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Corporate Digital Responsibility and the Business Implications of Quantum Computing

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Abstract

While artificial intelligence has been attracting increasing investment and controversy, a new, and potentially much more powerful technology, Quantum Computing, is on the business horizon. Already, organizations are assessing its potential for addressing a range of computationally challenging issues, such as last-mile optimization and cryptanalysis to break encryption algorithms, and are exploring possible applications in a range of business areas. While the advent of Quantum Computing may bring an array of opportunities and benefits, the companies developing and applying Quantum Computing technologies will face, and have to address, new sets of corporate social, ethical, economic, technical and environmental responsibilities. Using a qualitative research method based on secondary sources, this article examines the implications for Quantum Computing for corporate digital responsibility, and assesses the guidance currently being offered by leading consultancies for organisations deploying Quantum Computing. The results suggest that although there is some guidance on how companies can apply and exploit Quantum Computing technology, there is as yet little consideration of the possible downsides, including, for example, potential negative environmental impacts. Further research is needed to develop a more balanced assessment of benefits and disbenefits as Quantum Computing is deployed in the corporate world and wider global society.

Keywords

Quantum computing; corporate digital responsibility; CDR; ethics; responsible innovation; governance; cybersecurity; sustainability

1. Introduction and Background

In her Ministerial Forward to the UK's National Quantum Strategy [1], Michelle Donelan, Secretary of State for Science, Innovation and Technology claimed that the Quantum Technologies will have a major impact on everyday lives "from improving healthcare and speeding up drug discovery, to boosting economic growth and security and providing jobs", and that "they will also help us tackle climate change", and "build a sustainable future". Today's Quantum Computing is thus generally viewed as the second quantum revolution, following the invention of the transistor and the laser in the last century [2], and industry professionals generally support the positive stance of the UK Secretary of State. McKinsey [3], for example, claimed that Quantum Computing "uses principles of fundamental physics to solve complex problems very quickly", and that "quantum computers are poised to take computing to a whole new level"; and in the corporate environment, IBM [4] argued "this technology is widely expected to solve valuable problems that are unsolvable using any known methods on classical supercomputers".

Defining Quantum Computing is not straightforward. Gillis [5] defines Quantum Computing as "an area of computer science focused on the development of technologies based on the principles of quantum theory. Quantum Computing uses the unique behaviors of quantum physics to solve problems that are too complex for classical computing". For McKinsey [6], Quantum Computing concerns "applying quantum mechanics to perform computations", but McKinsey also note three related technologies: Quantum Sensing, which uses quantum systems for high-precision measurement of physical quantities; Quantum Communication, entailing the transporting or exchanging of quantum-encoded information; and Quantum Simulation which concerns the use of quantum principles to improve modeling and simulations. Here we are largely concerned with Quantum Computing, but some of the cited material refers to Quantum Technologies, which includes all of those mentioned above.

It is important to make a distinction between the creators or providers of Quantum Computing [7] - companies, for example, like IBM who are developing, building, manufacturing, and usually marketing and selling Quantum Computing products - and end users, who will be using and applying these products to support and advance their own business processes. That said, it is also important to note that some end users are working closely with the manufacturers/creators to develop new applications of Quantum Computing, and that this may involve a range of commercial arrangements, for example covering co-ownership and intellectual property rights. One example here is Airbus, who have partnered with US quantum computer firm IonQ to collaborate on the development of quantum algorithms for aerospace use cases in the field of optimization [8]. Hyundai Motor have also set up a partnership with IonQ, to develop next-generation batteries for cars [9]. On a larger scale still, Bosch, Zeiss, Trumpf and Astra-Zeneca and working with the Jülich Research Center, co-funded by the German federal government, to develop the first European made quantum computer [10].

The advent and increasingly rapid and widespread adoption of Quantum Computing may herald a wide range of opportunities and benefits across societies, but companies that look to harness these technologies must face, address, and manage several new sets of corporate social, ethical, economic, technical and environmental responsibilities. In making the case for a greater focus on responsible Quantum Computing, Ten Holter et al. [11], for example, argued that "the need for a responsible innovation outlook has only increased with the relatively closer prospect of commercialisable quantum computing". However, the responsibilities associated with Quantum Computing, and on how companies are facing up to these responsibilities, have received limited attention in the academic literature.

One of the ways these responsibilities are being captured is in the concept of Corporate Digital Responsibility (CDR). CDR can be defined as "a set of practices and behaviours that help an organisation to use data and digital technologies in ways that are perceived as socially, economically, and environmentally responsible" [12]. Whilst CDR is often considered as part of the broader concept of Corporate Social Responsibility (CSR) [13], there is an argument that the focus on technology application and its repercussions warrants a clear distinction between the two concepts. Mihale-Wilson et al. [14], for example, noted that "due to the complexity that technology adds to corporate responsibility and the fact that managing the consequences and the opportunities that technologies can bring about requires a strong technological focus, it seems appropriate to view CDR as distinct from CSR". Herden et al. [15] in their study of how CDR allows companies to win the trust of their stakeholders, as well as to gain a competitive advantage in the marketplace, concluded that "as each company has unique goals, business strategies and CDR needs, an individual CDR strategy is essential", but that CDR policies and organisational structures need on-going monitoring and revision to reflect the continual evolution of digital technologies.

While the academic literature on CDR in Quantum Computing is currently limited, some of the leading international business consulting companies have been looking to publicly offer guidance and advice to companies on the responsibilities associated with Quantum Computing. This short exploratory paper looks, in part, to identify the CDR issues associated with Quantum Computing, and in part to examine if, and to what extent, these CDR issues are included in the guidance offered by a number of leading commercial consulting companies. As such, the paper not only looks to make a small contribution to addressing the gap in the academic literature referred to above, but also to offer some balance to the generally optimistic political and commercial messages about the benefits Quantum Computing is currently generating.

More specifically, in light of this brief introductory discussion, this article addresses two research questions, namely:

RQ1. What are the CDR issues raised by Quantum Computing?

RQ2. What guidance is being offered by the major business and management consultancies for organisations embarking on Quantum Computing deployment?

Following this introduction, there follows details of the research method used to address the two RQs. The results are then presented in section 3, in which the two RQs are directly addressed. Section 4 then discusses some additional issues emanating from the research, including the need for a balanced awareness of the positive economic benefits and the possible negative environmental impacts of Quantum Computing. The conclusions section then summarises the contribution, notes limitations of the research, and points to possible future avenues of research in this field of study.

2. Research Method

To address RQ1 and to explore aspects of CDR that will be impacted by the introduction of Quantum Computing in the business environment, a scoping literature review was undertaken in July-August 2023, to identify key themes. This type of review is "best employed when there is limited literature to inform the research question of interest" [16] and can provide the basis for pursuing additional research questions. Searches were made using the Google Scholar search engine using appropriate search strings, and sources and relevant quotations from these sources were stored on a spreadsheet. As themes emerged, the spreadsheet was reordered and source material aligned around the key emergent themes and related issues discussed below in section 3.1.

To address RQ2, the authors looked to examine if, and to what extent, these CDR issues are included in the guidance and advice offered by six leading international consulting companies, namely Deloitte, EY, PwC, KPMG, McKinsey, and the Boston Consulting Group, in publicly promoting their services to end-user organisation on the deployment of Quantum Computing. The consultancies are widely recognised as being the leaders in their field, they have a strong international presence, they have built powerful reputations, and they are generally trusted by their clients. However, this paper does not necessarily advocate the use of these, or any other, consultancies by end-users, but rather attempts to analyse and assess the advice and guidance provided. Brief pen pictures of the consultancies are provided below.

The authors undertook a number of Internet searches between August and November 2023, via Google, using the name of each of the six selected consultancies, some of the themes identified in the scoping literature review, and responsibilities associated with Quantum Computing as the key phrases, and the material generated by these searches provided the base of empirical information to address RQ2. More specifically, this empirical material was drawn from a combined total of eleven documents posted on the Internet as referenced in the results sub-section 3.2 below. While some of the documents were individually authored, they were all posted under the consultancies' banners. The selected consultancies provided their advice and guidance in different ways and formats, but their approaches were well headlined and signposted and the authors harnessed this headlining and signposting, along with their own experience and judgement, to draw key themes on responsibilities and risks perceived to be associated with Quantum Computing. Again, a spreadsheet was used to record and collate appropriate quotations and emergent themes. The material drawn from the consultancies' websites offers a general exploration of the corporate responsibilities and risks associated with Quantum Computing, rather than a detailed systematic comparison of the guidance and advice published by the selected consultancies. The paper is based on information that is in the public realm and the authors took the considered view that they did not need to contact the selected consultancies to obtain formal permission to use this information prior to conducting their research.

Deloitte is a British multinational professional services network. The firm was established in 1845, it has some 415,000 employees and revenues (2022) of US $59.3 billion, and its services include audit, management consulting, financial advice, taxation and legal issues. EY is a British multinational services partnership established in 1989, though it can trace its origins to 1849, it has 359,000 employees and revenues (2022) of US $45 billion, and its services include assurance, tax advice, digital strategy, financial advice and strategy consulting. PwC is a British multinational professional brand of firms, operating as partnerships. The firm was formally established in 1998, but can trace its origins back to 1849, it has 328,000 employees and revenues of US $50 billion, and its services include assurance, risk assurance, data and analytics, digital transformation, and management consulting. KPMG is a multinational professional services network, headquartered in England and the Netherlands. It was established in 1987, though its origins can be traced back to the late nineteenth century, it has 265,000 employees and revenues of US $34 billion, and its services include assurance, actuarial work, financial and tax advice and consulting. McKinsey is an international consulting company, founded in 1926, which has 38,000 employees and revenues of over US $15 billion, and offers a range of professional services to corporations and governments. The Boston Consulting Group is a US international consulting company, founded in 1963, with 25,000 employees and revenues of US $11 billion, and offering a range of management consulting services.

3. Results

3.1 What are the CDR Issues Raised by Quantum Computing?

In looking to address the first research question, three main themes - namely, ethics, responsible innovation, and governance - can be identified in the research literature, which provide a point of reference and an academic context. These three themes give rise to a number of related issues that are encompassed within the scope of CDR, as depicted in Figure 1. The aim here is to provide some examples of the diversity and flavour of the relevant literature, rather than to offer a comprehensive review.

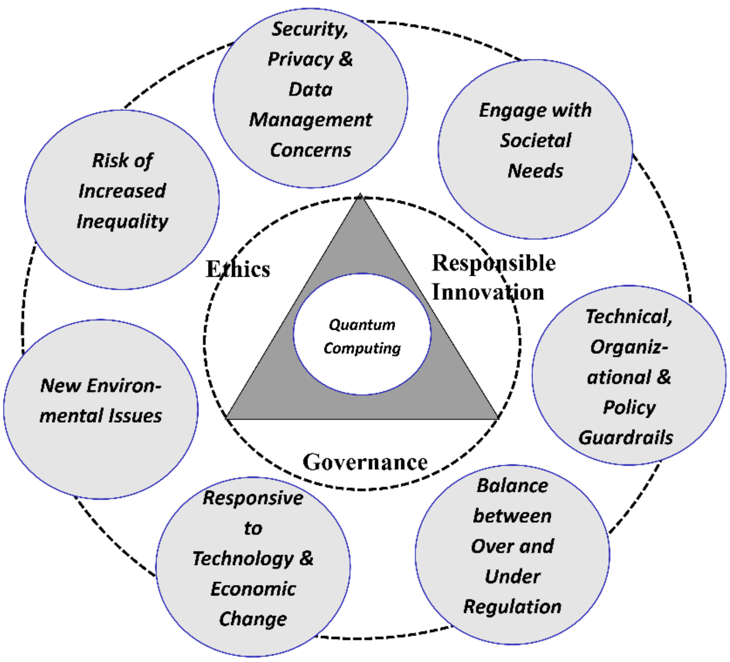

Figure 1 Quantum Computing and CDR: Main Themes and Related Issues.

3.1.1 Ethics

Perrier [17] suggested that "despite its significance, little if no structured research has been undertaken into the ethical implications of such quantum technologies". Perrier looked to site quantum ethics at the intersection of information science, technology ethics, and moral philosophy, and provided a series of specific illustrations, relating for example, to cryptography and distributional issues, to show how the emergence of quantum technologies give rise to normative and distributional ethical challenges. In examining the potential impact of Quantum Computing on society, de Wolf [18] outlined some of its ethical aspects, and ways to mitigate the risks. He identified cryptography, increased inequality, and the need to make the impact of Quantum Computing positive, as three important ethical issues. In addressing cryptography, for example, de Wolf [18] suggested that a breakdown of cryptography, due to Quantum Computing could lead to diminished privacy, that Governments would have great trouble protecting their workings from foreign spies, and that while the "right balance between privacy and justified surveillance for security purposes is a very tricky ethical question… this balance changes if the set of available cryptographic tools changes". In focusing on increased inequality, de Wolf [18] suggested that while it was difficult to guess how Quantum Computing would spread through society, it was quite possible that it would "not be widely accessible", and that "this could lead to a more unequal distribution of power and wealth: between America and the rest of the world, and between a few big companies and the rest of society".

Possati [19] identified an "emerging literature on the ethical problems posed by Quantum Computing and quantum technologies in general". More specifically, in looking to contribute to research on the ethical impact of quantum technologies and Quantum Computing, Possati [19] analysed some of the main ethical problems associated with Quantum Computing, and concluded that some of its features were extremely ambiguous, not least because they posed both risks, and opportunities, in terms of security, privacy and data management, and that further research was needed to better understand these issues and their implications. Possati [19] also argued that as Quantum Computing will generate new types of Big Data so it will require "increasingly complex data centres", and that "this could pose new environmental issues with ethical consequences", but he did not examine the environmental issues, such as climate change, natural resource depletion, energy use, and waste management, generated by all digital technologies [20].

3.1.2 Responsible Innovation

Ten Holter et al. [21] argued that "novel technologies such as Quantum Computing present new opportunities to support societal needs", but that "societal engagement is vital to secure public trust", and that "Quantum Computing is at a pivotal point in its journey, from foundational research to deployment which permits a moment for society to investigate, reflect, and consult on its impact and implications". More specifically, Ten Holter et al. [21] suggested that Responsible Innovation, which looks to identify and address the uncertainties and risks associated with novel areas of research, is one method for considering such impacts, engaging with societal needs, reflecting on any concerns, and influencing future trajectories. In their discussion, Ten Holter et al. [21] emphasised that informal pathways could provide clearer communication between researchers and policy makers, that it was important to generate two-way conversations between researchers and the public, that a wide pool of stakeholders should be included in the engagement process with industry, policy makers and academics, and that governments should look to ensure that their citizens are able to access Quantum Computing.

In arguing that Quantum Computing was poised to redefine the way "we understand and interact with the world", and in suggesting that "with such power shifts fueled by technological advancements comes the responsibility to innovate thoughtfully and conscientiously", Kop et. al. [22] proposed a set of "guiding principles" for responsible quantum innovation, organized into three categories, namely, "safeguarding, engaging, and advancing". The ten principles look to ensure that ethical, legal, cultural, socio-economic and philosophical dimensions are identified, and that beneficial opportunities are captured and promoted, while managing potential risks by putting appropriate technical, organisational, and policy guardrails in place. The safeguarding principles include making information security an integral part of Quantum Computing, proactively anticipating the malicious use of Quantum Computing, and seeking international collaboration based on shared values. Looking to the future, the "advancing principles" look to provide a vision for Quantum Computing's role in society, and include linking research and development in Quantum Computing explicitly into desirable social goals, and encouraging social dialogue with stakeholders about the future of Quantum Computing.

3.1.3 Governance

Ten Holter et al. [11] note that "societal attitudes towards Quantum Computing and quantum technologies are currently reasonably positive - and in order to maintain (and be worthy of) societal trust and acceptance, good governance is essential". However, in noting that quantum technologies were on the rise, and that Quantum Computing promised high security communications, but also brought the risk of broader surveillance and enhanced cyberattacks, Johnson [23] argued that a legal and policy framework for governing quantum technologies had not emerged. Here Johnson [23] suggested that "traditional command and control regulation could thwart promised advances and shirk national security imperatives", and "under-regulation may jeopardize privacy rights and fail to realize useful civilian applications", but that "softer governance approaches offer agility, flexibility, and an important first step towards responsible innovation and oversight in quantum technologies". By way of a conclusion, Johnson [23] argued that softer regulatory approaches should provide a balance between the goals of advancing security and protecting privacy, and encouraging beneficial applications.

Perrier [24] argued that "the emergence of quantum information technologies with potential application across diverse industrial, consumer and technical domains has thrown into relief the need for practical approaches to their governance". More specifically, Perrier [24] developed an actor-instrument model for quantum governance, and denoted the "quantum governance stack", across a governance hierarchy from states and governments through to public and private institutions", which set out "key characteristics that quantum governance should exhibit at each level in the stack, including identification of stakeholder rights, interests and obligations impacted by quantum technologies and the appropriate instruments by which such impacts are managed". Ultimately, Perrier [24] argued that quantum governance must be responsive, and based on the state of technology at the time, the resource and economic requirements for its development, and assessments and estimates of both the short- and long-term impacts of Quantum Computing.

3.2 What Guidance is Being Offered for Organisations Embarking on Quantum Computing Deployment? (RQ2)

The need for guidance in the implementation of new technologies is not restricted to Quantum Computing, and indeed recent literature has examined the implications for CDR of digital technologies in general [25], and more specifically as regards AI [26] and the Metaverse [27]. However, the potential impact of Quantum Computing in the business environment is on such a scale that it warrants further attention. The six selected consultancies provided a range of advice and guidance on Quantum Computing for end users. Rather than looking to describe each consultancies' approach in detail, the authors looked to identify a number of interlinked themes and draw out some related issues (Figure 2). Three inter linked themes - assessing and managing cybersecurity risk, planning for change, and embracing opportunities - were seen to collectively characterise the selected consultancies' publicly available advice and guidance on Quantum Computing.

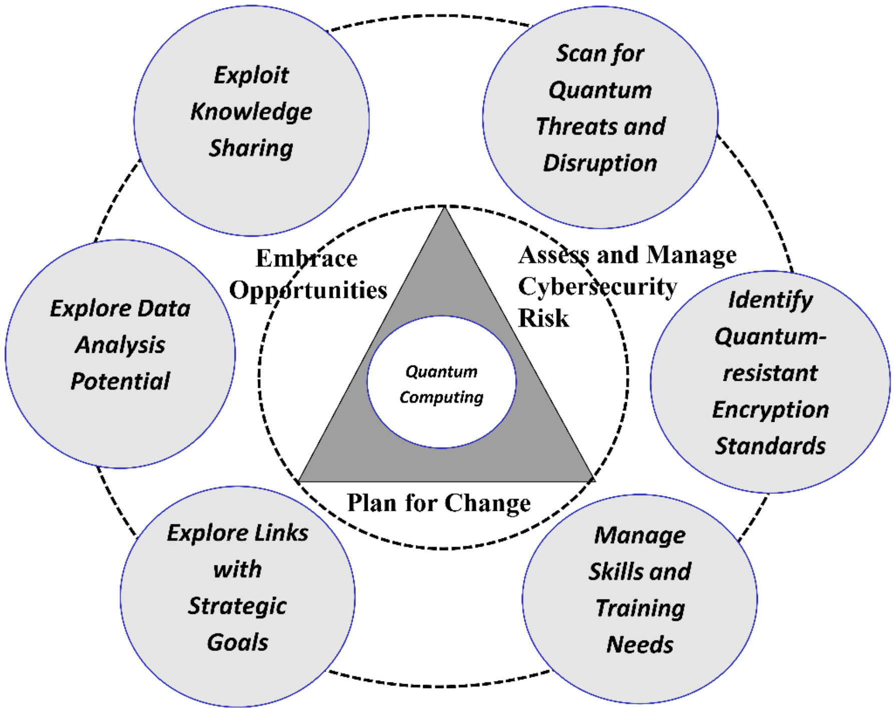

Figure 2 Quantum Computing Deployment: Main Themes and Related Issues.

3.2.1 Assess and Manage Cybersecurity Risk

Firstly, the consultancies offer advice and guidance on both existing and future cybersecurity. In addressing existing cybersecurity risks, there are fears, for example, that Quantum Computing could be used by individual hackers and hostile governments to break existing encryption protocols, thus potentially threatening a wide range of Internet based commercial and financial transactions. McKinsey Digital [28], for example, argued that "the technology's power also poses a significant cybersecurity risk. Fully error-corrected quantum computers will be capable of overpowering commonly used traditional encryption protocols". Here, consultancy advice is that companies should look to work collaboratively to identify quantum-resistant encryption standards and prepare for their adoption once they become available. Deloitte [29], for example, argued that "apart from the myriad of business opportunities the quantum era will bring about, it also reveals a fundamental threat to the backbone of today's digital trust. The new paradigm of Quantum Computing will be able to break the mathematical difficulty underlying many of currently used cryptography". More specifically, in the context of financial services, EY [30] also recognised that "Quantum Computing has the potential to be a boon for financial services firms, but it also raises a new level of cybersecurity concern", that "Quantum Computing can rapidly solve current encryption, putting at risk customer data and potentially leading to significant financial and reputational loss", but that "financial services firms can prepare now by engaging with regulators, looking at potential vulnerabilities with a quantum lens, and remediating vulnerabilities".

PwC [31] identified the "quantum threat" as "a situation where many of the cryptographic controls used across organisations today become redundant". Further, PwC [31] advised that in order to quantify the risk of the quantum threat, companies should look at its likelihood and potential impact by addressing three important questions, namely "which of my critical business processes are currently protected using cryptographic primitives that could be broken?"; "how long does my most critical data need to remain secret?", and "do I know the full inventory of my current cryptographic estate?" Ultimately in responding to quantum risk, companies should identify "which standards and protocols are used across their estate and whether the symmetric standards in use are considered quantum-safe; who is accountable and responsible for the maintenance and upgrade of the hardware or software that implements them; and finally, and most crucially which business-critical processes rely on them". PwC [31] argued that, equipped with these answers, "a company will be well-placed to create a more quantum-safe architecture".

Consultancies advised that the increasing adoption of Quantum Computing by businesses will create new ethical risks. EY [30], for example, warned of what it described as the "store now, hack later" scenario, in which rogue players will intercept important encrypted data now in the belief that they will be able to decrypt it when more sophisticated Quantum Computer capabilities become available. The consultancy also expressed concerns about two other new ethical risks, namely that from third parties as new companies spring up to meet the demand for new Quantum Computing capabilities, and reputational damage to companies and more generally to society.

3.2.2 Plan for Change

Preparing and planning for the new Quantum Computing future was a second common theme. KPMG [32], for example, emphasised the importance of "preparing for change", and focused on four themes, namely "data access", skills and training, "risk management", and "planning ahead". In addressing data access, KPMG [32] advised that companies should connect and access previously unconnected data sources to create "a proprietary knowledge bank", to provide valuable insights into future AI use, while upskilling was seen to be vital in ensuring that staff could make the best use of AI (facilitated by the new processing capabilities of Quantum Computing). In focusing upon risk management, companies were advised to establish mitigating control frameworks around intellectual property loss, data accuracy and security and ethical usage. Planning ahead centred on developing quantum-facilitated AI at pace in order to retain competitive advantage in the marketplace.

In planning for change, the Boston Consulting Group [33] offered advice to technology companies, end users and potential investors. Technology companies, for example, "should develop a clear milestone-defined quantum maturity roadmap informed by competitor benchmarks and intelligence", which will allow them to "determine the business model(s) that will allow them to capture the most value over time". In looking to offer guidance for end users, the Boston Consulting Group [33] advises that "companies in multiple industries likely to benefit from quantum computing should start now with an impact of quantum assessment", and that they also "should assess the value and costs associated with building a quantum capacity". Advice for potential investors emphasises the need for them to "educate themselves in three areas: technology, value flow, and risk".

Having identified that less than one third of UK organisations have embarked on strategic planning for Quantum Computing, EY [34] emphasised that "it is time for business leaders to begin planning for this new era of Quantum Computing". More specifically, EY [34] outlined five steps business leaders should take to "position their company for quantum success", namely exploring the intersection of Quantum Computing and strategic business goals; assessing the company's readiness for Quantum Computing; strengthening the company's cyber defences; developing a quantum ecosystem of partners; and scanning the horizon for quantum disruption. In addressing assessing a company's readiness for Quantum Computing, EY [35] advised on the creation of "a pilot team - preferably reporting to the board - to gauge where Quantum Computing could enhance future products, services and business operations", and "the availability of relevant skills". Scanning the horizon for quantum disruption, was seen to be important in that it alerted companies of the need to monitor the broader social, technological, economic, environmental and political landscape for signals of progress and disruption.

3.2.3 Embrace Opportunities

Thirdly, the consulting companies look to emphasise the opportunities and benefits of Quantum Computing, and to promote a positive corporate orientation to it. Although Deloitte [36], for example, recognised the dangers of cybersecurity threats, the consultancy stressed the need to "embrace change", and to take "a programmatic and responsible approach to first understand and then mitigate the quantum risk to cryptography". Deloitte [37] also argued that companies "can start thinking through the potential challenges and understand the ways their use of Quantum Computing may create ethical risks in the future", that "there are existing ethical frameworks for understanding the impact of technology, and many of the key considerations are generalizable to Quantum Computing", and that these frameworks "can help senior leaders think about how to build ethics into their work from the start". In a similar positive vein, KPMG [38] claimed that "by analysing extraordinary amounts of data, variables, and outcomes, Quantum Computing can help solve complex business problems that remain out of reach for today's classical computers", and that "as Quantum Computing gains momentum, more businesses are discovering its remarkable potential".

4. Discussion

The results reported above raise a number of issues that merit attention and discussion. Firstly, it is likely that the Quantum Computing deployment and the associated benefits will be within reach for many industries by the end of this decade. In 2021, McKinsey [6] suggested that "Quantum

Computing, one of the most revolutionary technologies of our time, is about a decade away from widespread commercial application". However, there are already a number of developments that suggest this timeline may be shortened. For example, supply chain logistics and transportation can take advantage of improved route planning and traffic optimisation enabled by Quantum Computing processing power, which can more effectively process and manage the vast amounts of real-time data now available from increasingly sophisticated in-vehicle systems [39], traffic flow data and weather patterns. Quantum computers can make a major difference here in their capabilities to process such large amounts of data in real-time, allowing optimal and constantly updated route planning for fleets of vehicles, with consequent environmental and efficiency benefits. This has already been successfully trialed by Volkswagen with buses in Lisbon, Portugal "to predict traffic volumes and route trips to minimize wait times for passengers and travel times for the buses, avoiding traffic jams and making the traffic flow as efficient as possible" [40]. Similarly, AI and machine learning (ML) capabilities may be greatly enhanced by Quantum Computing allowing simultaneous calculation of related problems. This has potentially enormous implications for automating and optimising tasks that can be used to support industrial processes. In addition, as McKinsey point out [6], the closely related technologies of Quantum Sensing and Quantum Communication could be available considerably earlier. Quantum Sensing "will allow for more accurate measurements and could offer higher accessibility than existing sensors", whilst Quantum Communication will "enable strong encryption protocols that could greatly increase the security of sensitive information, and it will also enable some critical Quantum Computing functions". McKinsey [6] concluded that "customer adoption will proceed at different rates, reflecting the diversity of underlying quantum technologies" and although these technologies can exist independently, "synergies may arise as quantum computing advances".

Secondly, concerns have been raised about ensuring equitable access to the benefits of Quantum Computing. Deloitte [37], for example, suggests that while it is unlikely that either an individual or a small company will own a quantum computer, due to their physical and technical complexity, this should not mean that they cannot benefit from Quantum Computing. Rather, "governments and companies that want to move everyone along the technology adoption curve in an equitable way should think how to share knowledge gleaned from quantum computers". Under the access umbrella, Deloitte also suggested that vendors who build and own Quantum Computing technology may also have a role to play in widening access. Here, the argument is that "investors are increasingly using environmental, social, and governance metrics to evaluate the companies they fund", and that "many enterprises now consider diversity, equity, and inclusion a top priority". In a similar vein, in advising companies to explore the intersection between Quantum Computing and strategic business goals, EY [34] emphasised that business leaders should focus on "organisational imperatives, such as environmental, social and corporate governance, talent and the future of work".

Thirdly, the consultancies have relatively little to say about responsibilities in general, and even less about CDR, associated with Quantum Computing. In one sense, this is perhaps not surprising in that in offering business advice and guidance, the consultancies are essentially looking to sell their services to companies considering deploying Quantum Computing to improve their business opportunities. A heavy emphasis on such responsibilities, and a recognition of the potentially high costs involved in addressing, meeting and managing these responsibilities, would hardly help consultancies to market their Quantum Computing services. In another sense, this begs the question of where the consultancies main interest lies, namely with their own business, or with that of their clients. Here, Gascoigne [41] for example, argued that the large consultancies may not be best placed to offer advice and guidance to small and medium sized companies, not least because they may not be sharply focused on the deployment of Quantum Computing.

This, in turn, raises the more general thorny question of whose best interests are served by Quantum Computing and the difficulties involved in making such judgements. Khan [42] for example, argued that “the impact of quantum computing across a whole swathe of humanity’s lived experience will be akin to an industrial revolution at an even larger scale than anything we have previously experienced”, and that the rise of such unprecedented computational power will bring new areas of ethical concern including “the acceleration of human DNA manipulation; the creation of new materials for war; or an intrusive Artificial Intelligence presence in most human activities”.

Fourthly, and more specifically, Quantum Computing offers opportunities to tackle a range of environmental problems, but the environmental consequences associated with Quantum Computing have received limited attention in the academic or the consultancy literature. On the one hand, Deloitte [43], for example, claimed that “quantum computing will likely transform the fight against climate change”, and that “by accelerating the development of innovative solutions to address technical challenges, quantum and digital solutions promise the acceleration of solutions to drive progress towards sustainable solutions and informed decision-making”. In a similar vein McKinsey Digital [44] suggested that “the emerging technology of quantum computing could revolutionize the fight against climate change, transforming the economics of decarbonization and becoming a major factor in limiting global warming to the target temperature of 1.5°C”. More generally, PWC [45] claimed that Quantum Computers “will also be suitable for research into environmentally friendly materials as well as for optimising the management of natural resources”. On the other hand, Quantum Computers require extremely low temperatures, and require powerful cooling systems, which consume large amounts of energy, which will, in turn, contribute to greenhouse gas emissions and place strains on existing power networks [46]. At the same time, increases in Quantum Computing will generate increased volumes of e-waste. In a wider context, there will certainly be justifiable claims that Quantum Computing can help in the achievement of some of the UN Sustainable Development Goals (SDGs), and SDGs 2,3,6,7 and 13 were recently highlighted by one leading expert as the most likely to benefit from Quantum Computing [47]. However, as noted above, there are also some negative environmental impacts, which need to be recognised and set against the undoubted benefits of heightened computing power, advanced data analytics capabilities and knowledge sharing.

5. Conclusions

This article set out to examine how the issues raised by Quantum Computing may affect the scope and operation of CDR (RQ1) and to assess the guidance provided by leading consultancies to organisations using Quantum Computing (RQ2). As regards CDR, the ethical and governance themes resonate in general terms with CDR concerns raised in the context of other recent technology developments, but responsible innovation is a new dimension to CDR emanating from the power of Quantum Computing and the rapid growth of AI applications. Related emergent issues of particular significance are the risk of unequal access to Quantum Computing, additional environmental aspects (both positive and negative) and an appropriate response to societal needs notably in the context of responsible innovation. Also evident was a renewed call for policy and organisational guardrails, in line with some of the recent discourse around AI [26]. This lends weight to the view put forward by Mihale-Wilson et al. [14] that CDR should now be viewed separately from CSR, and that new frameworks are now required. This is underscored by Kop [48], who notes that “the unique physical characteristics of quantum mechanics demand universal guiding principles of responsible, human-centered quantum technology”, and that it is now necessary “to put controls in place that address identified risks and incentivise sustainable innovation. Establishing a culturally sensitive legal-ethical framework for applied quantum technologies can help to accomplish these goals”. It may well be that the combined impact of Quantum Computing, AI and other new technologies will require a fresh assessment of the scope of CDR and its application and operation within organisations.

As regards RQ2, the guidance offered by the leading consultancies for users of Quantum Computing indicated the value of a balanced approach that recognises potential threats and associated risks, embraces opportunities, and plans for change. The related issues noted in Figure 2 provide a useful check-list for IT and business professionals. Appropriate resourcing and capability development are critical, notably for scanning for quantum threats and adopting quantum-resistant encryption standards, but there will also be wider skills and training needs as “quantum technologies are rapidly evolving from hypothetical ideas to commercial realities” [48] and their impact will soon be felt in the corporate environment. Exploiting the positive aspects of Quantum Computing will also need appropriate planning and skills development, to benefit from the data analysis and knowledge sharing opportunities enabled by Quantum Computing. This will bring about a more intense focus on certain aspects of CDR [49], which may well become an element of corporate strategy in many companies. In terms of navigating the intersection of corporate digital responsibility and quantum computing, strategies may include exploration of partnerships between major potential users (for example, companies in the energy, pharmaceutical, manufacturing and chemical industries) and Quantum Computing start-ups and medium sized enterprises, to comanage industry-based use cases deploying Quantum Technology solutions. Larger enterprises will also likely want to consider developing some in-house technology expertise in this field to inform a cross departmental steering group and/or working party which could explore and monitor policy issues and strategic impacts. Companies will also need to consider how they are monitoring and tracking these operations - it is of relevance that the major software houses are now offering Governance, Risk, and Compliance (GRC) software modules which include “tools and processes to unify an organization's governance and risk management with its technological innovation and adoption” [50].

This study clearly has its limitations, not least in that it is based on an analysis of secondary sources, but it does provide an exploratory examination of the responsibilities and risks end user companies are being advised to consider in adopting Quantum Computing, and also contributes to the developing theory around CDR. Looking to the future, as Roberson [51] has pointed out, further work is needed to expand on prior research and examine the societal implications and potential public good of Quantum Computing. More specifically, there is considerable scope for researching the impact of Quantum Computing in organisations and how management practices are adapting to accommodate this change. The focus here could be both on specific Quantum Technologies and also on organisational aspects including process change and people skills and competencies development (Figure 3). Case studies could focus on particular business applications and monitor costs and benefits through use cases. This may appear to be still on the horizon for many, but

Gartner [52] stated this year that 20% of organizations are already budgeting for Quantum Computing projects, and it will not be long before Quantum Computing features in the context of CDR and corporate strategy in many organisations.

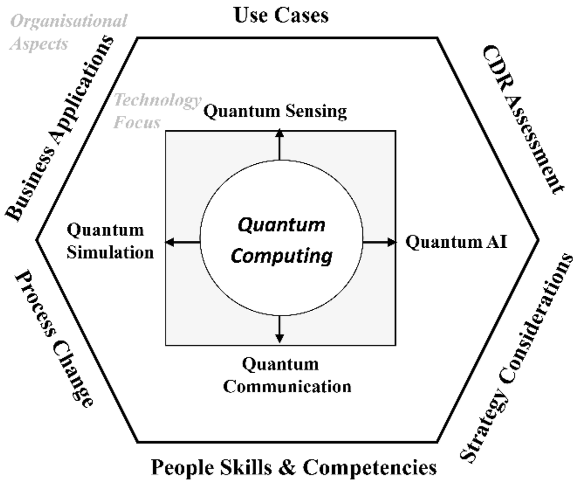

Figure 3 Quantum Computing: Future Research Avenues.

Author Contributions

Conceptualization, MW; methodology, MW and PJ; formal analysis, MW and PJ; investigation, MW and PJ; data curation, MW and PJ; writing-original draft preparation, MW and PJ; writing-review and editing, MW and PJ; project administration, MW. All authors have read and agreed to the published version of the manuscript.

Competing Interests

The authors have declared that no competing interests exist.

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