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The infrastructural conditions of (de-)growth: The case of the internet

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ABSTRACT

Infrastructure studies represent a domain that remains significantly uncharted among degrowth scholars. This is paradoxical considering that infrastructures constitute a fundamental prerequisite for the equitable distribution of many aspects of human well-being that degrowth proponents emphasize. Nonetheless, the substantial resource and energy consumption associated with infrastructures cannot be overlooked. The internet offers an instructive case study in this sense, at its best it forges human connections and is productive of considerable societal value. The resource implications of the often-overlooked internet physical layer of data-centres and submarine cables needs to be acknowledged. Furthermore, the ways in which assumptions of perpetual growth are built into this global infrastructure via the logic layer of internet protocols and other governing mechanisms such as finance and network design need to be examined if we are to determine the extent to which such infrastructures are inherently growth dependent. In making these two arguments, we draw upon the work of both Science and Technology Studies (STS) and Large Technological System (LTS) studies on the inherent problems of large infrastructures which have thus far seen little engagement with questions of degrowth. We review the case of the internet and suggest a number of scenarios that illustrate potential roles for such infrastructures in any planned reduction of economic activity.

1. Introduction

Postgrowth and degrowth scholarship has, with increasing force, made the case that present levels of consumption are incompatible with environmental and social sustainability. Yet, within these communities, the role of infrastructure remains relatively underexplored or undertheorized. This omission is problematic. The majority of degrowth scholars argue that high levels of societal wellbeing can be maintained in a non-growing economy, but only if current consumption/production arrangements are radically reconfigured to this end. Infrastructure is often a prerequisite for achieving the levels of material wellbeing degrowth scholars argue all are entitled to; reliable clean energy, fresh water and sanitation as well as opportunities for sustainable mobility and the chance to communicate with each other. Yet infrastructure systems also underpin and facilitate 'hypermobility' (Adams, 2001) and enable resource intensive lifestyles. Infrastructure networks represent considerable sunk resources and embodied carbon (Krausmann et al., 2017). The promise of new infrastructure holds political decision makers in its thrall to the point that any realistic appraisal of its ultimate costs are banished (Flyvbjerg et al., 2003; Frick, 2008) and, their continued expansion often appears predicated on maintaining economic growth (not only growth of Gross Domestic Product (GDP) but also of energy-matter throughput) at the global national and local scale (Kirkpatrick and Smith, 2011; Woetzel et al., 2016) to the point that the logic of growth appears written into their structures themselves.

When considering its vast geographical span and profound integration into our daily lives, the internet stands probably as humanity's biggest infrastructure (Blum, 2013). Therefore, nothing appears to embody these tensions more than the internet global infrastructure. This assemblage of different networks and technologies - including land and submarine cables, antennas, satellites, data centres, and a variety of electronic devices (Morozov, 2015) - has swiftly evolved into a vital component of our existence and connections. It now plays a fundamental role in shaping social processes and generating substantial societal value (Frischmann, 2005). The impact that the internet has on human societies is loaded with exciting opportunities but also charged with problematic elements. Digital surveillance, addiction, cybercrimes, and other practices with a detrimental impact on democracy and wellbeing, have proliferated (Morozov, 2015). Moreover, a significant proportion of the current internet content is advertising intended to drive individual

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consumption, and regulation of such content is integral to any attempts to foster wellbeing (Kozinets et al., 2017). Furthermore, access to the internet's physical infrastructures is becoming entangled with broader geopolitical conflicts and resulting militarization, as the recent tensions between the US and China suggest (Gross et al., 2023). Despite their importance, a full appraisal of these issues is beyond the scope or intention of this article (see for example Cartwright, 2020; Deibert, 2008). Here, we restrict ourselves here to a discussion of the material elements of the internet: Its resource and energy implications.

Thus far discussion on energy consumption within the internet has tended to focus more on the demands of specific applications, such as blockchain and the new generation of artificial intelligence (Naughton, 2023; Stoll et al., 2019). A more holistic approach, where the materiality of the internet infrastructure is considered as a whole rather than focusing on specific applications, is thus missing. In this regard, the internet has evolved into a global mega-infrastructure whose construction, maintenance and use demand immense flows of energy and resources. Foregrounding this material perspective is important to counter the widespread perception of the internet as a largely immaterial entity (Blum, 2013), which often leads to the erroneous assumption that growth of internet-based solutions involves a dematerialisation of the economy. At the same time, we take the view that a critical understanding of the internet's materiality cannot be reduced to a mere quantification of energy-matter flows without considering the political and social structures in which the latter are embedded. This conceptual move is necessary to address a second misconception in post-growth/degrowth literature, whereby infrastructural arrangements are treated as a purely technical domain devoid of political and ideological mechanisms.

In the following sections, we consider the following research question: to what extent are the politics of growth built into infrastructural artefacts? First, we draw on insights from Science and Technology Studies (STS) and, call for the foregrounding of global infrastructure networks within degrowth debates. This, we argue, raises questions about current conceptions of technology within the degrowth literature and the questions of scale which we explore in turn. Framed by key questions from STS on the relationship between infrastructures, the sociotechnical systems they constitute and their potential for change, we introduce an analytical framework based on the work of Winner (1980), Geels (2002) and Hughes (1993) to gain insights about the drivers of infrastructures expansion and their connection with the politics of growth. We then introduce a case study of the material elements of the internet. This is divided into a physical and a logical layer, the latter governing the extent to which the technology is shaped in the expectation of perpetual growth. We conclude with two points for discussion and further research. First is a discussion of the implications of the voluntary restraint degrowth implies for the governance and materiality of the internet, specifically of what a more 'sober' internet might look like with an acceptance of the limits of existing infrastructure combined with greater efficiency of its use and some restrictions on the more damaging content. Second, we return to our call for degrowth to engage more with large scale infrastructure and the need for further research in this area.

1.1. *Growthism in infrastructure*

In his seminal essay "Do artefacts have politics?" Langdon Winner (1980) paints a compelling picture of the capability of infrastructures to limit social possibilities and crystallise power relations within society. Winner relates the history of the construction of overpasses in Long Island by Robert Moses, the public official responsible for much of New York's infrastructural growth from the 1920s to the 1970s. He claims Moses' overpasses were designed in a way such that public buses could not pass underneath, preventing the users of such transport, working class and non-white New Yorkers, from accessing the public parks and beaches frequented by the rich. Thus, building his own prejudices into the physical infrastructure with the intention of maintaining this status quo long after he had gone. "Doing politics" by other means (in this case through urban technology and infrastructure) is central to the way STS examines the mutual constitution of technology and society. Winner's case of Long Island bridges has been the subject of fierce debate and criticism in the intervening decades over the extent to which intentions built into infrastructure actually shape the way it functions as human and non-human actors interact with it (Joerges, 1999; Rowland and Passoth, 2015). Nevertheless, within STS there is ample consensus about the capacity of urban infrastructures to enable or disable social possibilities. We argue such insights raise important questions about the extent to which other prejudices or intentions such as assumptions of perpetual growth are written into infrastructural systems.

Degrowth scholars have effectively problematised the concept of growth as a political project based on the lack of evidence it can be sufficiently and permanently 'decoupled' from resource consumption and greenhouse gas emissions (Parrique et al., 2019; Vadén et al., 2020). Simplistic conceptions of transitions from fossil fuel based on renewable energy infrastructural systems of the type reflected in pervasive narratives of 'green growth' have, likewise, been challenged on the basis that they also fail to sufficiently decouple growth from its consequences (Hickel and Kallis, 2019). Yet any project of democratic downscaling of the economy (at least in the Global North) has to contend with the elevated position of technological utopianism within growth-driven societies. Growth-oriented institutions project technological futures onto and into the socio-technical imaginaries, the deterministic visions of how the material basis of societies should evolve, that shape and justify the production of infrastructure (Jasanoff and Kim, 2015; Kerschner et al., 2018).

If this is correct, it means that unmaking imaginaries or changing people's values, as many degrowth advocates (Feola, 2019; Latouche, 2009), might not in itself be sufficient to enable planned degrowth. Growth may be locked-in to the material underpinning of contemporary societies. Following Shove and Trentmann (2018), we agree that pylons, highways, pipes, satellite and communication networks, wires, electric charging points, sewage systems or electric grids can constitute physically imposing sights and conspicuous icons associated with the infrastructures of growth. Their workings are, however, typically invisible in current postgrowth accounts of technology, innovation and social-transformation which tend to focus on particular forms of technology and action at the local level. Therefore, alongside this imaginative shift there is a need to understand two key elements of degrowth that have remained under-researched and that are relevant to our relationships with infrastructure, the relationship to technology and the question of scale.

1.1.1. *The relationship to Technology*

An important influence on contemporary degrowth scholars in this area has been the work of Ivan Illich whose work draws on an established distinction between democratic and authoritarian infrastructures (Samerski, 2018). His calls for greater autonomy – or freedom from large techno-infrastructures and the centralised bureaucratic institutions, public or private, that manage them – require what he calls convivial tools or technology to free humans from large hierarchical non-democratic techno-structures (Illich, 1973). Recently, scholars have sought to engage in a more nuanced way with Illich's critique and the 'love/hate' relationship between degrowth and technology (Kerschner et al., 2018). Two relevant strands include calls for and examples of the democratisation of technology (Bradley, 2018; Rommel et al., 2018) alongside shifts in its governance and appraisal methods (Vetter, 2018). The former still relies, for empirical evidence, upon 'nowtopias' or small-scale, real-world experiments (Demaria et al., 2019). These have the advantage of providing some empirical insight into what a degrowth world of democratic technologies might look like. Nevertheless, they remain as marginal experiments, both within their own societies and as a share of the infrastructural systems used by a significant proportion of the planet. They may generate evidence that alternatives are theoretically possible, but, beyond that, the ability of these experiments to replace established systems remains unproven.

STS again adds to the discussion in bridging the gap between technology and infrastructure without losing sight of the co-productive relationship both have with society. STS has a long heritage of studies into what are known as large socio-technical systems such as electricity grids (Hughes, 1993). Alongside more recent STS influenced authors (Geels, 2002, 2005), this is a body of knowledge that offers insights into the network of social relations, material factors, human and non-human actors that govern the transition from small scale technology to large scale infrastructure and crucially for debates on how a switch to less carbon intensive infrastructure might be achieved. Key among these insights is a challenge to simplistic technological-determinism and technological-optimism showing that technical change, far from being a neutral and apolitical process, usually reflects the values, ideologies and worldviews of the society in which it emerges (Pansera and Owen, 2018). In this view, a certain path of technological change is enabled by specific socio-economic conditions, convergences of interests and historical circumstances that might or might not materialise (Bijker, 1995; Callon, 1991). Furthermore, multiple paths of technological change are possible and often coexist, although over time one might become hegemonic (Leach et al., 2012). Once a certain technological path becomes dominant, it goes through a process of naturalisation that creates the illusion that this is the only possible way of doing things, an inevitable progress of human ingenuity. However, what looks like an inexorable evolution is often the result of convergent interests, asymmetric power relationships and in many cases systems of domination and violence (Harding, 2011). In a nutshell, over the last four decades, STS scholarship has provided robust evidence that the innovation process - the core of technical change - is socially, culturally and politically constructed.

This perspective is particularly valuable given the way degrowth literature largely overlooks existing infrastructural networks - and often misreads technology as simply material and inanimate (Jasanoff, 2002) - and the extent to which these are shaped by a growth-dependent political economy. These constitute the material foundation of our world and contain the embedded legacies of a very different set of relationships between and within states, and crucially towards the natural world (Serres, 1995). We argue that it is essential for degrowth to engage with this reality if it is to get beyond activities at the margins and to counter criticisms that it is in some way anti-modern or anti-technology and technological innovation. Indeed, it should not be assumed that all technologies envisaged under degrowth scenarios are inherently small scale. Moves towards a circular economy (Bauwens et al., 2020) and big shifts towards renewables are seen as compatible with and even central to this top-down reshaping of the economy (Mastini et al., 2021). There are productive avenues exploring which sectors should expand or contract and engage with the questions posed by degrowth at the scale of national economies (Hardt et al., 2021). But the question of science, technology and innovation (STI) and the way they combine to create macro conglomerates of infrastructures, remains a critical one. Particularly, the type of STI possible under degrowth scenarios remains an underexplored area for degrowth-minded scholars, having received very limited reflection thus far (Pansera and Fressoli, 2021). Indeed, much of the degrowth approach to STI remains critical of the way they currently function as drivers of capitalist accumulation and of technical fixes (Kallis et al., 2018; Kerschner et al., 2018). Whilst not seeking to reject the critical perspective we argue it remains important to explore the extent to which such intentions and uses can be disentangled from the process of innovation. This is essential if we are to conceive of what innovation and infrastructure, particularly large-scale infrastructure, might look like without the growth imperative.

1.1.2. The question of scale

The inherent difficulties in engaging with the larger than local scale have been acknowledged by some degrowth scholars who challenge the way early influences like Latouche uncritically accept the distinction between local, national and global (Kallis and March, 2015; Lloveras et al., 2021). Much discussion on technology within degrowth is informed by this simplistic interpretation of scale, where the "local" dimension is not only taken for granted, but also idealised as an optimal scale for degrowth-minded transformations (Lloveras et al., 2021). A fetishization of the local can, they argue, be seen in the emphasis on small scale technologies (Kallis and March, 2015). Yet there are emerging pathways out of this focus only on the small scale or local level. One such pathway is replication as an alternative to growth which Pansera and Fressoli (2021) point to as a means of avoiding both the tendency towards oligopoly in large aggregations and as a means of maintaining internal democracy. Echoes of this strategy can be seen reflected in Ebenezer Howard (1965) polycentric model for urban development based on an ideal sized community with new settlements established once a certain size was reached. This approach can likewise be seen in recent calls for the application of degrowth principles to urban planning through developing the concept of autonomy at a regional scale (Savini, 2019).

Variations on this theme are picked up in the work on degrowth and innovation. Both Vetter (2018), and Pansera and Fressoli (2021) identify modularity as an approach to growth that distinguishes conviviality from non-growth oriented technologies and organisations. Certainly, calls for a more modular approach within mainstream critiques of the problems of large scale infrastructures have something in common with similar approaches to convivial technologies (Ansar and Flyvbjerg, 2016). The main difference is that, whereas in this literature modularity is usually designed for upscaling, from a degrowth perspective this modularity should also offer the possibility of downscaling (Vetter, 2018).

Another possible pathway is the open source movement identified as a model for technological development that operates effectively at scale in a distributed manner whilst maintaining many of the features of openness. In this sense the notion of *cosmolocalism* represents a novel paradigm within degrowth scholarship, emphasising collaborative global design while advocating for local production, which is particularly significant in the discourse on scale (Kostakis et al., 2018). Despite problems in implementation and inclusion due to heavy gender imbalances (Vetter, 2018), open source technologies like Wikipedia or Linux offer examples of up to date technologies operating at scale on a collaborative basis. This final point is critical to how degrowth approaches to technology begins to engage more productively with the question of scale. It provides contemporary examples to support a body of evidence that questions the assumption that the management of complex infrastructures is inherently hierarchical and only achievable at the large scale (Graeber and Wengrow, 2021).

If a degrowth imaginary has any chance to succeed, it is necessary to understand how a planned contraction of the economy might work in practice at the scale inhabited by infrastructures such as the internet. This draws the question of infrastructure into sharp relief. As we have already suggested, posing the question at the local scale fails to go beyond the comfort zone of degrowth. And, it risks sustaining false assumptions about the nature of democratic governance as something that can only be achieved at such scales. Moving from the local to the urban scale engages with valuable real world examples of the introduction and reintroduction of both commons and public governance of infrastructure (Becker et al., 2017; Hall et al., 2019). Yet it still cedes too much space to the large scale state and market led projects, the imaginaries (Jasanoff and Kim, 2015) and elites that support them (Menga, 2018) and their reliance upon state support. This is particularly relevant to contexts where the state is either weak or captured by a global infrastructure industry (Kenney-Lazar and Ishikawa, 2019). It risks skirting around the power that now 'resides in infrastructure' (The Invisible Committee, 2017) and multi-trillion dollar programmes being called for to plug global 'infrastructure gaps'. Such are programmes are an embedded growth mechanism. They are intended purely to equip infrastructure systems to keep pace with projected economic growth. - Indeed sustainable development goals framed as an additional cost with yet more funding demanded if these are also to be met (see for example the Global Infrastructure Hub Update—June *2018, 2018*).

There is already an established critique of mega-infrastructure albeit one largely framed in the type of cost-benefit terms more appropriate to a growth paradigm. Here the ever escalating cost of mega-projects, their inability to meet deadlines or to deliver the levels of performance that were originally claimed for them is widely known (Flyvbjerg, 2014; Flyvbjerg et al., 2003). This still acknowledges the dangers of locking policy making into attempts to chase investments sunk into large infrastructure projects (Cantarelli et al., 2010). As technologies and reflections of modernity, such practices are often aided by the grip endeavours of such scale and sophistication appear to exert over policy makers (Frick, 2008). Whilst Flyvbjerg and others' critique of megaprojects serves as a valuable cautionary note of the risks of hubris, optimism bias, the dangers of politically driven lock-in, and the allure of technology, it arguably focuses predominantly on the relationships between state and market. In contrast, the internet is a large socio-technical system for which the physical infrastructure is predominantly in the hands of private actors. This may alter the makeup of the web actors and technologies yet the basic insights from STS remain: i) technological change and innovation occur in complex socio-technical systems that are underpinned by specific interests, values and social relations; ii) socio-technical systems, and thus infrastructures, are arranged in ways that enable or disable certain social practices; iii) on the one hand, an implication of the above is that socio-technical systems are path-dependent, meaning that they tend to lock-patterns and generate inertia; iv) yet on the other, socio-technical systems (including infrastructures) are never totally stable. They can be contested and renegotiated in interaction with users, as well as other stakeholders who seek to endow them with different values.

Based on these reflections, we propose an analytical framework to unveil the factors driving infrastructure growth. The consolidation and expansion of material infrastructures involves a complex and dynamic process that necessitates an understanding of historical, socio-economic, and technical complexities (Geels and Schot, 2007). To simplify this context, we combine the aforementioned principles of STS with the works of Geels (2002); Geels et al. (2016) and Hughes (1993), which respectively focus on *technological regime*[1] transitions and large technological systems (LTS). We begin by considering infrastructures as embedded within *socio-technical landscapes*, which are conceived as the legacies of a historical process involving multiple temporal layers and re-configurations of previously existing arrangements (Geels, 2002). These landscapes constitute the overarching socio-techno-political contexts that structure actor interactions, comprising not only the material and spatial arrangements of cities, factories, highways, and electricity infrastructures, but also 'a diverse range of factors such as oil prices, economic growth, wars, emigration, political coalitions, cultural and normative values, and environmental problems' (Geels, 2002: 1260). The landscape within which modern infrastructures have emerged and expanded is characterised by the gradual alignment of state and private interests around the so-called growth paradigm (Schmelzer, 2015). The growth paradigm involves three interrelated factors. First, the widespread acceptance of economic growth as a supreme societal aspiration, and the adoption of economic indicators such as GDP as a measurement for social progress. Second, the relentless pursuit of new energy sources and innovations to enable the expansion of society's metabolic flows, and the subsequent increases of energy-matter surplus. Third, the establishment of social relationships organised around lines of social class, private property, and the logic of profit maximisation. The institutionalised logics of growth shape the trajectory of infrastructures by creating an environment conducive to their expansion.

Geels (2002, 2016) employs the notion of landscapes to describe the evolution of technological regimes through complex interactions between social actors, markets, social institutions, and cultural factors. Hughes (1993, 2004), on the other hand, focuses on the emergence of LTS, such as electrification networks in Europe and the USA, and investigates the driving forces behind their growth. Hughes demonstrates how, after an initial phase of openness and flexibility in designs, purposes, and technological possibilities, infrastructure projects quickly become locked-in expansion trends within a capitalist landscape. For instance, the development of electric grids can be seen as a combination of technological and economic drivers. Regarding the technological drivers, the expansion of electric grids in the industrialised countries was primarily driven by the need to maximise the Load Factor, defined as the average load of electricity divided by the peak load within a specified time period (Hughes, 1993). In order to ensure the economic viability of electricity distribution, the load factor of the networks had to be maximised. This was achieved by electrifying more productive activities (e.g. factories, public buildings, roads etc.) and covering larger geographical areas. High voltage transmission lines were deliberately spread to connect different energy sources like water and coal, creating a complementary network that offered lower prices. As Hughes (1993: 463) puts it:

> Whereas load factor considerations led utilities to exploit the diversity of human geography, economic mix dictated expansion to exploit the diversity of natural geography […] The decisions made to improve load factor and economic mix shaped the growing electric supply systems in their cost-accounting settings.

Essentially, the system was only technically and economically viable insofar that it was capable of continuous expansion. Indeed any reverse or end to this model introduces serious problems for existing grids (Bakke, 2017). Economic and technical factors interacted to create a technological *momentum* - in Hughes words - that propelled the growth of infrastructures and reinforced existing technological regimes. Such momentum contributes to what Winner (2004) calls 'technological somnambulism', which refers to society's tendency to adopt and perpetuate existing technologies without critically examining their long-term implications. This inertia reinforces the growth of established infrastructures, making it challenging for alternative, more sustainable solutions to emerge. By employing this analytical framework, we can gain insights into the processes and forces that drive infrastructure growth. It allows us to identify the interplay between institutions, economic factors, technological momentum, and technological regimes, shedding light on the dynamics of infrastructural expansion. Understanding these dynamics is crucial for degrowth advocates to formulate policies and strategies that promote a downscaling of infrastructures while considering the broader societal and environmental implications of their growth.

1.2. A case study: internet backbones as a planetary infrastructure

The complex mesh of cables, machines, companies and software that constitutes the internet represents an ideal case to explore the limits to degrowth a mega-infrastructure. With its planetary network of submarine cables, its data centres spread across continents, and satellite communication links, the internet represents a truly global infrastructure (Blum, 2013). Somewhat paradoxically, it is also the most invisible one. Most of its five billion users worldwide mainly interact with terminal devices such as laptops or mobile phones while ignoring the complex hardware infrastructure that make possible streaming, gaming or uploading holiday pictures to the cloud. Far from being an immaterial utopia, the internet emerges from and depends on a very concrete and vast materiality. What Bratton (2016) has called 'the stack' does not only

[1] "A technological regime is defined by the particular combination of technological opportunities, appropriability of innovations, cumulativeness of technical advances and properties of the knowledge base."(Breschi et al., 2000)

involve software and hardware but also immense flows of material and energy resources, geographical territories in their traditional sense and the biosphere. Unlike other infrastructures of our industrial society, an interesting feature of this megastructure is that it is not the result of a coordinated master plan, although some of its key fundamental parts did emerge through planned and coordinated scientific efforts. Instead, its layered technologies converge in an emergent order that is largely the result of technical and social interactions at different scales and as part of different histories; interactions that are unmanaged and unplanned.

The internet has been instrumental to the current form of neoliberal globalisation. Born as a military project, then a scientific experiment, the network has been crucial to revolutionising global supply chains, de facto enabling an unprecedented acceleration not only of international trade but also the creation of complex planetary networks of production and consumption (Harvey, 1989). In this sense, the megastructure of the internet can be also thought of as a platform, a mix of standards-based technical and social systems with distributed interfaces that enable remote coordination of information and action (Wark, 2021). As a platform infrastructure, the internet enabled the emergence of neoliberal globalisation but it can and could also enable non-market forms like Commons-Based Peer Production, open source movements and endless possibilities for self-organisation and autonomy.

The Internet mega-infrastructure is then a critical element in understanding economic growth in the last 30 years since it has been instrumental in the expansion of digital technology which represents the fastest growing sector in the world economy (N. Jones, 2018). Although Gordon's (2017) research reveals the internet's unfulfilled promises regarding the expectations of a radical increase in labour productivity, it is undeniable that the internet has indeed facilitated new practices of capital accumulation and growth (Wark, 2021). But is this planetary infrastructure inherently designed to scale up indefinitely or, more appropriately, is the stack materially and/or institutionally locked-in a growth-dependent path? Reflecting on these questions is the first step to understanding to what extent a degrowth imaginary is compatible with planetary mega-structures or to think strategically of mechanisms to degrow mega-projects like the internet. In order to engage with these questions, it is useful to consider two analytical levels of the internet drawn upon the work of Frischmann (2005). The *physical layer*, includes the hardware and software infrastructures, and the *logical layer*, which consists of the different levels of the internet governance (Frischmann, 2005).

1.2.1. The physical layer

The physical layer of the internet consists primarily of submarine cables and data centres, landlines, radio links and satellites. This also includes the physical networks of terminals like computers, mobile phone networks controlled by human users. The materiality of the stack also includes the software layers, that are all the algorithms and code that allow computation, routing and management of the different hardware layers. More recently, there has been an increase of *non-human users* like sensors, 'smart' appliances, bots and others. It's estimated that humans represent only 36% of all internet traffic (Chinnasamy, 2022). The rest 64% is automated traffic including bots and hacking tools. For the sake of simplicity, we will focus only on the major elements of the physical layer: submarine cables and data centres.

Most people wrongly assume that satellites in space are what enables internet connection between different parts of the world. In reality, 99 % of the data travels between continents through a global maze of undersea, transoceanic cables (Starosielski, 2015). Built upon the telegraph cables infrastructure at the end of the 19th century, submarine cables wrap the entire globe (see Fig. 1). Within this context, two general trends are worth discussing. First, since 2016 demand for cable capacity has been doubling every 2 years (TeleGeography, 2023), fuelling a constant demand for more cables. Second, there has been a significant shift in cable ownership during the last 7 years. Traditionally, submarine cables had been funded by consortia of big carriers that include private companies and state agencies. These projects typically cost hundreds of millions of dollars to build. Carriers then sell broadband capacity to their customers, usually internet providers - who act as intermediaries between the large carriers and the end users. More recently, a new privately funded model has emerged where companies would fund an entire cable project and then lease capacity on the cable wholesale to carriers. Content providers like Google, Facebook, Amazon and others are directly funding submarine cable infrastructures with the intention

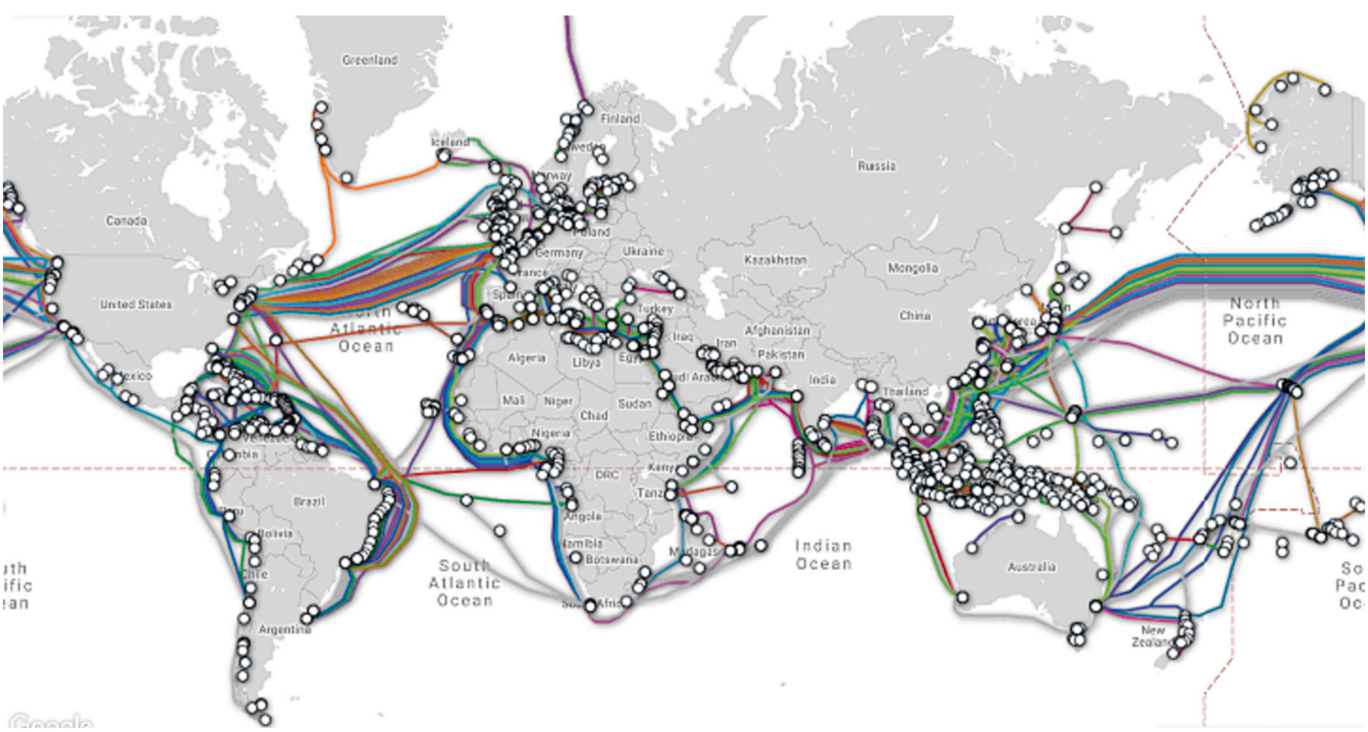

Fig. 1. Global Submarine Network database. Source: https://www.submarinecablemap.com/

to increase their bandwidth capacity and gain direct control over their traffic. This means that their hunger for big data will drive bandwidth growth. The Dunant cable, for example, that was launched in 2020 has the capacity to transmit the entire digitised Library of the USA Congress three times every second. Google was the first of the big four US-based hyperscale cloud platforms to start investing in this model based on content providers sidestepping carriers and directly building their own private submarine cables. The hyperscale group, which also includes Facebook, Microsoft, and Amazon Web Services, to date has invested around $20 billion in new cables all over the world (Sverdlik, 2021). (See Fig. 2.)

The network of submarine cables is intentionally designed to be resilient in order to cope with multiple sources of disruption (e.g. submarine landslides and earthquakes, large vessels anchoring and other human or natural activities). Furthermore, intercontinental submarine connections are equipped with backup lines (Blum, 2013). Additionally, cable bandwidth capacity is always over dimensioned, meaning they are conceived in a way that they can physically carry more data than needed. This is because these infrastructures are not designed to serve present demand but rather to be able to scale up if demand for traffic increases (Blum, 2013). In this sense, it is useful to distinguish between the *lit capacity* and the *potential capacity* of cable. The first indicates the capacity a cable is currently equipped to handle, whereas the latter is the theoretical maximum capacity that a cable can support if additional capital was invested to fully equip the cable (Blum, 2013). Most of the major transatlantic links, for instance, use less than 30 % of their potential capacity (TeleGeography, 2023). Although since 2018 we can observe an increase in the lit share of potential capacity, many companies prefer laying out newer cables because they are far more technologically advanced and their unit cost is cheaper than old cables whose lit capacity is increased. In other words, new cables have better economies of scale (TeleGeography, 2023). This mechanism, similar to the role that load factors play in the expansion of energy grids (Hughes, 1993), drives growth in bandwidth availability that in turn feeds an ever increasing demand for traffic.

Besides the submarine cables, another crucial element of the physical layer of the stack is the data centres. These are the physical infrastructures that store, process and transfer information and by far are the elements of the mega-infrastructure that consumes more energy (Jones, 2018).

Data centres are the real engine of the stack and are also a highly concentrated business. One of the reasons big data corporations are heavily investing in submarine cables is that they are also the largest owners and managers of data centres. Google, Facebook, Apple, Amazon, Microsoft, and Netflix together generate almost 57% of all worldwide broadband traffic (Gartenberg, 2020). These companies are interested in connecting their data centres around the world in such a way as to be independent of internet providers and to have the capability to decide where to land the cables (McGeachy, 2022). Data centres are usually located where large users' numbers are. If they control the cables, internet companies could effectively dictate internet policy, even if apparently that is not their explicit intent. In order to increase flexibility and resilience, data centres also implement backup and redundancy mechanisms. YouTube, for example, stores most of its data in Google Modular Data Centres. A modular data centre is a portable structure that can be replicated and placed wherever the data storage capacity is required (Jones et al., 2013). Data in these centres are constantly transferred and updated on the basis of the users' demand. To maximise the efficiency of the systems and to minimise the latency in the network, most of the time content providers store different backup copies of the same content. This, combined with an ever increasing demand for traffic, partially explains the exponential growth of data centre capacity (Fig. 3). Backup systems and the geographical flexibility of data centres have a leverage impact on the network expansion that is comparable with the role played by the load factor in the deployment of energy supply grids. In a nutshell, the efficiency of the network and the services provided increases with scale.

The growth of demand forced companies like Twitter to redesign their original network structure as their traffic grows faster than the company can re-architect an entire data centre. As a consequence, they started implementing a highly scalable architecture that allows adding capacity incrementally to cope with the increasing demand for data storage (Hashemi, 2017). The apparently infinite capacity to absorb data by the stack allows big actors like Google or Facebook to store content

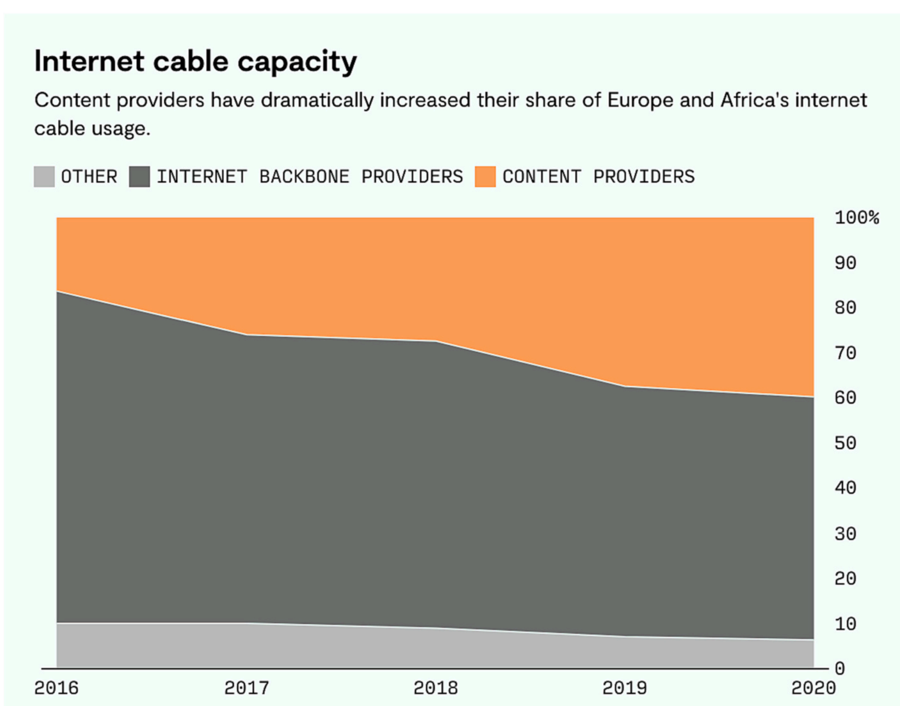

Fig. 2. Internet Cable Capacity Source: https://www2.telegeography.com/

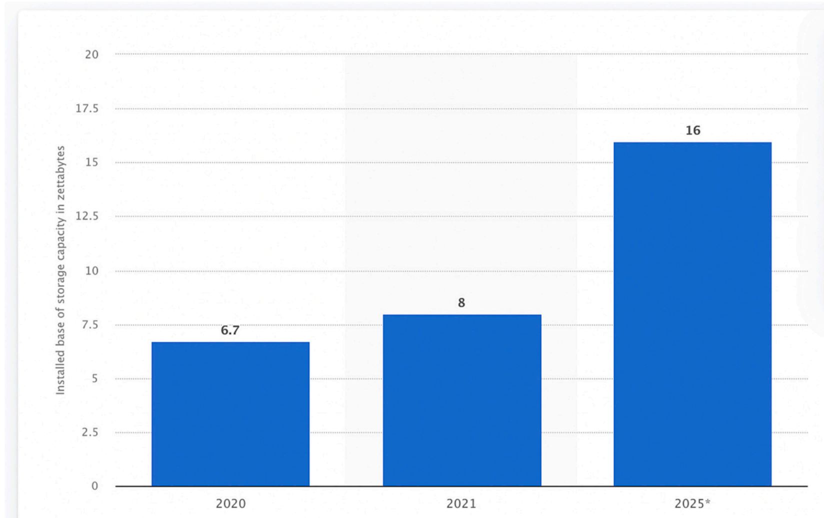

Fig. 3. Data storage capacity in the global datasphere. Source: (Sandvine, 2022).

and users' data virtually forever, which in turn expands the energy demanded by these data centres, as we show below. According to YouTube policy, videos are deleted only when an account is blocked or cancelled or when YouTube ceases its operation. Historically, Google has retained user data indefinitely, including very sensitive personal data and georeferenced data about users' positions. In 2019, however, the company rolled out a way to automatically delete data points after three months or 18 months, depending on the chosen setting (Google, 2023). Nevertheless, serious concerns can be raised about the transparency of data storage policy where no clear regulation is still in place. It appears reasonable to assume governments can store data indefinitely for security reasons. Considering also the fact that more and more companies such as Amazon profit through their data storage services, it makes sense to accumulate data instead of erasing and deleting it.

Data are not immaterial, they require energy and material to be processed and stored. If data increases, so do energy and material consumption. This inevitably requires and demands more growth. According to Freitag et al. (2021) the internet produces around 3.7% of global CO2 emissions and unlike other sectors of the economy, its energy intensity is increasing 4% per year. Belkhir and Elmeligi (2018) have calculated that the whole ICT's relative contribution will exceed 14% of the 2016-level worldwide GHGE by 2040 with data centres being the largest culprit (45%) followed by communication networks (24%). These figures do not take into account the development of the 'Internet of Things' and the cryptocurrency explosion (The shift project, 2018). Madlener et al. (2022) have modelled different scenarios of how the future energy consumption caused by video streaming could develop. In the worst case, energy consumption could increase eightfold by 2030. In conclusion, it seems evident that digitalization unleashes the potential to produce more economic growth-related emissions rather than leading to dematerialisation of the economy (Lange et al., 2020). Furthermore, the construction of data centres can be a source of environmental conflicts due to their disruptive nature, impact on local communities and their natural environments - e.g. excessive water consumption, as well as their impacts on landscapes and human health (Lehuedé, 2022; Rone, 2023)

1.2.2. *The logical layer*

There is also a logical layer that regulates many aspects of the stack such as communication protocols, rules and policies to coordinate and shape cyberspace. The basic structure of the internet, the backbone, consists of companies, government, and academic direct links known as Tier 1 connections. Tier 1 links are Internet Protocol (IP) networks that can reach every other network on the Internet via settlement-free interconnections, which means they exchange traffic with other Tier 1 networks without paying any fees(Blum, 2013). There exist only 15 Tier 1 networks, also called Tier 1 Internet Service Providers (ISP). The Internet mega-infrastructure is then a network of independently-managed networks, woven together by standardised communication protocols. All these protocols were designed to guarantee interoperability among diverse physical infrastructures and software on one hand; on the other hand, they were planned to be scalable and allow a virtually endless expansion of the network. For example, the protocol IPv6, which upgrades the IP systems, can uniquely address a trillion times the number of devices currently connected to the Internet. Such a dynamic governance of the internet, in principle, would allow a downscale of the network that would theoretically preserve the same functionality. However, in practice the way internet governance has worked to date has been based on the assumption of endless expansion of access demand and content provision. This is evident in the over-dimensioning strategy adopted in the design and implementation of both the physical infrastructures and the protocols that govern the network. As Libório et al. (2020) show, for example, over-dimensioning strategies could be particularly attractive for companies because they substantially reduce future investment in the network. Oversize strategies are common in the design of many web infrastructures in order to respond to peak usage. The crucial variable here is the capability of the network to transfer data. The trend is to create applications that use more data (videos) and to connect devices that acquire more data (big data for AI, sensoring, surveillance systems etc.). Media content (Netflix and other video streaming platforms already represent the majority of internet traffic, and this increased during the pandemic), big corps interested in big data acquisition and processing push for bandwidth increases. This treadmill of digital data production is perfectly embedded in a global hyper competitive market economy in which the main actors, mainly digital giants, expect ever increasing returns on investment (TeleGeography, 2023). As a result, even if the original architecture of the physical layer was designed to be flexible and, at least in principle able to descale, the financial superstructure that makes the internet functioning seems to be clearly set around expectations of endless expansion.

1.3. *Growth built-in mechanisms*

As discussed above, the internet infrastructure has been not explicitly designed with built-in mechanisms that compel the network to grow indefinitely. It is rather an emergent phenomenon of clusters of separate infrastructures that were in their origin unplanned and unmanaged. Nevertheless, although there's no deliberate 'growth design', following the tentative analytical framework introduced in section 2, we can observe clear incentives to grow in the way the physical layer has evolved and the way the logical layer functions. What emerges from our analysis is that at least two broad growth built-in mechanisms, or as Hickel et al. (2022) have called 'growth dependencies' are in place today in the internet mega-infrastructures: network-design and governance-financial.

1.3.1. Network-design

Originally the internet was thought to be a flexible, resilient and scalable infrastructure. However, the technologies on which it is based, especially electronic, software and telecommunication technologies, have shown exponential rates of innovation, with vast improvements in terms of efficiency (Brock and Moore, 2006). Such a spectacular historical trend has shaped the expectations of companies and users that access, bandwidth and speed of connection will increase forever. This is evident in the way submarine cables are installed with lit capacity much lower than their potential capacity, and in the way that the fiber-optic technology outruns the full exploitation of working cable links. Furthermore, infrastructures for digital communication, routers, computers, and electronic boards, have been traditionally over dimensioned to be upgraded and rarely to be downgraded favouring the growth of humans and non-human users (e.g. bots), the latter already representing a majority of all internet traffic.

The increasing share of private ownership of crucial infrastructures such as submarine cables and data centres seems to reinforce the embedded scaling potential offered by digital technologies. Big content providers have an interest in increasing the network capacity to accommodate their business models based on big data acquisition for AI, video streaming etc. To make matters worse, there is the fact that advanced applications such as AI algorithms require ever increasing amounts of data and computational power, and energy as a consequence, in order to improve their accuracy (Hao, 2019). In addition, social media tend to create accumulative effects by design. Big Data actors require an ever-increasing amount of data generated by the users to be monetised and sold. The increasing control over the stack by big players is likely to restrict states' and users' capabilities to question and negotiate alternative uses of the infrastructures that constitute the internet. Finally, the manufacturing and maintenance of submarine cables and data centres require continuous flows of energy and new materials which are supplied according to the logic of growth that underlies global capitalism, the landscape on which the internet has evolved. This means that electronic equipment, fiber-optic, motherboards and the like are usually affected by all sorts of planned obsolescence mechanisms with the intention to be upgraded by new technologies with augmented capabilities and potential for expansion (Slade, 2006).

1.3.2. Governance-financial

If the growth built-in mechanisms that we observed in the physical infrastructure design seem to be, at least in principle, reversible, the economic models that sustain the internet clearly show growth dependencies'. Similar to a gigantic Ponzi scheme, the need for endless growth of the stack is a direct effect of the process of financialization of the internet infrastructure (O'Neill et al., 2018). According to the R&D investment scoreboard published by the European Commission (EC), whereas EU investments in ICT services and manufacture from 2012 to 2021 increased steadily by around 20%, USA and China investments have quadrupled in the same period increasing expectations about returns on investment and the future growth of the sector (European Commission et al., 2022). In this sense, the internet is characterised by the same finance-based growth dependencies that affect the emergence of virtually any technological regime under the capitalist mode of production. As Pérez (2002) documented, similar to the emergence of other technological regimes like the fossil fuel industry, energy grids, roads and maritime transport, the role of financial capital is central in the internet's growth, with venture capital and other financial mechanisms driving the development of internet-based companies and infrastructure. This was necessarily combined with societal and institutional changes, as the internet's expansion required supportive policies, regulatory frameworks, and widespread adoption to reach its full potential and catalyse economic growth. Emblematic in this sense is the Digital Agenda for Europe, created within the Lisbon strategy in 2010 to facilitate the penetration of the internet in the productive ecosystems of the EU (EU, 2023). Nevertheless, it is interesting to note, rather than enabling a diversity of institutional settings, the internet has had a standardising effect on institutions around the world. Despite their diversity,

> […] the computational architecture of their operations is increasingly the same, varying only according to the minimal options offered by parameterized systems—from logging, billing, visualisation, data authentication, predictive analytics, business intelligence, search, conversion, publication, and backup (Rossitier, 2016: 240).

This means that on one hand, the model has crystallised around financial capitalism and on the other the digitalization has unleashed new potential for expansion creating positive feedback that leads to new cycles of capital accumulation and growth (Wark, 2021). In addition, all sorts of vulnerabilities created by the uncertainties of climate change are likely to influence the financial models that sustain the internet. Submarine cable maintenance for example, which is already extremely expensive, is likely to be affected in unforeseen ways (e.g. increasingly unstable weather conditions due to climate change, inability to access certain marine sectors due to geopolitical conflicts, etc.) in the future. There are also uncertainties related to the refrigeration of data centres if average global temperatures increase (Gartenberg, 2020). Moreover, microchip scarcity and their rising costs represent other huge uncertainties that push internet companies to promise and seek high returns to justify ever increasing investments (Celasun et al., 2022). These factors suggest that the financial model that maintains the internet infrastructures condemns the network to scale up rather than taking into consideration the possibility of a smaller, less energy intense internet.

2. Conclusion

Designed to be scalable and surrounded by expectations to dematerialise the economy, the internet has become a mega-infrastructure that drives growth and, at the same time, is driven by it. Similar to the expansion and growth of other key infrastructures like electricity supply, internet growth seems to be driven by a combination of technological factors (e.g. load factors, backup systems, over dimensioned equipments) and economics-efficiency related factors (e.g. maximise economic mix, increasing returns on investment, data monetization etc.). Yet unlike these previous structures over which the internet is layered, the internet is as much built of and from information and as such the logical layer is much greater making it possibly more amenable to social control. We can assume that the internet in a degrowth society would use only a fraction of its present energy and material consumption, and would be under social control. Nevertheless, it is hard to imagine how the intricate mesh of submarine cables, data centred protocols and power relations that sustain the 'stack' would survive the reductions of energy and resources that are needed to meet climate targets. Scenarios building and futuring techniques could be adopted to promote research on the exploration of plausible degrowth-minded infrastructural futures (Calisto Friant et al., 2020; Frase, 2011). Here for the sake of synthesis we contemplate a number of possible scenarios. First, there is a scenario of collapse in which the vast energy and material flows that sustain the stack are no longer available or must compete with other uses like food or other primary goods production. The internet in its current form collapses and only basic links with limited bandwidth will be available. This scenario does not necessarily mean that the internet as we know it will disappear. Rather, a collapse could lead to extreme forms of commodification whereby large companies and internet providers restrict access to elites. Although the internet has enabled the emergence of neoliberal globalisation, it can also facilitate non-market forms of exchange conducive to new modes of organisation and ways of life, including Commons-Based Peer Production, free information sharing, multiple ways of re-signifying and re-appropriate digital technologies (Likavčan and Scholz-Wäckerle, 2018), and the immense possibilities for self-organisation offered by the network. If degrowth means completely abandoning the internet megastructure it also means renouncing these opportunities. In other words, an internet collapse would seriously affect the potential for implementing degrowth imaginaries. A more desirable scenario might involve a sober internet. Given the vital importance of the internet to deliver many essential services, and the finite bandwidth available in such a context, it would be important to make collective moral decisions about its usage and distribution. Specific policies, caps and quotas could not only slow down the current trend towards ever expanding internet traffic, but also reverse them, without compromising universal access. In doing so, we should prioritise applications that have clear social and environmental benefits over those that serve aims defined purely in terms of economic utility maximisation. This scenario would necessarily combine sufficiency policies with an acceleration of data centres energy efficiency.

More recently, scholars and digital activists have proposed interesting analyses and frameworks that resonate with a degrowth-compatible conceptions of the internet and complement the contributions of low-tech movements that are already central in the scholarship and in the movement (Tanguy et al., 2023). Concepts like slow computing (Kitchin and Fraser, 2020), post-automation (Smith and Fressoli, 2021), technopolitics, and platform cooperativism (Scholz, 2016) share similar calls for reconfiguring the stack and its use. Of course, this is not an easy task. Big questions for degrowthers emerge from the above: how can the assemblages of submarine cables, data centres and multilayer software applications be made sustainable, and amenable to democratic governance, management and oversight? how can they be reimagined and reshaped as convivial technologies? Repairing and maintenance of infrastructures, as we shown in the case of submarine cable, are also crucially connected with social order and organisation (Dalakoglou, 2012; Schouten and Bachmann, 2022). When and for how long would it be legitimate to continue investing in their repair and maintenance considering the fact that we will have to coexist, probably for centuries, with the ruins of infrastructures designed on the premises of infinite growth? What are the social and political trade-offs?

The first step to imagine a degrowth-minded reconfiguration of infrastructures is to acknowledge that they are often intrinsically designed to enable expansion and growth. By drawing on a framework based on principles borrowed from Technological Regimes transitions and LTS studies, in this paper we have shown that the internet is captive, although not in a deterministic way, of at least two interdependent 'growth mechanisms' built-in, its *technical* design and its *financial* governance. On the one hand, the internet's physical layer is clearly characterised by growth-driven technological design, which is unsustainable in ecological terms. On the other hand, it was originally designed to be open enough to be used for many different purposes, even downscaled to a certain extent. Therefore, our research shows that the governance-financial layer is where the main problem lies. Financing mechanisms are designed expecting expansion whereas the governance layer pushes the physical layer to become a system predicated on growth. We argue that further research is needed to identify leverage points for disrupting the growth dynamics observed (van Oers et al., 2021). These can be regulatory initiatives, cultural phenomena, economic forces, or alternatives emerging through social movements such as open source, slow computing or climate change - related activism. In this sense, we advocate for a more advanced engagement of the degrowth community with STS, LTS, innovation and infrastructure scholars to formulate more precise and detailed frameworks to unveil the heterogeneous processes and the factors that interact and lead to the rise and decline of different infrastructures.

The case of the internet is a key example because of the way the stack has become a pervasive technology that shapes the lives of a great deal of humanity. More generally, similar analyses should be conducted on other fundamental mega-infrastructures such as housing, transport systems, energy and water supply, military industry, and even entire monetary systems due to the way such infrastructures are central to any understanding of prosperity and wellbeing. Yet their consumption of resources and energy can be significant and difficult to scale down without seriously compromising the quality of life they enable. It is unfortunate that, thus far, these issues have been largely overlooked within contemporary degrowth debates despite their significance in terms of conceiving a future without growth. Our work seeks to sketch out the foundations for long overdue further research in this area.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

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