessive risk reductions that could obstruct the hydrogen transition. Moreover, without appropriate risk communication, actual risks and public perceptions might deviate, creating a need for decision makers to explain their approaches and provide clear information on risks and measures.

In dealing with the risks and accidents with hazardous installations, the OECD developed the *Guiding Principles for Chemical Accident Prevention, Preparedness and Response*, with a third edition forthcoming (OECD, 2003[10]). These principles address issues related to preventing accidents, preparing for accidents, responding to accidents and follow-up after accidents. The OECD also developed among other things a *Recommendation concerning Chemical Accident Prevention, Preparedness and Response*, and is currently developing a new *Decision-Recommendation concerning Chemical Accident Prevention, Preparedness and Response* that brings together existing OECD legal instruments on the topic (OECD, 2004[11]) (OECD, forthcoming[12]).

The agility of regulation

To acknowledge and account for innovations, enhancing their benefits while managing risks, governments will need to adjust their traditional approach to regulatory governance. To advise governments how they can make their regulatory governance "innovation-proof", the OECD developed the *2021 Recommendation on Agile Regulatory Governance to Harness Innovation* (OECD, 2021[2]). It supports countries in defining more agile and forward-looking approaches that are able to absorb changes in highly uncertain and dynamic contexts. The recommendation is structured along four pillars:

- First, to ensure regulations remain fit-for-purpose, governments should adjust regulatory processes to make them more adaptive, iterative and flexible (OECD, 2021[2]). Existing “regulate and forget” approaches, in which regulations are not regularly assessed after their implementation, may not be robust for dynamic contexts. New technologies, emerging scientific knowledge and changing social and political contexts can create a mismatch between yesterday’s policies and today’s world (Bennear and Wiener, 2019[13]). Governments therefore require an “adapt and learn” approach in regulating innovations, to incorporate new developments and findings into the development of regulation (OECD, 2021[1]).[1] Stakeholder engagement throughout the different regulatory stages (design, implementation and evaluation), with a wide range of stakeholders, enables governments to bring in expertise from various sources and build trust. Wider international engagement and knowledge sharing can support countries in making use of the most up-to-date knowledge on technologies and approaches.
- Second, given how many emerging technologies crosscut and interlink traditional sectors and borders, governments will need to create the institutional foundations for strengthened co-operation and joined-up approaches (OECD, 2021[2]). Whole-of-government approaches can promote effective policy responses. Moreover, institutional co-ordination can be used to identify and resolve institutional or regulatory gaps and overlaps (OECD, 2021[1]). International regulatory co-operation can ensure policy responses and regulatory decisions are harmonised across countries where possible. This could prevent regulatory arbitrage by companies (giving rise to a “race to the bottom” among governments), and remove unnecessary discrepancies between regulatory frameworks.
- Third, governance arrangements should allow for the development of agile and future-proof regulation through forward-looking and outcome-based regulation and experimentation. Horizon scanning can help governments to anticipate developments and so build out institutional capacity and assign mandates in a timely manner. Outcome-based regulatory approaches can support a move away from prescriptive regulation, creating more scope for entities to introduce innovations that improve outcomes while also reducing the “pacing problem” (OECD, 2021[1]). Finally, experimentation, through regulatory sandboxes, testbeds and innovation spaces, can allow for policy learning at a stage where evidence and knowledge still need further development. The testing of regulatory frameworks through dedicated test projects can provide a platform for stakeholders to come together, discuss and assess regulatory improvements and to identify areas for further development (Vannan and Gemmell, 2012[14]).
- Fourth, governments and regulators should consider adapting regulatory enforcement activities to make them more risk-based and focused on outcomes and compliance promotion. Rigid processes and detailed, prescriptive rules can make regulatory compliance unnecessarily burdensome and stifle innovation. Instead, proactive support and guidance for innovators can support a sector-wide understanding of the regulatory framework, drive compliance and could, in turn, feed information to regulators about how to reduce regulatory burdens. At the same time, innovations and data-driven solutions can support the monitoring of compliance through real-time monitoring and continuous data collection (OECD, 2021[1]).

The above considerations to ensure regulations are effective apply broadly across sectors but may be especially relevant in the context of hydrogen. This is due to the characteristics of the hydrogen transition, namely the strong ambitions of countries in this domain, the rapid development of new hydrogen technologies at a larger scale and the emergence of new scientific knowledge. As new hydrogen technologies and applications fundamentally redefine the use of hydrogen across economies, policymakers and regulators will require more agile regulatory models to absorb changes and avoid “regulating the past”.

Box 3.2. Regulating hydrogen in practice: opening a hydrogen refuelling station (HRS)

A key problem is often that new applications of hydrogen have not been foreseen in existing legislation, and that they are thus "by default" either unaccounted for, subject to requirements that do not match its specific risks or facing regulatory uncertainty, particularly in terms of site approval and permitting. This does not in any way mean that hydrogen is generally over-regulated, and this report in any case does not cover the industrial processes involving hydrogen, which often benefit from long-established, specific regulations. Providing case-by-case comparison for every case and country would go beyond the scope of the report, we thus focused here on one simple example: opening a hydrogen refuelling station (HRS), looking at three jurisdictions (California, England, and the Netherlands).

- In California, the state seeks to develop HRSs and to phase out the opening of any new hydrocarbon refuelling stations (petrol stations). A regulatory framework has thus been developed to facilitate HRS openings. Still, the HRS opening process tends to be longer than for petrol stations, and mandatory safety distances for HRS mean that larger lot sizes are required to accommodate them. If there is insufficient space, then additional mitigation measures must be put in place (GO-Biz, 2022[15]). This, however, complicates the licensing process resulting in delays. Furthermore, lots that are large enough to comply with the distancing requirements might be hard to find in more densely populated areas, resulting in the HRS being in more distant locations that might be less convenient to drivers (Harris et al., 2014[16]).
- In England, while the overall opening process features much the same approvals and licenses, HRS require a "gas license" (as if the HRS belonged to a natural gas operator), which typically takes around nine months to obtain, and has very little to do in its specifics with the actual safety issues pertaining to hydrogen (Ofgem, 2022[17]). Larger installations will also require a specific safety approval, and an environmental approval, because all hydrogen installations are regulated as hazardous industrial installations, and there are no specific provisions for HRS.
- In the Netherlands, likewise, based on the current regulations, HRS require environmental permits which are also required for LPG and LNG stations, but are not usually required for petrol stations, unless they are unsupervised and located less than 20 meters away from houses or other vulnerable objects (WVIP, 2020[18]) (RVO, n.d.[19]). New regulation, which is expected to enter into force in 2024, limits the scope of the environmental permit to just the hydrogen fueling process, however, this is still a stricter requirement than for petrol stations, for which environmental permits will no longer be a requirement in any scenario (IPLO, n.d.[20]). In addition, other parts of the HRS licensing process take significantly longer than for hydrocarbons, because the existing development (zoning) plans do not foresee this land use, and "ample time" is required to obtain a special exemption from the plan (WVIP, 2020[18]).

Thus, even in the most favourable regime (California), opening an HRS remained longer and more difficult (restricted siting because of higher fire safety distances). In England, the process was much longer because of the current gas licensing requirements, which are not specific to hydrogen, as well as the safety and environmental permitting needed. In the Netherlands, it was both longer and more difficult because of no zoning provision for HRS and the need to obtain both zoning exemptions and environmental permits.

In summary: "Most countries currently lack specific regulation that target the dispensing of hydrogen in refuelling stations, as this is still new equipment that has not been targeted in regulations. For the HRS (Hydrogen Refuelling Stations) currently deployed, the permitting procedure follows existent guidelines on conventional fuelling stations combined with industrial hydrogen requirements or CNG specific regulation. Most countries agree that the lack of specific regulations increases the level of subjectivity in the permit decision" (MultHyFuel Project, 2021[21]).

Figure 3.1. Regulating hydrogen in practice: Opening a hydrogen refuelling station

Source: https://www.shutterstock.com/image-vector/green-sustainable-hydrogen-energy-gas-fueling-2061029765; https://www.shutterstock.com/image-vector/petrol-pump-fuel-car-auto-1408643744.

Regulatory delivery in the energy transition

Regulatory delivery looks at the activities and actions, measures and processes used to secure the implementation of regulations in practice (OECD, 2021[22]). It looks at regulatory delivery mechanisms such as licensing regimes, inspections and enforcement by regulatory authorities.

Licensing

Licensing is a tool used by governments and regulators to control the conduct of specific activities. Licensing is an overarching term for the use of permits, licences, certifications or other forms of authorisation before the start of an activity. It is understood to be any administrative procedure whereby official approval by at least one competent authority is required to perform, use or own something [BPP licensing]. Reasons for licensing requirements can be the achievement of public policy goals, the control and reduction of potential harms or a restriction to the use of certain goods or resources.

Licensing is a form of regulation in which activities usually cannot take place until permission in the form of a licence or other authorisation has been granted. For this reason, it can be perceived as a rather restrictive form of regulation, where it poses a burden on industry by slowing down the deployment of new technologies and reducing the agility of innovators. Licensing also gives rise to a potential risk of regulatory capture, whereby the regulator, having granted a licence or given permission for an activity, may feel a degree of responsibility for any adverse safety outcomes that arise.

Delays and bottlenecks due to licensing procedures can significantly delay the time it takes to build clean energy infrastructure such as hydrogen. The IEA finds that while construction is a relatively efficient process, taking two to four years depending on average, planning and permitting procedures may end up taking two to seven years, depending on the jurisdiction and type of infrastructure (IEA, 2023[23]).[2] Such lead times could pose an obstacle to the timely expansion of the hydrogen infrastructure.

A number of constraints in licensing requirements can affect the speed of rollout of innovations such as renewable or low-carbon energy applications. Complex licensing procedures with excessive safety requirements can make it more time-consuming to scale up and develop new energy technologies. Moreover, different regulatory requirements, sometimes enforced by different regulatory bodies with low levels of co-ordination, can lead to risk assessment in silos, without consideration of risk-risk trade-offs. This could therefore result in an unbalanced weighing of local safety risks against the more global risks of the climate crisis. Given the novelty of many green energy technologies, licensing requirements may sometimes still be based on older forms of technology or apply disproportionately high levels of precaution for relatively low levels of risk [licensing renewables paper].

A lack of scientific understanding of the actual risks of new energy solutions, combined with poor public perception, can lead to an overly cautious approach to their licensing. Even in contexts where overall risks of new technologies may be relatively low, the occurrence of accidents can negatively affect public perception and regulators or regulatory systems may be blamed for not preventing them (Van der Heijden, 2022[24]). The lack of absolute certainty on risks, given the novelty of technologies, can result in overly restrictive safety requirements in licensing procedures. Safety risks related to existing fossil fuel technologies often meet a higher risk tolerance, which may be explained by a higher degree of familiarity by the public with these applications and more publicly available data [licensing renewables paper].

To ensure licensing regimes are effective, governments should take a risk-based approach to licensing. The proportionality and burden of the instrument should match its purpose and the risks it aims to manage. The level of risk that a specific activity poses, based on reliable data and evidence, should be the key criterion for determining the severity of licensing requirements. Specifically, for the case of new green solutions, governments will also need to balance the harms from new technologies against the risk of climate change that these try to counter [licensing renewables paper].

Consequently, licensing should be the exception, not the default, when managing significant risk in contexts where there are no other regulatory instruments with a lower burden on regulated entities. A good practice is to minimise the use of licensing to the level absolutely necessary. However, in practice across countries, licensing is often applied more systematically for a variety of situations, regardless of its adequacy in protecting the defined public goals [BPP licensing]. A system with "silent consent" or notifications could be used for green technologies with a low risk profile, and prior assessments for larger-scale projects with higher risk profiles. This could reduce the need for assessment only at the end of projects, thereby reducing potential delays [licensing renewables paper].

Where licensing is required, governments and regulators should assess ways to lower burdens on entities. This will require simplification of requirements and procedures whenever possible, for example through the streamlining of processes or "one-stop shops", removing overlapping requirements, reducing document requirements to the absolute necessary, and digitalisation. Licensing authorities could furthermore provide straight-forward guidance material to innovators, informing them of the different steps and requirements. This could reduce the burden on both applicants and authorities by limiting the number of incorrect submissions and the delays and extra work they cause [BPP licensing].

Inspections and enforcement

Governments and regulatory bodies establish laws, regulations, and principles to guide the energy transition. These frameworks outline the specific requirements and standards that companies must meet. As the energy sector shifts towards cleaner and more sustainable energy sources, it is essential to monitor and enforce adherence to established standards.

Ensuring effective compliance with these rules and regulations is an important factor in creating a well-functioning society and trust in government. It can help to safeguard health and safety, environmental protection, and delivery upon other policy goals (OECD, 2014[8]). By designing effective inspection and enforcement frameworks for the energy transition, regulatory authorities can promote sustainable development, foster innovation in clean energy technologies, and ensure compliance with environmental and safety standards throughout the energy sector.

Inspections help verify compliance with regulations and ensure that companies are contributing to the established goals. They can evaluate safety protocols and risk management practices, which includes assessing worker safety, emergency response plans, maintenance procedures, and adherence to industry standards. Inspections are crucial for renewable energy projects such as hydrogen fuel stations, wind farms, solar installations, and hydroelectric plants. They help verify the proper implementation of these projects, including site selection, construction practices, equipment quality and grid integration.

Non-compliance with regulatory requirements can result in enforcement actions. These can include warnings, improvement notices, fines, license revocation, project shutdowns, or prosecutions. Regulatory actions complement other enforcement of regulation through information, guidance and prevention, data collection and analysis and inspections (OECD, 2014[8]).

Box 3.3 includes the OECD *Best Practice Principles on Regulatory Enforcement and Inspections*, which are crucial to design an effective framework for regulatory delivery to support the energy transition.

Box 3.3. OECD Best Practice Principles on Regulatory Enforcement and Inspections

The OECD defined eleven key principles on which effective and efficient regulatory enforcement and inspections should be based:

1. **Evidence-based enforcement.** Regulatory enforcement and inspections should be evidence-based and measurement-based: deciding what to inspect and how should be grounded on data and evidence, and results should be evaluated regularly.
2. **Selectivity.** Promoting compliance and enforcing rules should be left to market forces, private sector and civil society actions wherever possible: inspections and enforcement cannot be everywhere and address everything, and there are many other ways to achieve regulatory objectives.
3. **Risk focus and proportionality.** Enforcement needs to be risk-based and proportionate: the frequency of inspections and the resources employed should be proportional to the level of risk and enforcement actions should be aiming at reducing the actual risk posed by infractions.
4. **Responsive regulation.** Enforcement should be based on “responsive regulation” principles: inspection enforcement actions should be modulated depending on the profile and behaviour of specific businesses.
5. **Long term vision.** Governments should adopt policies and institutional mechanisms on regulatory enforcement and inspections with clear objectives and a long-term road-map.
6. **Co-ordination and consolidation.** Inspection functions should be co-ordinated and, where needed, consolidated: less duplication and overlaps will ensure better use of public resources, minimise burden on regulated subjects, and maximise effectiveness.
7. **Transparent governance.** Governance structures and human resources policies for regulatory enforcement should support transparency, professionalism, and resultsoriented management. Execution of regulatory enforcement should be independent from political influence, and compliance promotion efforts should be rewarded.

8. **Information integration.** Information and communication technologies should be used to maximise risk-focus, co-ordination and information-sharing – as well as optimal use of resources.
9. **Clear and fair process.** Governments should ensure clarity of rules and process for enforcement and inspections: coherent legislation to organise inspections and enforcement needs to be adopted and published, and clearly articulate rights and obligations of officials and of businesses.
10. **Compliance promotion.** Transparency and compliance should be promoted through the use of appropriate instruments such as guidance, toolkits and checklists.
11. **Professionalism.** Inspectors should be trained and managed to ensure professionalism, integrity, consistency and transparency: this requires substantial training focusing not only on technical but also on generic inspection skills, and official guidelines for inspectors to help ensure consistency and fairness.

Source: (OECD, 2014[8]), Best Practice Principles on Regulatory Enforcement and Inspections, Paris, http://dx.doi.org/10.1787/9789264208117-en.

Exercising precaution

While evidence-based decision making is essential to regulatory governance, innovations such as new hydrogen technologies and applications could force governments and regulators to make decisions based on smaller scientific evidence bases regarding risks than they are used to (or comfortable with). Governments may apply the precaution principle in such situations, to account for existing gaps in knowledge on risks. A complete discussion of this principle and its implications can be found in the OECD publication *Understanding and Applying the Precautionary Principle in the Energy Transition* (OECD, forthcoming).

The precaution principle (or precaution approach) can be applied in various contexts, including legislation, regulation, standards and licensing procedures. While there is no single definition, the principle is usually applied in situations characterised by a need for (environmental) protection, considerable scientific uncertainty, and a threat or risk of serious damage (Pinto-Bazurco, 2020[25]) (Sands, P. & Peel, J. (Eds), 2012[26]). It is based on the philosophy that a lack of scientific certainty should not be a reason to not take preventative action (HSE, 2001[27]). The precaution principle should not be confused with the concept of prevention, which deals with risks that are better understood.

The literature identifies both pros and cons to the application of the precaution principle. Proponents argue that it allows for the consideration of risks or effects that are not accurately covered under alternative methods. Importantly, the precautionary principle can help to address the risks of latent impacts or the delayed effect of risks – i.e. where it takes time before risks materialise, such as with the climate crisis. It can also help avoid a bias that disregards poorly understood risks that may not be covered under traditional cost-benefit analyses (Wiener, 2018[28]) (European Commission, 2017[29]). Criticism of the principle focuses on the multiple possible interpretations that may result in practice and the impact overly prescriptive approaches can have on innovation (Gemmell, J. Campbell; Scott, E. Marian, 2013[30]). Some argue that the absence of a clear definition could undermine legal certainty and that the principle appears not to be applied in a consistent manner (Wiener, J. and Rogers, M., 2002[31]).

Precaution principle as regulatory approach

The application of precaution matters for the exercise of risk governance by decision makers. It should not be applied where there is sufficient certainty regarding risks, as these situations can be dealt with by using "normal" risk management approaches (Von Schomberg, R., 2012[32]). However, where scientific evidence is lacking or there is no consensus on the likely adverse effects, precaution may be applied by policymakers (European Commission, 2000[33]). The exact application of the precaution principle may depend on which risks policymakers care about most, as well as the regulatory context and legal system, with differences in application across and within countries (Wiener, J. and Rogers, M., 2002[31]).

Risk trade-offs

A potential shortcoming from the application of precaution could be that policymakers focus too narrowly on a single risk, where minimising a specific target risk may be at the expense of other countervailing risks (Wiener, 2016[34]). Applying precaution too narrowly on a single risk could lead to a suboptimal outcome in terms of overall risk reduction. For example, in the case of the application of precautionary approaches to hydrogen technologies, precautionary measures to safeguard health or safety may impede efforts to decrease climate change risks or vice versa. To account for all different risks, a wider impact analysis beyond the single risk could be used to identify any countervailing risks and benefits in order to determine the degree of precaution required (Graham, J. and Wiener, J., 1995[7]) (Wiener, 2020[35]).

Iterative approach

As the precaution principle allows governments to factor scientific uncertainty on risks into decision making, the degree of precaution required will reduce as scientific knowledge evolves. New hydrogen technologies will face lower levels of scientific certainty regarding their risks during the earlier stages of development. As applications become more mature and more research becomes available, the degree of scientific uncertainty tends to decrease.

To allow for improvements in the scientific knowledge base, the regulatory analysis and application of precaution should therefore be based on an iterative process that can incorporate learning into the resulting regulations. In this way, precautionary measures may need to be modified or abolished as stronger knowledge on risks becomes available. This would not be dependent on time, but rather on the rate at which new scientific research becomes available (European Commission, 2000[33]). This iterative approach to policymaking in light of scientific uncertainty requires knowledge sharing and encourages more dynamic modes of stakeholder engagement.

Socio-political context

While the level of available scientific evidence will factor into the desired level of precaution, the socio-political context and psychological elements can play an important role as well. The degree of risk aversion that regulators exercise in their decision making may depend on how benefits and risks are distributed across society, as well as the mobilisation and engagement of different stakeholder groups.

As risk aversion may differ on a case-by-case basis depending on the decision-making context, the precaution principle tends to be applied with a high degree of discretion. Some argue that this is also one of the precaution principle's main functions, to provide "a rationale and justification for administrative discretion" (Heyvaert, 2006[36]). However, it has also been pointed out that the application of precaution to regulatory decision making could, in a politicised context, be driven by interests and circumstantial factors, rather than maximising social well-being based on a careful weighing of pros and cons (A. Dembe, Raffensperger, C., & Tickner, J., 2004[37]).

Behavioural biases and public perceptions

Public perceptions about the magnitude of risk and the associated costs and benefits can constitute certain behavioural barriers and biases. These biases have a real effect on the market and on people's acceptance of risk. Analysing and understanding these perceptions – also in relation to the economic and environmental impact – is a fundamental step for the regulator. Knowing in advance biases, behaviours and how people will react to energy innovations can help policymakers to design strategies and regulations to support a "proactive" perception and acceptance towards energy technology innovations.

To investigate the fears and risk perceived by society, various initiatives have been launched to identify the level of social awareness and the costs and benefits associated with hydrogen (Huijts, Molin and van Wee, 2014[38]) (Iribarren et al., 2016[39]). Several studies analyse how fears and non-acceptance may be connected with the absence or presence of social awareness and information campaigns (Heinz and Erdmann, 2008[40]). The risk-acceptance model built by Huijts et al. describes the structure of social acceptance as a cognitive model directly related to the level and quality of information shared with society (Huijts and van Wee, 2015[41]).

Heuristics and biases play a vital role in people's ability to receive information and make decisions. Sometimes the regulator has to respond to social pressure due to lack of information or biases that alter the perception of the available data. Research has shown how social cognitive heuristics play a decisive role in political and regulatory decisions, especially when faced with complexity, sustainability, lack of time and uncertainty (Korteling, Brouwer and Toet, 2018[42]).

A number of behavioural biases may be particularly relevant to policymaking and the regulation of risks related to an emerging energy technology such as hydrogen:

- The notion of the “risk regulation reflex” refers to situations in which decisions may be adopted too fast and based on little analysis, resulting in disproportional safety or protection measures and potential “regulatory inflation” (Blanc, Macrae and Ottimofiore, 2015[43]).
- There may be certain psychological impulses and political pressures that could lead politicians to “rush to judgement” and neglect trade-offs that are inherent to the decision making (Coglianese C., and Carrigan, C., 2012[44]).
- Path dependency refers to the theory “that policies, once established, can be difficult to change or reform”, resulting in a situation where earlier actions will have an impact on the actions of institutions today (Kay, 2005[45]).
- The “availability heuristic” or “availability bias” is where people assign a higher probability to events that come to mind more quickly when evaluating situations. Factors such as media coverage could result in people placing an increased attention on worst-case scenarios, making such outcomes appear more frequent than they actually are.
- The “present bias” or hyperbolic discounting refers to the bias in which people give a high importance to current needs and a lower importance to future needs (O’Donoghue and Rabin, 2015[46]) (Samuelson and Zeckhauser, 1988[47]) (Kahneman and Tversky, 1979[48]). This bias prevents people from being open to innovation that will have an impact in the future. This may be especially the case when combined with the “loss aversion bias”, whereby people make decisions mainly driven by the fear of losing someone or something important (Wang, Rieger and Hens, 2016[49]).

Public information and deliberation will affect the public perception of risks, as was shown through case studies on the public perception of hydrogen (Box 3.4).

Box 3.4. Ambiguity, complexity and uncertainty surrounding hydrogen and public views

The fact that some of the risks associated with the use of hydrogen energy are not yet perfectly known or quantified does not, in itself, justify the use the precautionary principle. After all, no risks are ever perfectly known or quantified. As the hydrogen industry, research, and regulation develop, there will be opportunities for further refining the regulatory framework as more evidence becomes available. To be sure, a number of specific applications of hydrogen energy (e.g. in homes) do warrant more precaution due to higher uncertainty and potential harm. However, even in these cases, precaution should not revolve around a yes-or-no question but rather rely on stepwise, scalable experimental approaches.

The International Risk Governance Council's (IRGC) model on risk governance suggests the use of the precautionary principle in risk assessment and management. However, in terms of alternative scenarios on the possible development of the hydrogen economy, there is also uncertainty reflecting different stakeholders' interests and values, and about appropriate regulatory regimes. Hence, the IRGC model recommends deliberative methods and participatory discourse to address some of these issues. In line with the notion of concern assessment, the framework includes consultation, participation, and public engagement to build more transparent and inclusive systems of risk governance.

As part of a wider series of case-studies about hydrogen in England and Wales, the authors carried out two all-day meetings with citizens' panels in Teesside (Middlesbrough, in North-East England) and Wales (Llanelli, South Wales) during 2008–2009. These two areas were selected as they already had some hydrogen production plants, as well as demonstration projects for hydrogen energy technologies.

During the two meetings, members of the public were provided with basic information about hydrogen including alternative scenarios created by a hydrogen economy. The authors identified several "knowledge gaps" among citizens about the nature and properties of hydrogen as an energy carrier, and the regulatory codes and standards to deal with anticipated risks. The authors found that "though the final deliberations by this panel suggested some positive interest in hydrogen use as energy carrier, this was conditional upon people receiving more detailed information and reassurance about measures to regulate safety in the entire system of production, storage, and distribution". This experience illustrates that public perception of the risks associated with hydrogen can depend on the knowledge and information made available. Citizen involvement can help ensure more transparent and inclusive risk governance, which is recommended in situations where there is a high degree of uncertainty surrounding the risk problem.

Source: (OECD, 2023[50]), Understanding and Applying the Precautionary Principle in the Energy Transition*;* (Bellaby and Clark, 2016[51]) (Flynn, Ricci and Bellaby, 2012[52]).

Precaution applied to innovation

New hydrogen technologies or applications that are introduced to markets are often accompanied by questions regarding their risk. As innovations, by their very nature, have not previously been applied, there is little experience with their exact consequences in practice (beyond a theoretical understanding). This therefore raises the question of how well precaution and innovation go together.

There is some controversy about the potential effects of the precaution principle on innovation, and some would say that the two tend to conflict. They argue that the precaution principle leads to legal uncertainty and that precautionary measures could "paralyse" innovation (Sunstein, 2002[53]). In addition, application of the precaution principle may not factor in the risk or opportunity cost of forgone progress or welfare that innovation could achieve (Orset, 2014[54]) (Institut économique Molinari, 2013[55]). As scientific uncertainty is often inherent to the introduction of innovation, regulations focusing too narrowly on eliminating risk and removing scientific uncertainty could therefore impede innovation.

Rather than hindering innovation, it has also been argued that precaution can be used to stimulate or steer innovation. The UK Interdepartmental Liaison Group on Risk Assessment states that an appropriate application of the precaution principle could "encourage technological innovation and sustainable development by helping to engender stakeholder confidence that appropriate risk control measures are in place" (Interdepartmental Liaison Group on Risk Assessment, 2002[56]).

The European Risk Forum (ERF) suggests including the innovation principle, to allow for the consideration of the impact of regulations on innovation. The "innovation principle" intends to give weight in decision making to the potential benefits that innovations can bring (such as job creation, growth, environment, health and well-being) and acts as a counterweight to potential risks. The European Commission defines the innovation principle as a "tool to help achieve EU policy objectives by ensuring that legislation is designed in a way that creates the best possible conditions for innovation to flourish" (Vos E. and Smedt K., 2020[57]). The OECD Recommendation on Agile Regulatory Governance to Harness Innovation also highlights the role of regulatory policy to ensure innovation can drive more sustainable and inclusive growth and address global challenges (OECD, 2021[2]).

The Responsible Research and Innovation approach was developed as a response to the challenge of reconciling the precaution and innovation principles, to systematically weigh precautionary measures against the societal benefits of innovation. The approach essentially encompasses four elements (Stilgoe et al., 2013[58]):

- *Anticipation*: "Involves systematic thinking aimed at increasing resilience, while revealing new opportunities for innovation and the shaping of agendas for socially-robust risk research."
- *Reflexivity*: "At the level of institutional practice, means holding a mirror up to one's own activities, commitments and assumptions, being aware of the limits of knowledge and being mindful that a particular framing of an issue may not be universally held."
- *Inclusion*: Means taking the time to involve different stakeholders in order to lay bare the different impacts of a new technology on different communities
- *Responsiveness*: "Responsible innovation requires a capacity to change shape or direction in response to stakeholder and public values and changing circumstances."

Safety-by-design

A specific elaboration of Responsible Research and Innovation are so-called safety-by-design approaches (also referred to as "safe-by-design", "safer-by-design" or "design for safety"). Safety-by-design approaches aim to combine the precaution and innovation principles by addressing safety issues during the design phase, thereby using innovation as a solution to safety concerns. By "frontloading safety", safety-by-design approaches can be used to strike a balance between the need for innovation, to bring societal benefits such as well-being or sustainability, and a need to be cautious about potential safety risks that could emerge (van Gelder et al., 2021[59]).

Looking at the hierarchical approach to risk management – ranging from risk elimination and substitution to control and mitigation – safety-by design approaches put a strong emphasis on earlier stages of risk control (i.e. reducing risks wherever possible during the design phase until the "design freeze"). It aims to facilitate preventative design practices that minimise risks, through inclusive and responsive approaches that help innovators to think as early as possible about hazards during the product life cycle (van Gelder et al., 2021[59]).

The extent to which safety-by-design approaches will be able to control risks will depend on the existing knowledge and data on potential risks that is available during the early stages of design. Importantly, safety-by-design approaches do not remove the need for other stages of risk management, such as control and mitigation, but can reduce the level of risk that needs to be managed at these stages (see Box 3.5 for a discussion of methodologies for the prioritisation and review of risk measures).

Safety-by-design approaches will require regulatory preparedness, in order to ensure innovations undergo suitable safety assessment before rollout to identify risks and appropriate safety measures and designs. Regulators need to become aware of upcoming technologies and develop foresight, skills and know-how at a sufficiently early stage of innovation if they are to drive action and use the appropriate regulatory tools. This will require open engagement and knowledge exchange between regulators, innovators, industry members and other stakeholders in order to anticipate the regulatory challenges and risks posed by new technologies (OECD, 2020[60]). By building more awareness across stakeholders, regulators can ensure procedures and regulations for safety assessment are available at an early stage, and that innovators will understand the relevant regulatory requirements.

The application of safety-by-design will require a culture change for both innovators and regulators. At present, there may not be sufficient open communication or collaboration to facilitate a collective approach to safety reduction during the design phase. The application of safety-by-design approaches would need to be supported by the implementation of safety-by-design approaches in frameworks, guidance and tools.

Crucially, the use of safety-by-design approaches will require an investment in terms of resources by regulators at early design stages. These additional resources will be needed to allow for sufficient time and capacity to exchange knowledge and thoughts with innovators and to develop expertise on new technologies. Not all investments will pay off, as some innovations will prove more successful than others.

Box 3.5. Methodologies for prioritisation and review of risk measures

One methodology that can be instrumental for prioritisation and review in the context of safety and risk management during the energy transition is the **Layers of Protection Analysis (LOPA)**. LOPA is a widely used technique that helps identify and evaluate layers of protection to prevent or mitigate potential hazards and risks. It is a semi-quantitative risk assessment methodology that assesses the effectiveness of existing protection layers and identifies any gaps in risk reduction. LOPA focuses on identifying independent layers of protection and their associated likelihood of failure on demand (LOFOD). LOPA presents several benefits for the prioritisation of mitigating measures such as: improved understanding of risk scenarios and potential consequences; identification of critical protection layers and potential areas for improvement; rational allocation of resources for risk reduction measures; enhanced decision making for risk management strategies and compliance with regulatory requirements and industry standards.

Another methodology that can be instrumental for prioritisation and review in the context of the energy transition is the **Bowtie Analysis**. Bowtie Analysis is a risk assessment and management tool that visually depicts the relationships between hazards, potential causes, consequences, and control measures. Bowtie Analysis is a barrier-based methodology that utilises a bowtie-shaped diagram to illustrate the relationships between threats (top event), causes (left side), consequences (right side), and control measures (barriers) in the middle. It provides a clear and concise representation of the risks and the controls in place to manage them.

Bowtie Analysis presents several benefits such as an intuitive visual representation of risks and control measures; comprehensive understanding of the relationships between hazards, causes, consequences, and controls in a holistic manner; helps identify gaps or weaknesses in the control measures, highlighting areas where additional measures or improvements are needed; facilitates the prioritisation of actions based on their potential impact on risk reduction and can be used as communication tool to engage stakeholders and support discussions on risk management.

Other methodologies that can be considered for prioritisation and review include **Fault Tree Analysis** (FTA), **Event Tree Analysis** (ETA), **Failure Mode and Effects Analysis** (FMEA), and **Hazard and Operability Study** (HAZOP). Each methodology has its unique characteristics and suitability depending on the specific context and objectives of the analysis. It is important to select the most appropriate methodology based on the nature of the risks, available data, resources, and expertise within the organisation.

Source: CCPS (2001), *Layer of Protection Analysis: Simplified Process Risk Assessment,* John Wiley & Sons; HSE (2008), *Bowtie Methodology: A Technique for Risk Management and Incident Analysis*, Offshore Technology Report OTO 2008/030.

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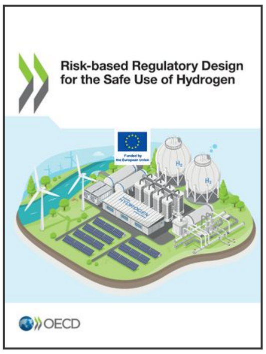
Notes

[1] This would involve "more holistic, open, inclusive, adaptive and better-co-ordinated governance models to enhance systemic resilience by enabling the development of agile, technology neutral and adaptive regulation that upholds fundamental rights, democratic values and the rule of law" (OECD, 2021[1]).

[2] The IEA report uses the time to develop natural gas infrastructure as a proxy for the time it takes to deploy hydrogen infrastructure, due to similarities in project types and processes (IEA, 2023[23]).



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