Developing policies for the End-of-Life of Energy Infrastructure:

Coming to Terms with the Challenges of Decommissioning

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Abstract

Energy sector policies have focused historically on the planning, design and construction of energy infrastructures, while typically overlooking the processes required for the management of their end-of-life, and particularly their decommissioning. However, decommissioning of existing and future energy infrastructures is constrained by a plethora of technical, economic, social and environmental challenges that must be understood and addressed if such infrastructures are to make a net-positive contribution over their whole life. Here, we introduce the magnitude and variety of these challenges to raise awareness and stimulate debate on the development of reasonable policies for current and future decommissioning projects. Focusing on power plants, the paper provides the foundations for the interdisciplinary thinking required to deliver an integrated decommissioning policy that incorporates circular economy principles to maximise value-throughout the lifecycle of energy infrastructures. We conclude by suggesting new research paths that will promote more sustainable management of energy infrastructures at the end of their life.

Keywords: Decommissioning; Infrastructure; Circular Economy; Waste Management; Megaproject; Power Plant;

Highlights

- Historically, energy policy has focused on planning and delivering new infrastructures
- Many energy infrastructures are now reaching the end of their life
- We provide an overview of these infrastructures and their decommissioning challenges
- Infrastructure designers must consider decommissioning to enhance resource recovery
- Sustainable decommissioning policies must integrate circular economy principles

1 Introduction

Decommissioning refers to the suite of processes involved in withdrawing a facility from service at the end of its life; its deconstruction and dismantling; and the removal of components for reuse, remanufacturing, recycling, storage and/or disposal. Until recently, decommissioning challenges in the energy sector (with the exception of nuclear) have been widely overlooked by public and private stakeholders, who have historically focused on high-status 'new build' or retrofit projects. The result of this is that energy policies have largely focused on the planning, design and building of new infrastructure rather than its decommissioning. Yet, in common with nuclear power plants (IAEA, 2018), many fossil fuel and 'first-wave' renewable power plants around the world are at, or are rapidly approaching, the end of their operating lives (CarbonBrief, 2020; Raimi, 2017; WindEurope, 2018). Many of these infrastructures no longer satisfy safety, security, ethical, moral, economic and regulatory standards, with many more expected to experience a similar fate in the short to medium term. Much of this energy infrastructures will therefore need to be decommissioned in the immediate future, but policies, experience and capabilities are limited within the sector to perform this effectively and efficiently (Invernizzi *et al.*, 2019c).

In this paper, we introduce the magnitude and variety of the challenges related to decommissioning in order to raise awareness and stimulate debate regarding the necessary policies, planning and delivery of existing and future decommissioning projects. We suggest that best practices and lessons learned from completed and ongoing decommissioning projects must be shared to improve the process of decommissioning of existing and future infrastructures. We also discuss the need to integrate the principles that underpin the circular economy for more sustainable project delivery in the most resource-efficient way, especially where old infrastructures contain critical materials that should be reused. We now present the most notable energy infrastructure sectors that will be prone to decommissioning.

2 Energy Infrastructure

2.1 Nuclear Energy

As of April 2020, the nuclear sector has installed a global net capacity of 391 gigawatts (GW), with 442 nuclear power reactors currently in operation, 53 under construction and 187 in permanent shutdown (IAEA, 2020). In contrast, only 17 nuclear reactors (accounting for about 3% of the total number or capacity) have been fully decommissioned (OECD/NEA, 2016; WNA, 2020). Hence, the suite of policies, experience and capabilities associated with designing and building nuclear power plants outweigh that associated with decommissioning by orders of magnitude. Still the challenges regarding decommissioning are increasing, as most reactors were only designed to operate for 30 to 40 years and their licences are expired, or about to expire. Reactor operators need either to ask for licence extensions (requiring investment in new policies, refurbishment of components, and upgrades to current safety standards) or commence decommissioning of such reactors. Additional nuclear infrastructures have been installed in recent decades (including approximately 250 research reactors) that will also eventually require decommissioning (WNA, 2020).

2.2 Coal-fired and Gas-fired Energy

Global coal-fired power capacity has doubled to almost 2,000 GW since 2000, driven largely by demands for power from economic growth in China and India (CarbonBrief, 2020). However *“From 2000 to 2019, OECD countries commissioned 121.7 GW of new coal power capacity and retired 189.9 GW, resulting in a net decline in the OECD of 68.2 GW […]. Coal power capacity has been falling in the OECD since 2011, where the coal fleet is on average* *twice as old as the rest of the world (35 years compared to 18 years)"* (Shearer *et al.*, 2020). In Europe, the use of coal has decreased by 24% over the last 25 years, and the average age and operating life of European power plants are 25-35 years (Alves Dias *et al.*, 2018). In the US, the average age of the 911 operating coal plants was reported to be 43 years, with almost a third aged 50 years or more (Raimi, 2017). Thus, a sharp increase in decommissioning-related expenses can be expected in both the US and Europe.

Currently, gas-fired power plants are the second largest producer of electricity. They generate about 23% of the world electricity, a substantial increase of 15% when compared to the early '90s (IEA, 2020a). The contribution of natural gas power plants is not expected to decrease in the near term. Natural gas power is needed to provide a base-load and to back-up renewable energy sources (e.g., wind and solar). In addition, gas-fired power is needed to offset the demand in electricity that arise from decommissioning ageing nuclear and coal plants (IEA, 2019). Gas-fired power plants are increasingly popular as they are relatively cost-effective to build. In comparison to other types of fossil fuel plants, they produce less harmful emissions and are more efficient (Schlömer *et al.*, 2014) making them less controversial. The contribution of oil power plants to world electricity production is minimal and their use is declining (IEA, 2020a). However, the infrastructure for the production of hydrocarbons (i.e. oil and gas) plays a critical role in the world's energy market and supports almost all industrial sectors. As of August 2019, globally, there are 764 offshore rigs including jackups, semis, and drillships (Smith, 2019) that are producing the hydrocarbons needed to support our economic and social well-being (WEF, 2015).

2.3 Renewable Energy

Based on available data for 2019 (IRENA, 2020), at global level, renewable energy accounts for 2,536 GW. Half of this is provided by hydroelectric sources and wind and solar account for a further quarter of production each. According to (Wind Europe, 2020) Europe installed 15.4 GW of new wind power capacity in 2019 (13.2 GW in the EU). This is 27% more than in 2018 but 10% less than the record in 2017. Europe now has 205 GW of wind energy capacity: 183 GW onshore and 22 GW offshore. Investment in new wind farms in 2019 was €19bn. The capacity factors of the EU's fleet of wind farms were on average 26% and wind accounted for 15% of the electricity the EU-28 consumed in 2019. Europe decommissioned 178 MW of wind capacity in 2019 (Wind Europe, 2020). The US has a total installed wind power capacity of 106 GW at the end of 2020. The US wind industry has invested over £142 billion in new projects over the last decade (AWEA, 2020a). Over three-quarters of US wind turbines are less than ten years old, and only a small number of wind turbines have been decommissioned, 0.043 GW in 2017, (AWEA, 2020b) and there is a noted lack of research in this area (Topham and McMillan, 2017).

Global solar photovoltaic (PV) deployment has also grown rapidly, reaching 647 GW of installed capacity at the end of 2019 (PowerWeb, 2020) and is expected to increase to 700-900 GW by 2024 (IEA, 2020b). The average panel life is projected to be 30 years. Less than 1% of the cumulative mass of all the installed panels (4 million metric tonnes) have been decommissioned (IRENA, 2016). Thus there is a pressing need to develop the capacity and skills to efficiently and effectively undertake this process.

Biofuels only contribute to approximately 2% of the world's electricity generation (IEA, 2020a), a value that is expected to be relatively stable in the medium to long term. Challenges exist with producing biofuels commercially (Balan, 2014), but this is an energy source where future infrastructures can make a positive contribution to: combating climate change (i.e.

reduce carbon sources); responding to the increasing demand for energy consumption; securing a consistent energy supply; better-making use of the waste and residue from materials.

2.4 Summary

Figure 1 graphically provides an overview of the data presented in the previous sections. For all the technologies, the amount of power installed is one or two orders of magnitude higher than the power decommissioned. Figure 1, and this section, discussed technologies in terms of power (GWe) installed vs decommissioned. However, for the same power to be decommissioned, different technologies have different unitary costs and various challenges in dealing with the arising waste. These aspects, and other, are discussed in the next section.

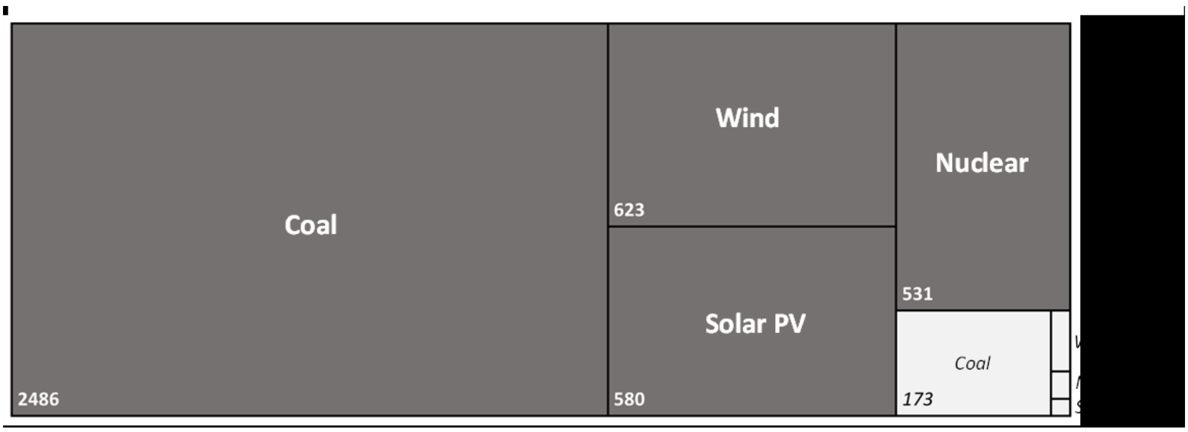

Figure 1 Estimates of global installed (dark) and decommissioned (light) generation capacity for selected technologies / GWe

3 The Magnitude and Challenges of Decommissioning

The decommissioning of energy infrastructures is affected by several multifaceted and interdisciplinary (technical, legal, economic, financial, social and environmental) challenges. The following sections shed light on how they influence the decommissioning of existing and future infrastructures.

3.1 Existing Energy Infrastructures

Technical challenges to decommissioning existing energy infrastructures often involve the management of radioactive, toxic and hazardous materials arising from decommissioning, and the handling, transportation, reuse, recycling and/or disposal of large components (Brown *et al.*, 2017; RSA, 2015). These challenges are exacerbated by an overall lack of harmonised recycling policies and end-of-life waste management regulations, which are evolving to place an increased emphasis on the producer's and/or operator's responsibility to deal with end-of-life waste (Cherrington *et al.*, 2012; Xu *et al.*, 2018).

The economic costs of decommissioning are certain to be significant and will increase as more assets reach the end of their life, but few operators have put aside sufficient funds to effectively decommission their assets. For example, in the UK, the estimates for the decommissioning of civil nuclear assets range from £99 to £232bn (GOV.UK, 2020a) having grown from £20-40bn in 2005 (NDA, 2006), demonstrating the considerable under-estimation and uncertainty in decommissioning costs (Figure 2). A single site, the biggest in the UK (Sellafield), accounts for most of the decommissioning cost and increase in cost. In Bulgaria and Slovakia, the estimates of decommissioning costs have not changed significantly from

2010, while the Lithuanian ones have increased considerably, as pointed out in Figure 3. These figures are some early examples of how decommissioning costs increase or decrease, while there is only a limited understanding of why this happens (Invernizzi, Locatelli, and Brookes, 2019b).

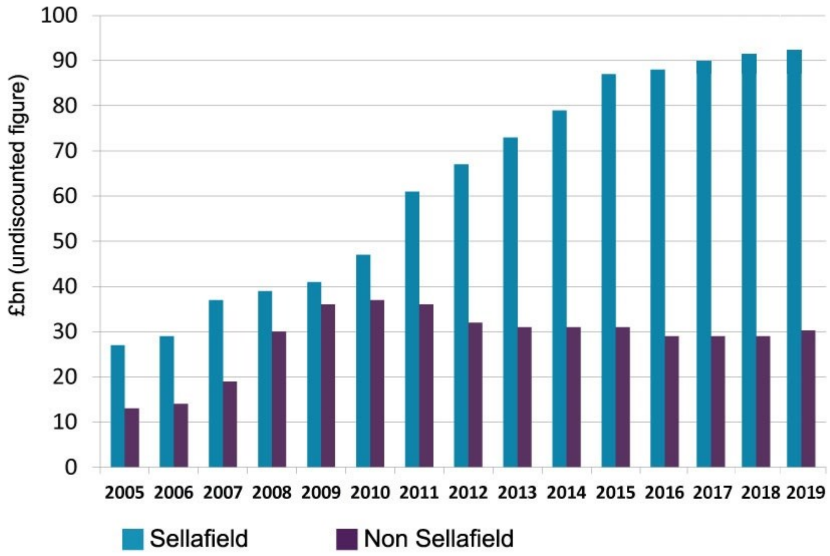

Figure 2 Decommissioning cost of UK legacy (GOV.UK, 2020a)

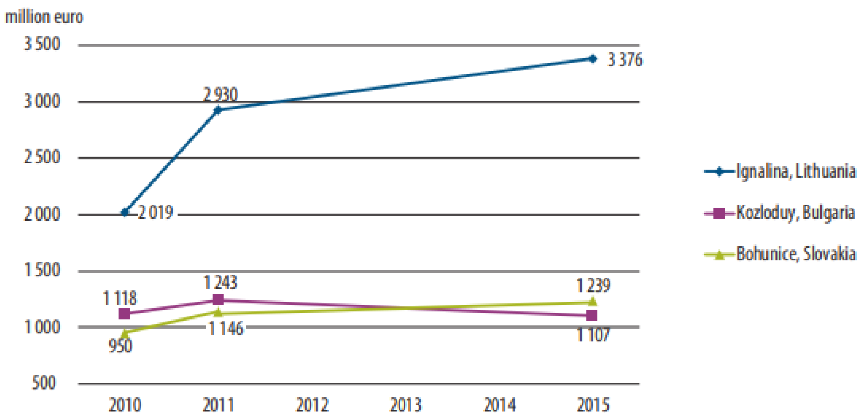

Figure 3. Estimated decommissioning costs from 2010 to 2015 of Ignalina (Lithuania), Kozloduy (Bulgaria) and Bohunice (Slovakia) (European Court of Auditors, 2016).

Most nuclear decommissioning in Europe is funded by the public sector (Taebi, Roeser, and van de Poel, 2012) and insufficient funds have been reserved by operators. Taxpayers will generally be required to bear the cost of decommissioning in the future although in most countries.

At the global level, decommissioning costs in the nuclear sector are in the range of US$ 1 billion - US$ 1.5 billion per 1,000-megawatt plant (Market Watch, 2019). As of today, there are about 391,000 MWe of nuclear power installed (IAEA, 2020), bringing the total cost in the ball-park of $400-600 billion. In addition, the cost to dismantle the facilities related to the fuel cycle, research reactors, laboratories needs to be taken into account. A recent general overview of nuclear decommissioning cost is presented in (OECD/NEA, 2016).

The nuclear sector is not the only sector facing enormous decommissioning costs.

Estimates for the cost of decommissioning the UK's oil and gas assets in the North Sea are of comparable magnitude. The most recent decommissioning Cost Estimate (2019 inventory, 2018 prices) see the estimated costs reduced to £51 billion in 2019 (compared to £59.7 billion in 2017) despite including more assets and infrastructure than the 2017 inventory (Oil & Gas Authority, 2020). In this sector, taxpayers are footing ca. 30-50% of the bill through tax relief schemes (NAO, 2019).

At the root of these high decommissioning costs is the lack of the consideration of the end-of-life of a facility during its planning (NAO, 2019). Highlighting the economic consequences of this lacuna (and the importance of "planning for decommissioning") is essential if future energy infrastructure business models are to incorporate decommissioning challenges. This is especially valid in a regulatory environment where extended producer/operator responsibility for end-of-life issues may become more prevalent (ChinaDaily, 2017; EP, 2012; GOV.UK, 2020b)

Other sectors also have staggering figures. Offshore wind decommissioning costs are in the region of $223,000-$668,800 per MW (NewEnergyUpdate, 2016). Studies dealing with the decommissioning cost of solar systems are scant. However, Nyserda (2020) recently describes cost in the order of $60,000 for a ground-mounted 2-MW solar panel system, i.e. a $30,000 per MW. Costs for dam removal varies enormously depending on factors such as types, size and location. Broadly, by 2050 the US should have between 4,000 and 36,000 total removals and estimate total costs varies between $50.5 million and $25.1 billion (i.e. mean - $10.5 billion, median- $416.5 million) for all removals (Grabowski, Chang, and Granek, 2018).

Decommissioning also presents social challenges (Invernizzi, Locatelli, and Brookes, 2017a). For example, in managing the transition of an asset from normal operation to end-of-life, the workforce often must take part in decommissioning their own source of jobs. The public controversy surrounding decommissioning-related activities can also hinder their progress. This is particularly prevalent in nuclear decommissioning, where the construction of nuclear waste repositories is often indefinitely delayed by political processes (BBC, 2013) or completely abandoned due to protests (Invernizzi et al., 2017).

Moreover, environmental challenges arise during attempts either to restore decommissioned infrastructure sites to their previous condition, or prepare them for subsequent use. In the case of nuclear decommissioning, for example, these challenges are justified in comparison to the risk of "doing nothing", which could lead to the leakage of dangerous pollutants if proper decommissioning and waste management is not carried out (IAEA, 2014). For other infrastructure (e.g. dam removal), the ecological response has to be evaluated more carefully and balanced with the need to retain the functionality of the site (Wilcox *et al.*, 2019) and risks, including catastrophic collapse. In the case of offshore wind decommissioning, the accelerating transition to a low-carbon economy means that existing sites are expected to continue producing power with new or reconditioned turbines, and full decommissioning of sites is unlikely. Other environmental challenges arise from the growing demand for primary materials, their subsequent depletion and the environmental damage associated with their extraction (Vidal, Goffé, and Arndt, 2013). Ensuring that modules, components and materials used in energy infrastructures contribute to a circular economy by being reused or recycled, is essential to reduce this impact (Mignacca, Locatelli, and Velenturf, 2020; Velenturf *et al.*, 2019). This is particularly relevant for low-carbon electricity generation infrastructures, which often contains so-called 'critical materials' (EC, 2019). The supply of these materials is difficult to expand and likely to be significantly exceeded by demand over the coming decades. This will increase pressure on resource security and encourage recovery from end-of-life structures. These materials include the rare-earth metals in wind turbines permanent magnets and the optoelectronic materials used in photovoltaic panels (Dawson *et al.*, 2014; Goe and Gaustad, 2014).

The above challenges are made harder to understand and address by the limited number of completed decommissioning projects from which lessons can be learned (Invernizzi *et al.*, 2017b, 2019b). Not only is the initial condition of the infrastructure to be decommissioned often uncertain; the final outcome of decommissioning (e.g. whether some facilities remain on-site, and whether they and/or the site can be reused for other purposes) might also not be well-defined at the beginning of the process. In addition, a lack of clear policies regarding suitable starting and ending points for decommissioning will hinder the smooth progress of any decommissioning project. For example, a nuclear site that is to be reused for housing development needs a greater degree of remediation than one that will be reused for the storage of waste. Decommissioning offshore oil and gas facilities after decades of operations may involve a spectrum spanning from full removal of all physical assets, to structures being deliberately left and used to create artificial reefs. Debate on whether full removal causes more harm than good is ongoing (Bull and Love, 2019; Chandler *et al.*, 2017). The best response will be site-specific: there is no "one size fits all" solution (Smyth *et al.*, 2015).

The remoteness of many energy infrastructures causes both technical and social challenges during the process of decommissioning. Whilst isolated locations have been historically chosen for safety and security-related reason, or preserving visual or coastal access amenity (e.g. for offshore wind), remoteness affects the infrastructure decommissioning process by making it more difficult to mobilise equipment and resources. A case in point is the experimental Dounreay nuclear power development, which is located in the far north of Scotland, more than 400km from the major urban areas of Glasgow and Edinburgh. The local community was very much dependent on the jobs provided by this nuclear site and thus starting its decommissioning, inevitably caused social disquiet and disruption (Invernizzi *et al.*, 2017a).

These various challenges assume different relative weightings depending on the characteristics of the particular energy infrastructure involved, and they are often interdependent. For example, in nuclear decommissioning, radiological concerns conflate conventional safety and environmental concerns, and for offshore wind, remoteness and a lack of recycling facilities for composite materials conflate environmental and logistical concerns (ARUP, 2018; Purnell *et al.*, 2018).

3.2 Future Energy Infrastructure

The installation of new energy infrastructures in developed countries is forecast to be dominated by more sustainable alternatives, satisfying commitments to cleaner energy production (GOV.UK, 2017). In developing countries, entirely new energy infrastructures are required to support their economic growth. Limited attention is given to the end-of-life of either of these infrastructures, with decommissioning plans apparently just exercises designed to comply with weak regulations (Topham and McMillan, 2017). In most cases, there are no policies regarding ‘designing for decommissioning’. Limited “design for decommissioning” (if any) is required during the planning and construction of nuclear new build, where construction and operations span decades, and decommissioning is inevitably seen as an issue for future generations to resolve. Similarly, for low-carbon infrastructures, dealing correctly with the volume and variety of materials to be managed during decommissioning (particularly those with no recycling infrastructures such as composites), or in demand from other industries (such as rare earth metals) is severely underestimated.

Indeed, business models that involve reuse, repair, remanufacture and recycling of materials from low-carbon infrastructures are almost entirely absent, and plans to manage the waste arising from decommissioning low-carbon infrastructure are still at a preliminary phase. Despite legal requirements to include these in decommissioning plans, only nominal adherence is evident, as often waste management or recycling solutions are not yet available. It has been argued that waste management solutions that are available have focused on deep geological repositories, but these are not yet fully developed, and their long-term viability is questionable (Ramana, 2019).

This lack of clarity on decommissioning invites the criticism that low-carbon infrastructures is not as sustainable as it proclaimed to be. Without strong decommissioning and waste management solutions, the issue of preserving finite resources is not adequately addressed but instead, transferred from one finite resource such as coal, to another one such as the Neodymium in permanent-magnet in wind turbines (Dawson *et al.*, 2014). Additionally, neither is the whole-life environmental benefit, as mining of many of the materials used in low-carbon infrastructure releases CO_2 and pollutes local environments (Haque *et al.*, 2014) and the lack of credible routes to deal with the waste arising from wind farm decommissioning (Purnell *et al.*, 2018).

4 Outlook: The Need to Learn from the Past and Develop Energy Policies For Decommissioning

Several countries are making headway with their decommissioning laws and practice. For example, the Netherlands emphasises the application of circular economy principles in their “masterplan for decommissioning and reuse” for oil & gas assets (ebn, 2016). The UK now insists on increasingly precise decommissioning plans for new offshore renewable energy infrastructures (BEIS, 2019). However, there still remains a considerable amount of work to be done at the construction stage of existing infrastructures. Requirements to consider decommissioning are limited, if not completely missing (Ars and Rios, 2017; Dinner, 2012). In addition, society has never before faced the problem of imminently redundant infrastructures on this scale (Heffron, 2018). Energy infrastructures assets such as nuclear or coal plants and dams are complex, and often bespoke non-modular structures (Mignacca and Locatelli, 2020). Their condition can be, at times, difficult to monitor and their components are hard to disassemble.

In contrast, offshore oil platforms are modular and standardised. Topsides are relatively easy to dismantle, but these benefits are counteracted by the inaccessibility of the asset locations and the limited potential to recycle material such as composites and concrete sustainably. Furthermore, regulations regarding decommissioning and waste management tend to become stricter (i.e. compliance becomes more costly) with time. For instance, in the case of radiologically contaminated asbestos from UK nuclear sites undergoing decommissioning, complying with additional safety-related issues in already radiologically contaminated environments profoundly affects the costs of decommissioning projects (Invernizzi *et al.*, 2019a). Indeed, as a consequence of new regulations introduced in the UK, the number of landfills that accepted asbestos waste was reduced from around 270 to less than 20, which caused the cost of disposal to "literally double overnight" (Downey and Timmons, 2005).

The considerations outlined above should, during the initial phases of infrastructure design, drive the formulation of policies regarding planning and design for decommissioning and waste management. This must include the implementation of systematic knowledge management that is used to ensure an asset's initial condition, modifications and incidents that may have occurred over its life, are documented. Stakeholders should also proactively monitor regulatory and policy development, and evaluate the scope of changes that these might trigger. Currently, these lessons have been learned in some energy sectors (e.g., oil & gas) (BEIS, 2018a) but have failed to reach the renewable energy industry, and the cost of decommissioning (e.g., offshore wind) is still considerable (BEIS, 2018b).

In this paper, we have presented only an initial list of aspects that will affect how we must address the challenges of decommissioning. Nonetheless, they demonstrate that policy makers and industry need to first understand and make explicit the magnitude and challenges of decommissioning. This understanding can then enable actions to be put in place to mitigate the potential economic, social and environmental impacts that may arise when an asset comes to the end of its life.

We believe that there is a need to develop explicit policies that can be used to determine 'if' and 'when' to decommission energy infrastructures. These policies need to consider technological, economic, social and environmental challenges, and their interactions. Some policies are already in place in certain countries (e.g. the UK policies for Oil & Gas), but these are exceptions, rather than the rule. In developing a robust policy, a detailed analysis of both technology-specific and generic decommissioning challenges and their evaluation is initially required. Different challenges have changing roles to play for various types of energy infrastructures (e.g. nuclear has problems with radiological aspects, oil & gas with site remediation, offshore wind with material management, and hydroelectric with hydrogeological issues), but some issues (e.g. remoteness, scale, environmental impact, community implications) are ubiquitous.

We suggest extending and tailoring existing principles to tackle decommissioning challenges. These include adopting the principles of the circular economy, which could support more sustainable decommissioning. Circular economy requires products to be designed to be reused, refurbished and repaired, preserving the function or service they provide, and preventing its 'technical value' from becoming waste in order that demand for raw materials is drastically reduced (Mignacca *et al.*, 2020). This requires economic innovation whereby 'servitization' (i.e., the supply of products-as-services) displaces traditional business models based on selling even more resources. When further reuse is no longer possible, the materials are recycled; product design must ensure an asset can be dismantled into components of a single material for easy and efficient recycling, sometimes called 'closing the loop'. The resource needs of a sector or geography can thus be satisfied largely by recycling in-service resources and importing materials from other circular sectors (Purnell, Velenturf, and Marshall, 2020; Velenturf *et al.*, 2019).

Energy recovery or controlled storage in landfills are considered only as a last resort. Energy policies to support the circular economy in energy infrastructures is necessary to address climate change. For example, the renewables sector is one of the top consumers of critical materials (i.e., rare earth metals) and its long-term viability will depend on its ability to circulate these materials internally in the face of competition for raw materials (e.g. the automotive and electronics sectors) and between geographies (e.g. China and Europe) (Wang *et al.*, 2019). The energy sector is also a repository for hard-to-recycle materials (e.g. composites, concrete). In densely populated countries such as the UK, France and Germany, the cost and availability of land is a pervasive problem that confronts the governments and the private sector. Finding sites for new landfill remains challenging, especially in a policy environment where circular economy and reduction of landfill is a priority (GOV.UK, 2018). Designing these materials out is probably not possible, but considering how they should be refurbished and reused rather than assuming they will be dealt with elsewhere, should be a design priority. New technologies to support decommissioning will be required, and particularly for new infrastructures, the design should start with decommissioning in mind, “design for decommissioning”.

5 Conclusion and Policy Implications

Decommissioning encompasses a vibrant and interdisciplinary research agenda of interest to many branches of academia and industry. It is also a stimulating topic for policy makers and regulators, who should provide clear strategy, guidance and funding mechanisms with rewards for minimising the impact of the whole infrastructure’s lifecycle, not just during the operational generation phase. The interplay between decommissioning challenges triggers the need to balance the array of all stakeholders' social, organisational and cultural needs and demands. This is necessary to ensure that decommissioning projects positively contribute to an economy's development. In summary, the decommissioning of conventional and renewable energy infrastructures face several challenges, and therefore, there is an immediate need to:

- engage and enact in the process of learning from the decommissioning that has already been and is being undertaken. In addition, mechanisms need to be established that will enable the fostering and sharing of knowledge between various areas of the energy sector about issues associated with the design' for decommissioning' and its process at the end of an assets' life; and
- be more proactive in preparing and implementing policies and solutions to enhance the circular economy for future energy infrastructures.

As economies continue to evolve and demand more sustainable energy assets, old infrastructures will need to be decommissioned and dismantled in ways that make them available for new developments through reuse, remanufacturing and recycling measures. Applying circular economy principles to the decommissioning of existing infrastructures is possible, but costs and benefits can be optimised more effectively if the asset is designed and built with these principles as key drivers. This will add a further layer of complexity to forthcoming energy decommissioning projects, which needs to be accounted for in future energy policies.

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