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From my Perspective

Failed technology management: Introducing 'future technology myopia' and how to address it

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ABSTRACT

The management of technology is increasingly fuelled by societal challenges and user problems. For effective technology development and implementation, it is important that both are relevant not only in the present, but also in the future. Technological development and implementation take time which means that a technology originally meant to address a particular societal challenge, may be no longer relevant at the time it is implemented because the challenge or problem may no longer exist. We call this 'future technology myopia'. This myopia implies that while analysing the possible future development of a technology, sufficient vigilance should be given to the persistence of i). the technical challenge and ii). the development of the societal problem, and of alternative ways to deal with both. In view of the increasing interdependence between technology and society, broadening the technology management and analysis is therefore relevant for the effective development of technology to address future societal and user problems and for developing relevant strategic technology policies. In this paper we develop a Technology Management Ailment Matrix that identifies imbalances that might arise during the technology development process. It enables firms to identify and compare different technology management ailments collectively; it also identifies a further new ailment: future technology myopia.

1. Introduction

The extant innovation literature seems to agree that science and technology provide one important origin of innovation, while demand is a crucial component to direct the innovation trajectory towards the right economic venues (e.g., Dosi, 2000; Kline and Rosenberg, 1986; Slater and Narver, 2000; Fang et al., 2011). The literature recognises that many technological innovations have their origin in science and technology but still need a market and a complete system of related complementary assets (Teece, 1986) to be successfully commercialized (e.g., Christensen and Bower, 1996; Gatignon and Xuereb, 1997; Ortt and Kamp, 2022). A crucial role for the market and more broadly society is to inform science and technology, at every stage of R&D, about technical feasibility, marketability and profitability (Dosi, 2000, p. 155).

When it comes to recognising best practices for R&D, technology managers recognise that demand-pull and technology-push are "(N)ecessary, but not sufficient, for innovation; both must exist simultaneously" (Mowery and Rosenberg, 1979). The need for a combination is especially necessary for large-scale R&D projects. Industry specific characteristics also play out here (Pavitt, 1984). The adoption of one technology depends upon complementary innovations and the potential of one may stimulate investment in the other (Mowery and Rosenberg, 1989). The main challenge now for scholars studying technological innovation is to better understand the interplay between technological knowledge, organisational resources and capabilities, and the societal and user environment. The days when technology development took place in a vacuum, separate from societal developments and user needs, when Cedric Price (1979) asked "technology is the answer, but what is the question?", are behind us.

Regarding strategies for the management of technology, both companies and governments are currently making greater efforts to target their technology development to address societal challenges. Concepts and approaches such as 'mission-driven innovation policy' (Mazzucato, 2021), 'responsible innovation' (Von Schomberg, 2013), the use of 'Sustainable Development Goals' (Wydra, 2015), 'democratizing innovation processes' (Von Hippel, 2005), and 'designerly-approaches' (Brown, 2008) have become widespread. As such, this change in technology management might even lead to dismissing technology push

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altogether as a source for technology management, thereby saying farewell to 'technology determinism', defined as "…the idea that technological development represents the (or a) key force that drives social change" (Swer, 2014, p. 201), as its underlying view on technology development.

The relationships between technology management and societal needs must therefore be carefully considered. For example, how can technology management and development effectively meet societal needs? And what are these possible future societal needs?

An important aspect of the failure of the technology management during development processes is the misconception of the effect of time. That is, it takes time to develop and implement a technology from its earliest idea or invention to its embodiment in an innovation and its implementation in practice. During this time interval many changes might occur, in the societal context or in other technologies. It is worthy of note that although time is of central importance to technology management, research in the field has viewed time as simply the background against which activities occur (see Ellwood and Horner, 2020). For example, according to experts, the development of so-called 'Personal Aerial Vehicles' (PAVs) (i.e., flying cars in urban environments) has great potential. However, Fleischer et al. (2019, p. 60) noted the following during a workshop in which this technology was explored: "Some participants of the focus groups stated that the level of automation required for these kinds of PAVs would, if implemented in cars instead, probably solve many current congestion problems on the ground, and considered PAVS to be 'overengineering'". It is an example of a technology that would take too much time to develop to address a societal issue (i.e., traffic congestion) because the time required for its development could allow the development of a different more efficient, safer, and cheaper technology to address the societal issue (such as connected autonomous vehicles). In other words: the focus on developing PAVs would be a kind of myopia. Once the PAVs are available on a large scale, the congestion problem is most probably already solved with other, simpler technologies.

The increasing importance of the development and application of new technologies in addressing societal problems places high demands on the quality of the management of technology. Linking long-term technology development to societal problems should be designed such that the development of a particular technology solution is not myopic in its approach; where it does not recognise that the societal problem has already been solved by the time the future technology is ready. Organisations developing technology to address a societal problem, often become fixated on one technology, and then fail to value alternative technologies or solutions. We call this 'future technology myopia'. Time is an important factor in this phenomenon, both the time to develop and implement the technology solving the problem as well as the time in which the problem remains relevant.

Indeed, large scale technology development processes (such as those linked to environmental challenges), require substantial investments before reaching competitiveness. Also, the high levels of uncertainty about future returns of R&D investments are an on-going challenge (Jaffe et al., 2002). Furthermore, the technological change needed is often very large and may require more than a series of incremental innovations over time. Radical technological innovations are qualitatively different from incremental ones (Freeman and Soete, 2009); they often involve discontinuous events, usually involving deliberative effort; and they may have only a minor relatedness to existing products (Garcia and Calantone, 2002; Dahlin and Behrens, 2005; Nemet, 2009). When it comes to such large-scale R&D projects (Nemet, 2009) that often span many years, the R&D team risks missing its target by offering up a solution for today's societal problems rather than tomorrow's societal problems.

The aim of this article is to describe and explain 'future technology myopia' by clarifying the causes and dynamics of how a technology can lose societal relevance before it is implemented. The awareness of this management of technology failure can support governments and companies in formulating technology policy and drawing up technology portfolios. Indeed, the socialization of technology means that the ties between society and technology are becoming ever closer and thus the coordination between them is becoming increasingly important. Insight into how technology development can help solve societal problems, has therefore become indispensable. Synchronization is required between the timing of technology development and societal problems, assuming that these are two different phenomena with a different timeframe. Frequently, both phenomena interact, but at the same time they have their own dynamics and are therefore partly autonomous. Therefore, our research question is: How can 'future technology myopia' be explained?

Understanding 'future technology myopia' is relevant in different ways. Developing and implementing radically new technological innovations to solve a societal problem, requires considerable resources over prolonged periods of time. Future technology myopia means resources are spent to develop solutions that are not needed once they become available. It is societally relevant to prevent such a waste of resources. Managerially it is also relevant to recognise future technology myopia, it prevents endless investments in technology without a return. Scientifically it is interesting to be able to preview and understand future technology myopia: it is an ailment that can be contrasted with some more well-known ailments in technology management.

We develop a 'technology management ailment matrix' that identifies imbalances that might arise during the technology development process and the societal problems in the course of time. It illustrates potential challenges faced by organisations attempting to develop and implement new technologies. We contribute to the technology development literature by providing a unique schema to identify and compare different technology ailments collectively; it also identifies a further new ailment: future technology myopia and it also positions this new ailment in between more well-known ailments (Dosi, 2000; Teece, 1986; Christensen and Bower, 1996; Ortt and Kamp, 2022).

The paper is organised as follows: Section 2 describes the context of 'future technology myopia' in which we relate it to other forms of technology management failures and thereby contextualise it. In Section 3 we elaborate on the concept of 'technology myopia' and in Section 4 we give two examples so that we gain insight into how 'future technology myopia' occurs in practice. Organisations naturally want to avoid being troubled by 'future technology myopia', so in Section 5 we describe the conditions under which it can occur so that organisations can determine for themselves to what extent the technology they are developing poses the risk of 'technology future myopia'. In this section we also indicate those strategies organisations can apply to deal with 'future technology myopia' and how these relate to the conditions mentioned. We close the paper with a discussion on how 'future technology myopia' is related to, and contributes to, the development of similar concepts and theories from the management of technology and innovation and what 'future technology myopia' means for technology managers and policymakers. Finally, we address the limitations of our paper.

2. 'Future technology myopia' in context: failures in the management of technology

That technology continues to impact our lives and society is without question; both in positive and negative ways. It is also well-established that how technology development is managed is a decisive factor in both the performance and quality of the resulting technological innovations and their societal and economic impact. Building knowledge about the management of technology during development processes and about its failures is therefore vital for ensuring the potential positive societal impact of technology. Nevertheless, the management of technology during development processes will remain an uncertain activity. There are indeed many classical examples of technology that had high hopes but never came to fruition (yet), such as the airship, cold fusion, and the Wankel engine. In the future, more examples will most certainly follow.

Imbalances (or mismatches) are not new. In 1922 sociologist William Fielding Ogburn (1922) coined the term 'cultural lag' to refer to the notion that 'material culture' (i.e., technology) changes first and faster than 'adaptive culture' (society) which causes "social maladjustments, create disorganization, and bring about social problems" (Del Sesto, 1983, p. 185). A related imbalance was defined in the 1970s by Alvin Toffler (Toffler, 1970) as the 'future shock' meaning that people become overwhelmed with societal changes due to radical technological developments as expressed by the transition from an industrial society to a post-industrial society. While Ogburn looks at imbalances between technological and societal developments, Toffler shows that within society, imbalances between subgroups become visible during transitions. Another 'future imbalance' is the Collingridge-dilemma which states that "… the social consequences of a technology cannot be predicted early in the life of the technology. By the time undesirable consequences are discovered, however, the technology is often so much part of the whole economic and social fabric that its control is extremely difficult. This is the 'dilemma of control'. When change is easy, the need for it cannot be foreseen; when the need for change is apparent, change has become expensive, difficult and time consuming" (Collingridge, 1980, p. 11). Collingridge thus explains why aligning the societal and technological developments is difficult, despite a methodology such as (constructive) technology assessment aimed at exploring the possible negative societal impact of new technologies to prevent these from happening by influencing the technology in an early stage of its development (Rip et al., 1995). In forecasting new technologies in particular, Geels and Smits (2000) conclude that during development and implementation of new technologies, the required societal changes are often overlooked or misjudged.

Other failures that are more specific to the management of technology are the lack of standards, lack of capital, the absence of commercially relevant applications (Ortt and Kamp, 2022), and the overoptimism of technological performance (Schnaars, 1989) leading to unrealistic technology forecasts (Schnaars, 1989). Unrealistic expectations regarding technology are highlighted in the hype cycle (Fenn and Raskino, 2008).

These theories, in different ways and from different perspectives, explain how the mismatch between societal problems and technological developments comes about. The explanations are based on various factors, be it organisational, governmental, or commercial. These factors can be related to making wrong decisions during technology development. It is interesting to note that given the increasing importance of technology for organisations, we could conclude that the downfall of organisations is partly caused by technology management. This means that we adopt a social constructivist's perspective to the management of technology because we ultimately consider the failure of technology not rooted in problems with technology itself (as with technology push) but caused by how organisations manage it. Thus, following Rosenberg (Rosenberg, 1982), we do not consider technological development as a 'black box' but as ultimately shaped by organisational decision making. Forms of technology development as described above are the domain of Science and Technology Studies (STS) but management sciences are also involved in technology development, focusing on how decisions during the process of technology development provide input to innovation processes. The importance of innovation for the business success of companies is undisputed which makes it interesting to note why, paradoxically, companies often fail to develop and implement the right technology in a timely manner.

Different theories try to explain the mismatch between technology and societal issues. For example, 'marketing myopia' (Levitt, 1960) refers to companies not considering different types of technological systems (from different industries) that serve the same needs albeit in a different way. A famous example is the failure of European national railroad companies in the 1980s thinking that they were monopolists in international people rail transport causing them to overlook low-cost air carriers such as EasyJet that were able to serve the same need but at a much lower price. Teece (1996, p. 203) refers to myopia as '(O)rganizations become closed to changes in the market and business environment and to new sources of technology' so that they "fall into the trap of adopting a citadel mentality" (Teece, 1996) Another 'technology management failure' is the 'innovator's dilemma' (Christensen, 1997) which is where organisations tend to underestimate the speed of upcoming and possibly competing technologies which are yet underperforming in comparison with their own current dominant technology. A third classical example of technology not being aligned with business needs, is the 'not-invented-here'-syndrome (NIH-syndrome) which basically means that technology developed 'elsewhere', meaning outside the organisation or outside the innovation-team, is not accepted simply because its intellectual ownership lies 'elsewhere'. Even though this other technology might better suit the needs of potential users or customers or addresses societal problems and challenges better than the technology developed by the organisation, it continues to be rejected by the incumbent team.

2.1. *Development of the 'technology management ailment matrix'*

Given that the uncertainties are greater in case of long-term technology development, the corresponding risks of failure of technology development are also greater. We map these risks on a simple conceptual framework in Fig. 1. R&D management teams need to be mindful of the following technology ailments that can all too easily engulf the technology management team and its technology. This is most notable where the functionality of the technologies being considered is similar. To develop a coherent framework within which to explain the distribution of outcomes illustrated in Fig. 1, two fundamental building blocks must first be put in place: the technology principles or scientific roots of a technology and the comparison and evaluation of technologies over time. The matrix shows four different ailments that deal with how a technological innovation compares to a competing technological innovation. The innovation can be based on a similar or a different technological principle and the comparison between those competing technological innovations can be made at a specific moment or over a longer period. These two criteria relate to different ailments and have been chosen because they enable us to make a clear and therefore useful distinction for future technology myopia, for which the technological principle and the dynamics of technology development are essential. We have positioned these on the vertical and horizontal axis of our framework respectively.

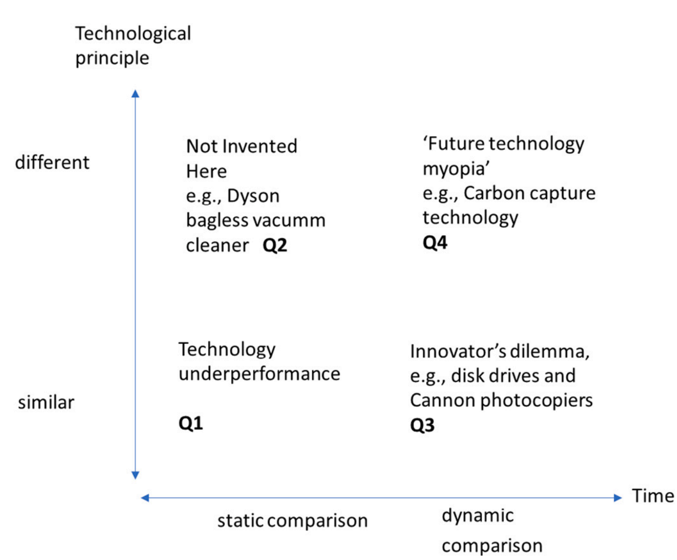

Fig. 1. The 'technology management ailment matrix', a typology of imbalances between technology principles and time perspectives.

Fig. 1 presents a simplified taxonomy of the possible outcomes from long-term technology development projects. These may be described as potential ailments. Quadrant 1 represents those technologies that a particular organisation judges to be inferior to their own existing offerings usually in terms of performance, across a wide spectrum of specifications. This is the most common ailment that befalls new technologies. The list here is long and includes ‘technology battles’ such as copper versus optical (in telecommunication), and steam versus electricity (in manufacturing industries). In these cases, incumbent companies underestimate the potential performance of a new technology that will ultimately compete with their own technology.

Quadrant 2 represents those technologies that offer a radical improvement and hence are often described as discontinuous to the existing technologies in a particular organisation. Within R&D laboratories such new ideas can succumb to the Not-Invented-Here-syndrome (NIH-syndrome) where the technology is dismissed by technology staff. This is usually because the R&D teams have many years of experience with the existing technology and view themselves as leaders in the field. Thus, anything new that did not come from within is viewed with suspicion. This is closely related to the phenomena of core rigidities and path dependency. James Dyson experienced this when he offered his bagless vacuum cleaning technology to existing vacuum cleaner manufacturers. All rejected the option of licensing the other (new) technology.

Quadrant 3 represents those technologies where the technology principle is the same or similar. And where comparisons with other technologies occurs repeatedly over time. Such characteristics are applicable to Clayton Christensen's ‘innovator's dilemma’. Here incumbent firms are in close contact with their customers and track competitors' actions carefully; they invest their resources to design and build higher-performance, higher-quality products that will yield greater profit. Thus, when a similar but often poorer performing technology is considered, it is understandably rejected because their existing customers reject them; the technology performance is initially lower, and the market size is small. But in this light of reasoning, a potentially large and new customer base is ignored. Clayton Christensen used the case of Disk Drive technology to illustrate this dilemma. In this case, simpler, smaller, and thus cheaper disk drives would cater a much larger portion of the market and thereby generate turnover and profits by which the companies producing those simple disk drives could outcompete the companies that aimed for ever more advanced systems that overshot the performance wanted by customers.

Quadrant 4 is the focus of this paper. As with Quadrant Three the comparison of the technology takes place over time but unlike Quadrant Three here the technology principle is different. Unlike Quadrant Two comparisons continue over time and hence the likelihood of the ailment of NIH will diminish during repeated evaluation of the technology and subsequent learning effects (see Lichtenthaler and Ernst, 2006). An even more dangerous situation occurs, because organisations are not even aware of comparable technologies being developed elsewhere, in a different industry, in different parts of the industry, or even in different parts of the same (large) company. Here we position our two case studies: Carbon Capture Technology and the Phillips Cathode Ray Tube (see Section 4). We will show how Philips suffered from future technology myopia even regarding a technology that they were developing in another part of the corporation for different purposes.

3. The concept of ‘future technology myopia’

Competition between technologies is based not only on the (potential) performance of a technology, but also on the speed of the development of a technology (Christensen, 1997). Technologies can have different dynamics. The most competitive technology is one that outperforms another technology, that solves the (societal) issue more effectively, and is developed and hence available faster than a different technology. We can interpret the latter feature as technology reaching a certain future level of maturity in a shorter time frame than a different technology addressing the same societal issue. The specific future level of knowledge required for the technology development can then be considered part of a general future level of knowledge.

We define ‘future technology myopia’ as: *the tendency to take no notice of the option that the future level of general knowledge will in time enable a different technology that will address faster the societal challenge that the initial technology intended to address*. The effect of developing a technology that is meant to address a societal challenge that has already been addressed by another technology in the meantime, can be regarded as a “reverse anachronism”. Technology is ‘out of time’, as it were. With a ‘normal’ anachronism we attribute something belonging or appropriate to a period other than that in which it exists, especially a thing that is conspicuously old-fashioned. Whereas with ‘future technology myopia’ the technology is placed in a future time where it does not belong because a different technology will have made it superfluous or because the problem the technology was supposed to address has already been addressed in a different way.

A technological development should therefore not be seen in isolation from other technologies, by which we don't mean that this is about the “usual” competition between technologies offering a similar functionality. Here with “future technology myopia” this ‘tendency’ is about how a different technology, which is part of a different technological system, solves in a different way the societal problem that the technology being developed is also aiming to solve. More precisely, the “winning” technology does not solve the problem directly but changes the societal context in which the problem is not so much solved but simply disappears. For example, 3D Printer produced letter openers will no longer be necessary because digital developments have rendered physical mail almost superfluous and reduced drastically the need of physical letters to be opened. These digital developments will also ensure that there is no need to develop self-driving mail buses with robots that empty letterboxes autonomously. Another illustration could be how congestion problems in urban areas might be solved in a different manner before the advent of those PAVs. And F16s might not be needed anymore if the way we fight wars has changed fundamentally. The ‘winning’ technology could indeed have a preventive effect on the other technology to be developed, provided that the actors developing that other technology see and recognise it in time and decide to stop or redirect their technology development activities. Thus, the timing of technology development is important and developing new technology for an ‘old problem in society’ is not smart. It is also not wise to invest and develop a technology while a different technology has a steeper growth curve (Christensen, 1997). That is, a technology can also be ‘outperformed’ by a technology from a different technological system.

To be clear, future technology myopia is not a synonym for organisational inertia caused by path dependency and the subsequent development of core rigidities. Technology myopia concerns technology management decisions in the future. There is a “time” distinction between: a) the continuing reluctance and perhaps delay in the adoption of new technologies often characterised as a rigidity due to previous decisions concerning technology investments (see: Heracleous et al., 2017); and b) Future Technology Myopia which is a condition that affects the firm's inability to take account of societal and technological change in present and future decision making.

To visually illustrate ‘future technology myopia’, consider Fig. 2 which shows two different rates of technology development: T1 and T2. It is assumed that the rates are linear although the shape of these curves is not essential. The main point is namely that a particular technology (on which solution 2 is based) from a different technology system, has a steeper development curve which reaches the future minimal required performance level to address the problem earlier than the technology on which solution 1 is based. It must be noted that the lines representing T2 and T1 are projections of the future which means that for a solution for a societal problem a future minimal technology level is required. The focus on one technology (T1) could blind organisations to alternative technologies from a different technology system (such as T2) that could

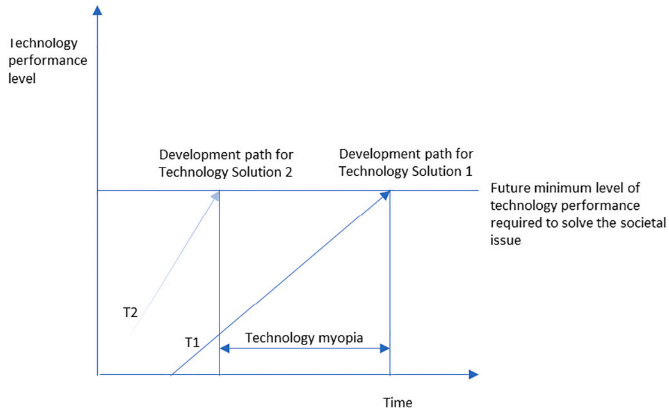

Fig. 2. The graphical illustration of 'future technology myopia'.

lead to alternative solutions that address the (societal) problem sooner. The situation for T1 might become even more difficult if T1 assumes a higher minimal technology level. The surprise appears when different technologies from another technology system, are apparently not considered. The developing of PAVs is considered in a competitive relationship with other mobility-based technologies (such as train 'smart infrastructure', electric scooters, and new types of subway-related means of transportation) and not with technologies that indirectly address the issue of congestion such as working from home or digital developments regarding the changing nature of work and thereby of commuting. Fig. 2 looks similar to the 'innovator's dilemma' by Christensen (1997), but there is an important difference. In case of future technology myopia, contrary to the 'innovator's dilemma', the 'winning' technology curve immediately takes up a steeper development trajectory. This winning technology addressing the societal issue or customer need at an earlier stage and thus makes other technologies irrelevant. In contrast, in the 'innovator's dilemma' the 'winning' technology starts with a relatively low performance and needs much more time to reach a higher performance level. In general, future technology myopia differs from the innovator dilemma in several ways. Firstly, the innovators dilemma refers to competition from a simpler version of the same technology, whereas future technology myopia refers to competition from an entirely different technology (based on another technological principle). Secondly, in case of the innovator's dilemma, the simpler technology is known by the company providing the currently more complex technology, but the potential of the simpler technology to develop further and compete in due course with the complex technology is overlooked. In contrast, in case of future technology myopia, the alternative technology is not known and is thus completely overlooked. Thirdly, the simpler technology that is central to the innovator's dilemma will initially appeal to a different customer segment than the more complex technology. In contrast, the alternative technology that is central to future technology myopia is addressing the same problem and hence customer group.

4. 'Future technology myopia' in action: the cases of flat CRT screen and carbon capture storage

To illustrate how 'future technology myopia' takes place, we describe two cases, the first one is a historical case, and the second case is a prospective case by which we mean that 'future technology myopia' is likely to occur, unless proper strategic action is adopted by companies involved.

4.1. Flat CRT screen

In the late 20th century, many households owned a television set. The television market grew rapidly over the second half of the 20th century. Traditionally these television sets had a screen with a fluorescent layer and a Cathode Ray Tube (CRT). A CRT could produce an electron beam that, once deflected properly, could form a picture on the screen by striking the fluorescent layer on the inside of the television screen. The quality of the CRT television sets, in terms of detail, colour quality and responsiveness, were very high. There was one main issue: to produce the electron beam, a tube was positioned behind the screen that made the television set very bulky. Customers preferred larger screens, yet these screens required more extensive tubes behind the screen and that made the television sets even more bulky. Understandably, customers preferred thin television sets that could be positioned against the wall without taking up too much space in the room.

In the late 20th century, Flat Panel Displays (FDPs) such as LCD screens, entered the market. LCD screens are based on a different technological principle than CRT screens and R&D groups working on LCD screens were separate from the groups working on thin CRT screens. LCD and CRT screens were on different trajectories of technology development and diffusion. They were also part of different networks of actors and technology innovation systems. Initially the quality of these LCD screens was well below the CRT screens and thus several consumer electronics manufacturers tried to make thin CRT screens by repositioning the tube and then deflecting the beam accordingly[1] (see for example Ha et al., 2006). This development required considerable resources, it is estimated, for example, that one of the main television manufacturers[2] spent about a billion Euros on R&D that ultimately led to thinner CRT screens. The development of the thin television sets took time, and when these screens were available to produce on a large scale, the LCD screens had developed so quickly that the thin CRT screens were outdated. So once the thin CRT screen entered the market, it fulfilled a demand that was better fulfilled by another technology, that was developed in parallel. Thus, the development of the thin CRT (television) screen suffered from future technology myopia. Significantly, the main electronics manufacturer that we studied, worked in parallel on flat CRT screens for televisions and LCD screens for other purposes. Initially, those LCD screens were not intended for televisions but for displays to show text. We believe that these teams did not suffer from organisational inertia to work on the new LCD technology. The team working on flat CRT screen simply overlooked another technology, in their own company, that would become relevant for television screens. Hence, we consider this an example of future technology myopia rather than organisational inertia.

4.2. Carbon capture storage

Carbon capture storage (CCS) is a range of technologies able to capture CO2 from the air. CO2 gas emissions have significantly increased through industrialization and increased transportation. CO2 gas emissions are driving the climate crisis through a simple mechanism. The sun emits light with a wavelength smaller than 4ɥm, this light warms up the earth. The earth in turn emits heat with a wavelength typically larger than 4ɥm. Normally there is a balance of heating up the earth's surface by the sunlight and cooling it down through emission of heat. That balance is disturbed when more CO2 gasses enter the atmosphere because CO2 does not absorb the incoming light but does absorb the outgoing warmth and hence this gas is a cause of heating the atmosphere, and that affects our climate on earth. So, limiting the amount of CO2 gasses in the atmosphere is of utmost importance to limit the disastrous consequences of climate change.

CCS refers to technologies capturing, transporting, and permanently storing CO2 that would otherwise be emitted into the atmosphere. CCS

[1] https://www.pcmag.com/encyclopedia/term/flat-crt#:~:text=A%20TV%20picture%20tube%20(CRT,and%20was%20the%20preferred%20design.

[2] Personal conversation with former R&D director of that particular manufacturer.

can be applied to industrial installations, such as cement or steel plants, and in power plants (Wilberforce et al., 2021). Considerable investments have been made to explore, develop, and implement such technologies, for example by the EU.[3] Hence, some experts view the CCS technologies as crucial and claim that they should be implemented as soon as possible.

Other experts, however, claim that CCS technologies are not a long-term solution (Jacobson, 2023). The emphasis on these technologies assumes that CO2 will be produced by humans for prolonged periods of time. The investment in these technologies is huge, and that investment could also be devoted to implementing clean energy technologies, like wind, solar, water, and geo-thermal technologies in combination with green hydrogen to store energy and thereby level-out the difference between clean energy production and consumption during the day, during the seasons and across different regions. Carbon capture technologies make us deal with the symptoms of the CO2 problem but do not solve the problem by directly limiting the emissions resulting from burning fossil-fuels. Finally implementing carbon capture technologies will take many years whereas the climate crisis requires solutions within the coming decade. "Carbon capture and storage is solely designed to keep the fossil fuel industry in business," Jacobson says. Only some of the CO2 is captured and buried, he says, and deadly air pollution continues unabated. Blue hydrogen, produced from fossil gas with some CO2 then captured and buried, is far inferior to green hydrogen produced directly from renewable electricity, Jacobson says: "Blue hydrogen is just really convoluted."[4]

If Jacobson is right, then developing and implementing carbon capture technologies may represent a clear example of 'future technology myopia'. Once the technology of carbon capture is fully developed and implemented it will be no longer be needed once fossil-fuel based technologies are fully abandoned and replaced by sustainable energy technologies.

5. Conditions of and strategies for 'future technology myopia'

The ailment of 'future technology myopia' does not always happen in technology development processes that are aimed at addressing a societal problem. The likelihood of the ailment depends on specific conditions. A situation in which 'future technology myopia' is likely to occur, is when the technology development time is relatively long. In addition, we expect 'future technology myopia' to be more likely to occur when the societal problem is complex and when many different technologies or solutions are capable of addressing the same issue. In short, conditions that favour the emergence of 'future technology myopia' are:

1. Development and implementation of the technology takes a relatively long period of time.
2. The (societal) problem the technology is meant to solve is complex, and changes erratically over time.
3. Many alternative socio-technological arrangements can be designed that address the same problem in an entirely different way.

These conditions do not necessarily lead to 'future technology myopia'. However, this is more likely if those involved in technology development adopt a 'ceteris paribus'-clause, meaning that they assume that all conditions outside their own technology and the direct system around it, are invariant.

For technology managers the key question is: What strategies are available to deal with or prevent 'future technology myopia'? A first strategy to avoid myopia, is to analyse whether the social problem is still relevant and applicable at the time the technology can be implemented. This does not only require an analysis of the social problem, but also an analysis of potential other technologies that may in due course solve the social problem. The core issue here is that the different speeds of the various technologies involved are examined to make a comparison. Or, to put it differently, the expected timing in which the minimum required performance and functionality is achieved by alternative technologies, is crucial.

A second strategy is based on 'expectations' (Rosenberg, 1976; Brown and Michael, 2003; Van Lente, 2012). Expectations can drive the development of a technology by influencing how various actors involved think of the future course of the technology development. If expectations focus on one technology, then 'future technology myopia' is more likely to occur. To cope with 'future technology myopia' these expectations should focus on (future) societal issues or problems rather than the technology. An obvious recommendation would therefore be to not only formulate social issues as the starting point of technology development, but also to give 'social actors' sufficient time and freedom to formulate the future societal issues. A third strategy is to pay more attention to envision the complete socio-technical system around each technology that in due course may address the societal problem. We should formulate 'visions' of socio-technical systems as suggested by Sand and Schneider (2017). In short, strategies to address 'future technology myopia' are:

1. A broad exploration of possible technologies that are potentially capable of addressing the societal issue and/or customer need. In practice, this exploration involves a search for technologies, applied in different industries and developed in different disciplines, that are (potentially) capable to provide a functionality capable of addressing the societal issue. This is a very specific search outside the common market and technology frame of reference of companies.
2. A thorough analysis of the societal issue to indicate whether the issue will be present and relevant in the future. In practice, this analysis requires a vision that entails the specification of conditions in which the issue will be no longer relevant (or solved in another way). The next step is to track those conditions, and be prepared once the conditions change. A well-known method for this comes from foresight and is called horizon scanning, which consciously chooses the broadest possible perspective on the future and systematically looks not only at trends, but also at possible, apparently isolated events ('signals of change') (van der Duin et al., 2016). Crucial here is that "horizon scanning challenges our current norms and images of the future by searching beyond the mainstream fields or 'outside the box' to identify new sources of data and information often on the fringe" (European Environment Agency, 2023, p. 7). So, "(h)orizon scanning tries to identify early weak signals that may evolve into emerging issues in the future but are not yet present in current-day research or media" (European Environment Agency, 2023).
3. Bringing in more socio-technical visions into the technology development process to ensure that it is a shared vision within the technology development team. In practice, both technologies and societal issues evolve over time. Creating a shared vision among all actors involved, specifying in which conditions a technology (or an alternative thereof) can be applied to address an issue. 'Visioneering' is therefore a social activity that must be intrinsically linked to innovation and technology management processes that must result in visions that "actively (are) created, shaped and utilized to transform the present" (Sand and Schneider, 2017, p. 21). Regarding the content of these socio-tech visions, Schoemaker (2002) points out that from an organisational perspective such visions are a statement of what the organisation wants to be and how it will get there, which in particular concerns, among other things: concrete goals and milestones, required core capabilities that need to be developed,

[3] https://energy.ec.europa.eu/topics/oil-gas-and-coal/carbon-capture-storage-and-utilisation_en#:~:text=Carbon%20capture%20and%20storage%20is,be%20emitted%20into%20the%20atmosphere.&text=Carbon%20capture%20and%20storage%20(CCS,plants%2C%20and%20in%20power%20plants.

[4] https://www.theguardian.com/environment/2023/jan/23/no-miracles-needed-prof-mark-jacobson-on-how-wind-sun-and-water-can-power-the-world.

robustness of the vision in the face of multiple scenarios, and a stretch to reach beyond the organisation's current grasp.

Table 1 provides an overview of how the different strategies can relate to the three different conditions favour the emergence of 'future technology myopia', for which we use a qualitative scale: 'limited relevant - moderately relevant – relevant – very relevant'. For example, Strategy 2 is relevant to Condition 3 because exploring possible future societal needs can provide insight into the complexity of future societal problems. Strategy 1 is moderately relevant for addressing Condition 2, although complexity can also arise from the combination of technological and social developments. And Strategy 3 is very relevant for Condition 3 drawing up a "vision" for the future can provide a deep insight into the wide range of socio-technological arrangement.

The main function of the conditions and strategies in exploring 'future technology myopia' is to make it easier to identify when there is a reasonable chance of 'future technology myopia' occurring and how this can be reduced by the timely implementation of certain coping strategies. It may be impossible to completely prevent the emergence of 'future technology myopia', but the coping strategies show that 'future technology myopia' is not an unavoidable natural phenomenon but is linked to organisational decision-making on technology development.

Table 1
The conditions of and strategies for 'future technology myopia' combined.

Conditions	Strategies		
	1. Broad exploration of technologies	2. Future assessment of societal issue or customer need	3. Using socio-technical visions.
1. Development and implementation of technology takes much time.	Relevant because the time frame probably also enables development of other technological solutions.	Relevant because the time frame probably enables the societal issue to evolve, change or even vanish.	Relevant because by using future scenarios the development of new technologies can be investigated to what extent they are in line with possible future developments.
2. The societal problem is complex.	Limited relevant because this condition is about societal problems for which a technology scan probably would not yield much relevant information.	Very relevant because the future assessment (e.g., horizon scanning) is aimed at finding and exploring societal issues.	Very relevant because the complexity means that the solution may come from different directions and many different stakeholders will be involved.
3. Many alternative socio-technological arrangements are available.	Relevant because this approach is specifically aimed at finding new technologies outside the usual scope although is less focused on the social aspects of new technologies.	Moderately relevant because horizon scanning is mainly about finding new developments and changes and less about looking for combinations between societal and technological developments.	Very relevant because these visions are specifically focusing on societal and technological developments by involving many different stakeholders and the scenarios are well equipped to explore different socio-technological arrangements.

6. Concluding remarks

Scholars developing theories of technology management have long been interested in the increasing interdependence between technology and society. As organisations become ever more complex and technologies ever more interwoven, we need new approaches to understand how to develop effective technology to address future societal and user problems. Such approaches are important when developing relevant strategic technology policies. Based on our synthesis of multiple bodies of literature, we have proposed a new technology management ailment, 'Future technology myopia' and we have discussed how organisations can avoid 'future technology myopia'. Fundamentally we have illustrated that technological development and implementation take time which means that a technology originally meant to address a particular challenge or problem, may no longer be relevant at the time it is implemented because the challenge or problem may no longer exist. We call this 'future technology myopia'. Our central assertion is that the criteria for addressing future technologies is insufficient and that when analysing the possible future development of a technology, increased vigilance should be given to the persistence of i). the technical challenge and ii). The societal problem, and of alternative ways to deal with both. Thus, a broader technology analysis needs to be adopted.

Building on prior research and integrating insights from different theoretical perspectives we have highlighted the relationship between technology development and societal problems and possible imbalances that might arise during the technology development process and the societal problems in the course of time. This is distinct from the continuing reluctance and perhaps delay in the adoption of new technologies due to path dependency and core rigidities. Technology myopia concerns technology management decisions in the future. It is a condition that affects the firm's ability to take account of societal change and technological change in the future (Heracleous et al., 2017). Our 'technology management ailment matrix' (Fig. 1) attempts to position the concept of 'future technology myopia' along two axes of time and (fundamental) technology principle. This illustrates potential challenges faced by organisations attempting to develop and implement new technologies. The framework proposed enhances our understanding of the technology development and foresight challenges. We contribute to the technology development literature by explicitly linking time, technology development, and societal change (Dosi, 2000; Teece, 1986; Christensen and Bower, 1996; Ortt and Kamp, 2022). In particular, unlike the extant literature focusing on singular technologies, we propose a broader perspective on technology by studying multiple technological trajectories and their interactions. Our framework is novel as it provides a unique schema to identify and compare different technology ailments collectively; it also identifies a further new ailment.

One of the main problems or ailments in technology management is 'technology push': developing technological innovations that are not needed. Future technology myopia addresses a societal need or customer need and wants and hence is not 'technology push' in its purest form. However, future technology myopia may solve an important problem and fulfil a need yet may not be preferred by potential customers involved, because other solutions are easier and simpler, and thus preferred. Or the technology would have been preferred by customers when it was available early on, but when it becomes available much later, the customer preference may have changed due to complimentary and network effects (see Srinivasan et al., 2004).

Our framework offers several implications for organisations. First, we call attention to the need for technology managers to adopt a broader technology analysis. In our paper we have outlined three conditions and linked strategies that organisations can mobilise to deal with or prevent 'future technology myopia'. Managers may intuitively maintain heightened vigilance to identify when there is a reasonable chance of 'future technology myopia' occurring and how the chance can be reduced by the timely implementation of certain coping strategies. Such an approach will help improve the performance of organisational decision making on technology development and implementation. Technology management is management in a turbulent environment. Our ambition is to help firms behave like great players. For example, “A good hockey player plays where the puck is. A great hockey player plays where the puck is going to be.” — Wayne Gretzky, Canadian former ice hockey player.

In this article we have introduced the concept of ‘future technology myopia’ and have used two technology development case studies for illustrative purposes. To increase and strengthen the empirical validity and the theoretical basis of ‘future technology myopia’, further research is of course necessary. For example, it can be investigated whether there are other conditions under which ‘future technology myopia’ can occur, how the conditions can relate to each other and the combinations between conditions and strategies can be further elaborated. The relationships between the various technology ailments can also be further specified and an assessment must be made of how and to what extent government technology policy can address ‘future technology myopia’. Researchers could also examine the extent of these technology management ailments. Possible considerations are: emphasis on the performance progress of singular technologies; insufficient emphasis on the competition between multiple technologies; the embedding of technological innovations in practice. More ailments than the three we described to contrast with ‘future technology myopia’ can be formulated, and new ones may emerge.

The conceptual framework we propose offers promising avenues for future research. Researchers can undertake in-depth, qualitative analysis of large-scale R&D projects to assess the interdependence of the technology and societal change. Researchers can use the proposed theoretical framework to unpack and analyse technology development programmes to search for the existence of the conditions that may lead to future technology myopia.

Data availability

Data will be made available on request.

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