Socio-technical Development and Imagination: A Multi-Level Analysis of the Hyperloop as a Prospective Mobility System and Social Imaginary in the Netherlands and Europe

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Abstract

The Hyperloop is an emerging, novel, and experimental mobility innovation, where a low-pressure environment facilitates a pod to propel at extremely high speeds. In its prospective technical capacity, it promises a new frontier of high-speed, scalable and sustainable mobility. Technological innovation is the ostensible binding agent of sustainability and growth. A growing number of stakeholders between geographical and organizational contexts are working to develop, realize, regulate, scale and provision a hyperloop future. The hyperloop niche is in an early but highly dynamic stage that is galvanizing research and attention between academia and industry, especially in the Netherlands. With a focus on how niche innovations intricate themselves in existing socio-technical systems, this paper conducted a qualitative multi-level systemic analysis on the hyperloop's dual conception as a mobility system, and construction within socio-technical imagination. This emphasizes the relationship between social imagination and socio-technical development, acknowledging technological innovation as a socially mediated process of imagining, anticipating, articulating and developing socio-technical futures.

It was found that the hyperloop is perceived to be an unprecedented scalable, modular, integrable and sustainable technology. The hyperloop's perceived and tangible capabilities are being filtered through imperatives for feasibility, driving changes in top speed, sustainable and scalable material construction, plausible cargo and passenger use cases, and multi-use applications in energy storage. Currently, there remain key gaps in feasibility that require further innovation. Acknowledgements of fiscal and material intensity contend with beliefs in a long-term and desirable guiding vision. A hyperloop system would contend directly with the political preferences and competitive position of existing modalities, broader trends of austerity and euroscepticism, the fruition of international hyperloop collaboration, and plausible resistance against megaprojects perceived as socially exclusive or ecologically irresponsible. In its imaginative make-up, the hyperloop catalyzes desires for high-speed, urban-centric, futurist and seamless mobility. In the European context, this effectuates an imaginary of a hyperconnected, continent-wide, cosmopolitan urban network. In all, this research demonstrates the hyperloop interpolates imagination and innovation towards aspirations for technologically enabled sustainable mobility futures; the veracity, desirability and feasibility of which will contend with imperatives for an urgent and equitable sustainable mobility transition.

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1. Introduction

Urbanization is the preponderant logic of our current global arrangement (Swyngedouw, 2015). The material infrastructures of cities enabling the flow of people, information and goods are central conduits in our global urban tapestry (Hajer & Dassen, 2014). This accompanies a paradigm geared towards intensifying space-time compressions necessary for interconnecting sites of knowledge, life, and production (Nicholson, 2019), the undertaking of which valorizes technical artefacts and scientific expertise in urban governance (Prince, 2016). This rational-technological paradigm is deeply aware of a necessary imperative for an immediate sustainable transition, the failure to do so threatening incalculable and irreversible social and economic costs to global ecology, economy and society (Freudendal-Pedersen & Kesselring, 2016). It is within this context that an ecomodernist ideology has cemented itself within the premise that innovation can stabilize sustained, sustainable and desirable economic growth (Isenhour, 2016). It is within these conditions the hyperloop captures attention as a plausible advancement in sustainable mobility.

1.1. Overview of the Hyperloop

The hyperloop's central idea – low pressure environment facilitating high-speed transit of a moving object - is not new. Concepts for vacuum-assisted transport have existed since the late 19th century, however, there has been minimal experimentation (Pedata, 2017). The Hyperloop arose to positive public attention in the release of Elon Musk's 2013 whitepaper (SpaceX, 2013), garnering attention from investors and building a positive image around the technology. The concept has been galvanized as a new frontier in high-speed transit, bestowed with the title of being a 'fifth modality' beyond rail, sea, road and air (Hirde et al. 2023). Musk's company SpaceX funded a hyperloop university competition between 2015 and 2017. This competition was won by the Delft University hyperloop team, one of 29 international participants (TU Delft, 2017).

Rebirthed in the heart of Silicon Valley, it is noted in Musk's biography that the hyperloop was his response to California's high-speed rail initiative, an endeavor he perceived as expensive and inefficient (Marx, 2022). The original Musk-era hyperloop 'hype' cycle in the 2010s was exuberant and unrealistic, but drew ample attention (Decaminada, 2022). The technology has evolved rapidly since 2013, with distinct stakeholder clusters in Asia, Europe and the United States (Mitropoulos et al., 2021). There is significant academic, scientific, industrial and entrepreneurial attention to the concept in the Netherlands (van Wayenburg, 2023). Notwithstanding a frenzied origin, the maturation and diffusion of the hyperloop concept proves it would be short-sighted to disregard its potential impact upon the high-speed transit landscape.

1.2. Technical Overview

The hyperloop is a novel and emerging high-speed mobility technology. The hyperloop design is made up of a pod interfaced with a propulsion mechanism into a track system that drives the pod through the low-pressure vacuum tube (See Figure 1).

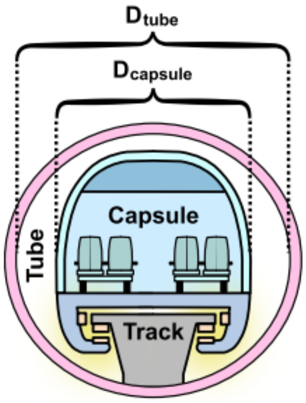

Figure 1. General Hyperloop Design (Nøland, 2021)

The low air resistance and electrically powered propulsion system allows the pod to, in theory, to reach immense speeds of up to 1200 km/h (Nøland, 2021). However, prototypes in the Netherlands currently promise up to 700 km/h (van Wayenburg, 2023).

Figure 2. Hyperloop Tube & Pod (Hardt Hyperloop, 2023).

The hyperloop tracks maintain a consistent low-vacuum air pressure state. Boarding is conducted through airdocks which facilitate access while preserving vacuum within the tube. Low interchange time between pod departures is critical, as the system is designed to allow a high-volume of traffic as to compensate for lower passenger capacity (van Goeverden et al., 2018). This necessitates a secure, demonstrable, and hardwired traffic management and communications system (Hardt Hyperloop, 2023).

Figure 3. Hyperloop Rendering (Hyperloop Development Program, 2021)

Passenger safety and experience is paramount to its operability and attractiveness. The hyperloop system will be designed to account for heat and energy generated within the tube, and be resilient to a wide range of extraneous conditions to maintain structural integrity. The tube will also be designed to depressurize and facilitate evacuation every 500 meters in case of emergency. The suspension system will be built to sustain low-radii turns and speed in a manner that maintains passenger comfortability akin to airplane turbulence (Hardt Hyperloop, n.d.-b).

1.3. Focus and Scope: Development in EU & the Netherlands

Academic hyperloop literature is in largely early-stages. More significant work is being produced by organizations in the hyperloop landscape itself, specifically in Europe. Mitropoulos et al. (2021) found that out of 81 key hyperloop stakeholders operating in Europe, there are two high-impact organizations in the Netherlands, one private stakeholder (Hardt Hyperloop) and one public university-guided one (TU Delft, Delft Hyperloop). Hardt Hyperloop and Delft Hyperloop have produced a plethora of relevant reports and deliverables for public access (Delft Hyperloop, n.d.; Hardt Hyperloop, n.d-b). The European Commission is formally involved in funding research and testing of the Hyperloop, and there is sizeable literature forecasting conditions and scenarios on what a European hyperloop network would entail (Gago & Peréz-Seoane, 2021). As of now, the largest hyperloop testing track in Europe is in Veendam, outside Groningen. It spans 420 meters and is open to any hyperloop organization for a wide range of testing and experimental purposes (European Hyperloop Center, n.d.). There are notable smaller testing and research centers in Toulouse, France (HyperloopTT, n.d.) and a new 4-million-euro contract was commissioned in Italy to develop a working prototype (Hyperloop Italia, 2024).

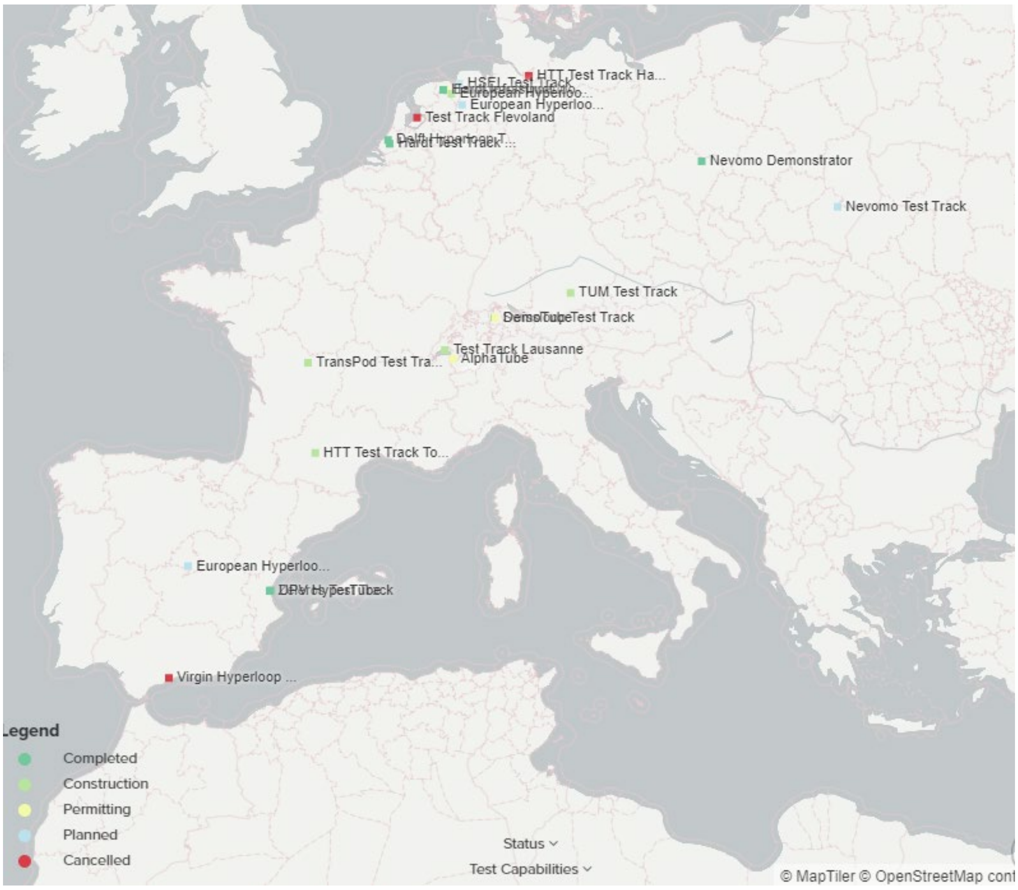

Figure 4. Hyperloop Rendering (Hyperloop Development Program, 2021)

1.4. Social Relevance

Managing a sustainable bioeconomy within planetary boundaries while continuing to approach the asymptotic horizon of unyielding economic growth is a challenging and urgent contradiction (Ramcilovic-Suominen et al., 2022). The complexity, depth and magnitude of our current ecological crises are unprecedented, with the intrinsic relationship between environment, economy and society rendered more visible than ever (Suša, 2019). Our global 'operating table' aims to mend technological innovation, economic feasibility and scalability with existing governance into a prognosis for socio-economic harmony (Long, 2021). The European Commission (2011) acknowledges adverse and inequitable inefficiencies and impacts of current economic dynamics (resource extraction, supply chains, fair pricing, etc.), and is invested in facilitating just and sustainable economic growth. However, growing dissatisfaction and parochialism of technocratic and market-driven visions are critiqued in activist and academic circles for entrenching path-dependent, top-down or Eurocentric dynamics (Brand et al., 2020). There is a recognizance that the opportunity for meaningful and democratically deliberated sustainable action is constrained by coinciding imperatives for growth and security (Berg & Hukkinen, 2011; Ossewaarde & Ossewaarde-Lowtoo, 2020). It remains clear that throughout the spectrum of positions, whether green-growth advocacy (Popp, 2012) or critical scholarship (Wells, 2018), technological innovation is a shared and significant area of focus; The question of how we construct and command advanced technology to solve these issues is paramount. Transport accounts for an extremely significant share of global energy consumption and emissions (Toledo & La Rovere, 2018, p. 2). The mobility landscape is ripe with various innovations and advancements geared to mitigating social, ecological, and economic burdens of movement (Butler et al., 2021). This is further emphasized given current ecological imperatives for a green transition, whereby companies can embolden market position and profitability at the cost of the very socio-ecological objectives they profess awareness of (Demaria et al., 2013), expanding unsustainable economic activity instead of reducing it (Johnsen et al., 2017). This contradiction reflects how sustainability is betrayed by misperceptions of the efficacy and impact of innovations. The concept of social imagination highlights the dialectic between idealism and materiality. Social imaginaries circumscribe paths-of-action while simultaneously mobilizing our ambitions towards realizing them (Jasanoff & Kim, 2015). Within which, technologies are not just scientific artefacts, but amalgamations of discourses, narratives and beliefs restructuring and reifying material conditions (Geels, 2010, 2012).

1.5. Academic Relevance & Research gap

The hyperloops current state as a novel and developing technology underlines present gaps in literature. Existing hyperloop literature is largely present in engineering, computational and technical fields, pertaining to knowledge directly beneficial for building, refining, and scaling the technology (Gkoumas & Christous, 2020a, 2020b). The hyperloop has become a widely discussed topic in many master's theses and dissertations (Tudor, 2023; Rana, 2020; Callahan, 2023). The growing prevalence of the hyperloop in this academic grey literature, albeit not peer-reviewed, gestures to the emerging sincerity, attention and ambition accumulating around the topic (Paez, 2017). There has been a large increase in academic articles and conference papers between 2016 to 2021, mostly pertaining to issues of energy, operations, communications, aerodynamics, or safety. There are far fewer papers analyzing policy, financing, scenario project or regional impacts (Gkoumas, 2021). It remains clear there is a substantial absence of multidisciplinary, socio-technical or geographical undertakings on the technology.

What remains is a lack of literature that systematically and holistically extrapolates the hyperloop as a coherent socio-technical mobility system, or emerging niche mobility regime. Transition literature attentive to multi-level dynamics of emerging niches and incumbent systems are a growing field of study, constructing analytically fruitful and holistic understanding of socio-technical dynamics and configurations (Schot & Kanger, 2018). The academic task taken by this paper is then to analyze how the hyperloop's current position towards emerging as a prospective mobility system, discerning how the discursive construction of emerging technologies instantiate, legitimize and propel their development (Ruhrort, 2023). This contributes to connecting systemic, technical and tacit body of the concept as it matures and rouses a competitive position within the sustainable mobility landscape.

1.6. Research Objective & Questions

This thesis will have two primary research objectives. Firstly, forming an empirical understanding on the development, state, prospects, and characteristics of the Hyperloop. Secondly, expounding the role of discourses and imaginaries in legitimizing and proliferating the concept as a plausible mobility infrastructure. This will bridge a concrete assessment of this emerging technology to the nested images, notions and ideas around the direction and development of transportation technologies, specifically highlighting the underlying rationales and tensions of governing and legitimizing technologically complex and innovative mobility solutions. The development and implementation of mobility technologies is a contested field nested between path-dependent institutional arrangements and emerging and innovatively disruptive niche advancements, the potentials of which prevail being equally a question of prudent policy and investment as much as preconceptions over desirable future trajectories.

This thesis thus contributes to an understanding of the hyperloop in the Netherlands and Europe as both an object of imagination and a socio-technical system, furthering an understanding of how technological mobility innovation necessitates and shapes social imagination. It will branch conceptual, discursive, and empirical understanding into a cohesive analysis of the hyperloop within a socio-technical and socio-imaginative landscape. Within academic paradigms, this will weave economic and social geography of hyperloop and tech-oriented mobility formats. The primary research questions are as follows:

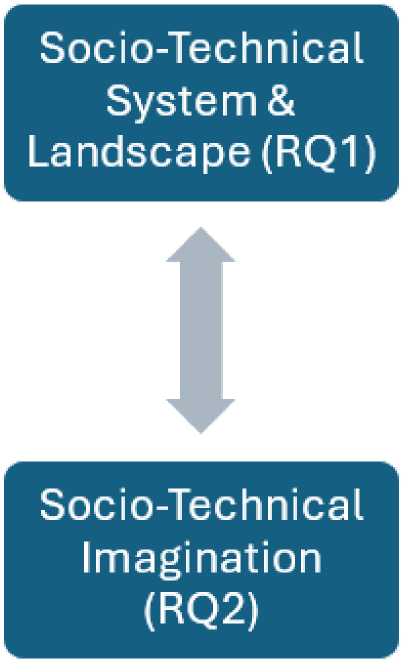

Figure 5. Research Questions. Made by Author.

RQ1: How is the Hyperloop conceived as a prospective socio-technical mobility system within the Netherlands and EU?

RQ2: How is the hyperloop constructed within socio-technical imagination?

RQ 1 will focus on the intertwined characteristics of the prospective hyperloop system, both as a contained system, and in relation to extraneous mobility regimes and landscape dynamics. This will elaborate on the logic, rationales, priorities and efforts being taken to realize a hyperloop system. RQ2 will focus on the discursive legitimization, construction, and contextualization of the hyperloop. These two questions prepare a combined understanding of how the hyperloop's socio-technical development is tethered to its imaginative and discursive construction. Without socio-technical imagination, systems feign appearance as natural and teleologically rational. Without concrete attention to how a system is constructed, dissecting the way it is imagined loses empirical, context-specific, and explanatory potential. Both research questions substantiate and ground the other, illustrated in Figure 5.

2. Theoretical Framework

The theoretical framework will comprise of two parts. Firstly, a comprehensive theoretical framework around the spatial, economic, discursive and imaginative conditions of mobility, innovation and technological development. This is followed by an account of mobility arrangements in the multi-level socio-technical theoretical framework. This aims to integrate the context-specific, technical, and varied literature around the hyperloop within the theoretical context and socio-technical landscape it is purported within.

2.1. Conceiving Space-Time

Mobility and transit innovations center around the premise of achieving a 'death of distance,' that being an ultimate compression of space and time. Perceptions of space-time, and the opportunities available to people to move themselves faster through the affordances of technology, are defined by socio-economic and material infrastructural (Jensen, 2013). This 'death of distance' is prescriptively desirable, inspired by ideological fixations of productivity, leisure, personal fulfillment and social belonging. Transit is specifically engendered by the logics of productivity, and the accelerating movement of goods and people between sites of economically coded value-creation (Harvey, 1990). In this nexus of productive and personal imperatives of movement, the reflex to move faster forms a taken-for-granted rationale around what technologies and mobility arrangements are reasonable to pursue, and by extension anticipated in social imagination (Doughty & Murray, 2016). Evidently, mobility arrangements that frame high speed transit as desirable are socially constructed and materially structured; speed is produced through an allocation of material resources, and experienced within a socio-cultural context of productivity, fulfillment and connection.

2.2. Economics of Movement

Mass mobility remains inbuilt into the velocity and vitality of economies in serving the needs of people (De Freitas & Blum, 2023). European cities at large are undertaking radical shifts in developing sustainable, efficient and accessible mobility solutions, with research on sustainable mobility having grown immensely more interdisciplinary (Holden et al., 2019). High-speed transit is fundamental for increasing economic competitiveness, attractiveness and connectivity (Diao, 2018). Within Europe, the precedent of seamless movement and soft borders is integral to national and European identity and economy (Jensen, 2013). In terms of transporting goods, the European Union (EU) incentivizes intermodal environmentally friendly transit pathways, but this is constrained by the interoperability and affordability of sustainable options (Bask & Rajahonka, 2017). This is furthermore difficult because underserved regional or municipal markets lack the funds, networks and existing infrastructure that justify development (De Freitas & Blum, 2023). These asymmetries are specifically visible and pernicious within gentrification-driven social displacement, where urban centers increasingly encase and serve wealthier residents and travelers (Gillespie et al., 2021). In the case of the hyperloop, the challenge is in sourcing investment and ensuring a recapturing of operation costs, all while mitigating displacement and ensuring accessibility for peripheral or rural areas.

It is first important to recognize the asymmetries and privilege innate to current mobility. Wealthy travelers in the top 10% income bracket consume 55% of all global mobility-related transport energy (Oswald et al., 2020). There is growing awareness around how mobility megaprojects exacerbate multi-scalar spatial mismatch and embolden social disparities via fragmented accessibility (Tiznado-Aitken et al., 2023). This underlines the relationship between mobility and 'network capital,' a form of social capital in which the quality and reach of one's relations, profession, status and prestige shape their privileges towards accessing, affording, and moving oneself through wider networks of opportunity (Kuttler & Moraglio, 2020). It is observed that high social and network capital lead to highly kinetic and 'hypermobile' lifestyles, producing a mystique and glamour around rapid, luxurious, and novel transit, rich in notions of epicurean and experiential comforts, and connotated closely to professional success (Cohen & Gössling, 2015). Additionally, the line between business and leisure travel is blurring as remote work blends with leisure. The demand segments are not discrete, and affordable high-speed transit enables distanced or freelance workers to engage in this emerging phenomenon of 'digital nomadism.' (Floričić & Pavia, 2021). Post-pandemic transit impacts have not disappeared, and transit providers have innovated in leveraging the elasticity of transit demand in high-transit routes (Redelmeier & El-Geneidy, 2024), as well as leverage a reconfigured preference for distanced work and the autonomy granted through digitally converging work and leisure (Chertkovskaya et al., 2020).

Long-distance mass transit is no longer an elite privilege, as was the case in the early 20th century. Air travel has become the dominant conduit of mass tourism and movement, and affordable airlines have become a popular mode of transport appealing to those with limited disposable income (Fisher et al., 2016). The wicked problem of mass tourism is caught in the schism of prolific desires to consume 'places' through commodified and marketized circuits of experience. Consequentially, the opportunities for experience rendered possible within existing arrangements set a standard that must be maintained throughout any reconfiguration (Barr, 2018). This is why the aviation industry is more amicable to emission off-setting schemes, mitigating substantial downscaling and leaving governments to work around their scope of service (Scott et al., 2016). Aviation requires airports tethered near dense urban hotspots, while ground-zero modes like rail and hyperloop require consistent and complete corridors. As so, incentivizing ground-zero modalities contends with constraints in allocating funding, subsidization and providers between and through regions of varying socio-economic status (De Freitas & Blum, 2023). Aviation's large scope of service, especially for passengers with less disposable income, forms a self-justifying rationale that obfuscates its disproportionally intense ecological footprint and socially asymmetrical usage (Magowan, 2022). While mobility innovations work to seemingly widen opportunities for sustainable and accessible movement (Cardoso, 2014), it is imperative to recognize mediums of movement simultaneously respond and produce demands of tourism, business and leisure.

2.3. Economic Dynamics of Megaprojects

Flyvbjerg's megaproject formula is "Underestimated costs, overestimated revenues, undervalued environmental impacts and overvalued developmental effects equal project approval" (2005, p. 18). The urgency of sustainable long-term solutions embattles the short-term constraints and prerequisites faced by investors and planners in the present (Ward & Skayannis, 2019). Rothengatter (2019) argues time efficacy and cost-benefit are limited metrics to gauge a megaproject's viability, and illustrating long-term development potentials offers a meaningful vehicle for realization. This diagnosis is relevant to the hyperloop. It can be assumed at face value the hyperloop *will* exist at some point, but barriers in support and investment are contingent upon the political will and economic capacity to facilitate realization, with limited scope of use and cost-recapturing in the first years, while still following through on a timeline which would allow scalability over time. A long-term vision becomes necessary.

The relation between cost, risk and benefit intensifies when the project scale increases. There is a growing 'megaproject paradox,' where even considering recognized prevalent risks neglected by urban megaprojects, they are increasing growing in scope, complexity, and price. This is partly due to intensifying imperatives for infrastructure catalyzing growth, their symbolic and discursive effectiveness in positively appraising political leadership and technological prowess, and their captivating allure in marketing urban landscapes (Söderlund et al., 2017). The existing approach to balancing the irreversibility and risks inherent in massive infrastructural projects necessitates privatization of land and housing, the commodification of amenities and a focus on recapturing land value, weighing uncertainties of prospective development with a need for accessibility in public space and services (Savini, 2017). This exemplifies the megaproject format as one formulated through market imperatives, multi-purposed as innovative edifice, political mechanism, symbolic artefact and economic catalyst.

As a megaproject, the hyperloop's future is mediated in the tension of justifying the initial capital investment, minimizing obstruction and complexity of construction, and ensuring post-construction maintenance and operation burdens are manageable (Rothengatter, 2019). Compared to other smart mobility innovations like AVs or EVs, the hyperloop requires the construction of its own central infrastructure to operate; it is not privileged to utilize existing road or rail networks (McCann & Ortega-Argilés, 2016). Furthermore, while other mobility innovations enjoy the benefits of experimentation and iterative feed-back implementation (Brown et al., 2003), there is no easy post-hoc adaptation or reconfiguration for the hyperloop. The final standard and technical makeup of the technology will require full certainty around its operability, as well as assured adoption by commuters to fulfill its business case.

2.4. Discourse and Development

Armin Grunwald states "the role of language is fundamental in discourse on the future, because the future only exists in language" (Dickel, 2022, p. 84). This describes how images and narratives of what the future beholds arise out of discourses, consequentially outlining, informing and guiding material and scientific developments. Within this process, technological prototypes are more than mere schemes, but social objects which connect anticipation and action, iteratively re-problematized and reconfigured, and refined to produce the evidence required to continue to realization of said prototype (ibid., 2022). The hyperloop can be understood as a prototype undergoing this process, and with a strong conceptual vision guiding its development. The task of demarcating images and outlines of future arrangements and advocating for the necessary trajectories to reach them is complex; Combinations of subjective judgments, assumptions, simplifications, and rational outcomes or predictions are combined to create plausible scenarios (Banister & Hickman, 2013). Whether in the vast array of technical hyperloop literature, pre-feasibility and scalability papers, or scenario and route-specific analyses, the future of the hyperloop is nested in how it is articulated and framed.

Visions of the future are systematically produced within social bodies of entrepreneurial, corporate, and political power which command inherent legitimacy in regulating, informing, and disseminating desirable images of life to be attained (Luri et al., 2023). It is clear that "theories, abstract ideas, visions and concepts" are transformed into narratives that further policy goals (Freudendal-Pedersen and Kesselring, 2016, p. 577). It is this "combination of an influential narrative with a strong discursive agent that forms a key condition for change" (Simoens et al., 2022, p. 1849). This reflects how organizational and technical documents are ripe for discursive analysis geared to excavate the visions, procedures and prerequisites of development (Jasanoff & Kim, 2015). The translation of scientific knowledge into policy programs requires an understanding of how stakeholders produce evidence and truth claims that are interpreted differently between involved actors and the broader public (Wesselink et al., 2013). The narrative and discursive construction around the hyperloop is as important to analyze as its material make-up. The reproduction, institutionalization, and legitimization of discourses are paramount to naturalizing and (de)stabilizing extant socio-technical regimes and landscapes (Simoens et al., 2022).

2.5. Socio-technical Imagination

Socio-technical imagination encompasses "collectively held, institutionally stabilized, and publicly performed visions of desirable futures, animated by shared understandings of forms of social life and order attainable through … advances in science and technology" (Jasanoff & Kim, 2015, p.6). Imaginaries interface present and future, reflecting and reinvigorating sites of political and discursive struggle which mobilize agency and allocate capital (Hausstein & Lösch, 2020). Veering away from rational or actor-network models of mobility transitions, socio-technical imagination evokes a constructivist and interpretivist frame towards recognizing the construction of agency as a symbolically mediated and sense-making process (Geels, 2010). Policymaking itself is a symbolic process that exercises authority through cultivating public consensus (Hajer, 2009). This exemplifies that material landscapes (infrastructure, megaprojects, mobility artefacts) share space between lived and imaginative landscapes; Socio-technical visions are reverse engineered to reveal a necessary approach for realization, framing a purported vision within the necessary conditions for its attainment (Banister & Hickman, 2013). Emerging niche technical innovations gain momentum not solely through beneficial cost-benefit profiles, but through a palpable image of life and society perforated through the technology (Martin, 2021). All technologies are rendered within an interaction of aesthetics and application, whereby technology carries symbolic associations and connotations that provide pretext and inform how the object is perceived, utilized, and experienced. Technologies are both material and social objects (Freudendal-Pedersen & Kesselring, 2016). These imaginaries are apparatus of both representing a desire and fulfilling it, illuminating a possibility and ascertaining its proximity to reality (Hauser, 2005).

2.6. Innovation in Policy and Development

Innovation can be understood as a function of scientific knowledge, imagination and industry, whereby knowledge is translated into application in new ways. Innovation is highly variable and speculative, tied to a 'political economy of promise' that financializes the processes, appropriates the knowledge and establishes the resilience needed for novel technologies to become feasible and effective factors of production (Reynolds & Szerszynski, 2012). Technological innovations aim to mend economic growth and socio-ecological vitality, enabling efficiency increases, emergent industries and quality-of-life improvements necessary to sustain post-industrial prosperity. However, the nature and rate of innovation is neither endless nor consistent, and the perceived inevitability and universality of innovation are increasingly challenged (Neubauer, 2011). There are two key points here. Firstly, technical innovation requires critical interrogation as to how new developments shape and sustain life. As noted by Thomas Piketty, "If one truly wishes to find a more just and rational social order based on common utility, it is not enough to count on the caprices of technology" (Piketty, 2017, p. 294). Secondly, there is more uncertainty as to how innovation can continue to spur growth with urgent sustainable responsibilities (Gordon, 2012). Innovation occurs within parameters of marketized and privatized schemes weighing public benefit insofar its diffusion or adoption can be profited upon and demonstrate prospects for growth (Hollands, 2015). Noting the inconsistencies within how innovation-afforded productivity gains are translated into increases in compensation through the EU (Theodoropoulou, 2019), innovation is not innately equitable; the awareness of which is reflected in the increasingly divergent attitudes towards how technological advancements infuse themselves in our lives and societies (Kerschner & Ehler, 2016). This challenge is traversed by policymakers who understand, advocate and agenda-set emerging niches within policy deliberation (Capano & Galanti, 2021). This is well-evidenced in the landscape of niches that have detailed Dutch smart mobility policy, especially automated (AV) and electric vehicle (EV) initiatives (Gironés et al., 2020). There is a strong, but unstable, reflex between policymakers and entrepreneurs to support and scale the most attractive and feasible visions (Funk, 2019). They also must determine the value of innovations past their ostensible potential or curated promises to ascertain real feasibility, viability and socio-ecological utility; fantasies of the future cannot substitute or override solutions in the present (Marx, 2022). The challenge lies in incubating and scaling these initiatives in an innovation-friendly but rapidly changing and demanding environment, keeping an idea alive while giving it space to develop.

2.7. Bounded Rationality of Innovation

There are three critiques waged against the prolific ratification and valorization of technological innovation; The profusion of technological solutionism, an overreliance on sourcing quantitative data, and emboldening notions of socially or politically 'neutral' technologies (Bina et al., 2020). Technological solutionism speaks to the myopic and managerial outlook bestowed upon developed; problems are framed as natural and solutions necessary, the processes which respond to them become common sense (Kitchin, 2015). Quantitative overreliance forewarns the fault of seeing humans as wholly rational and efficient social entities, acknowledging the inherent spontaneity and serendipity of meaningful living; this is to protect our rights to a quality of life not fully reflected in quantifiable metrics of productivity, opinion and behavior (Haklay, 2017). The false apolitical premise around technological advancement establishes an apriorist and univocal basis for assuming technologies to be separate from the socio-political arrangements they are both produced within and poised to resolve the shortcomings of (Vanolo, 2014). While not all technologies are equally intense in their political considerations, complex megaprojects and green propulsion technology operate at a high threshold of investment and impact (Geels, 2012).

These 'blind spots' of technical rationality are grounded in deterministic framing of technology as a 'placeless' and self-contained phenomena, untethered from socio-ecological context. This follows the logic that artefacts with consistent and fixed technical characteristics can predictably transfer between contexts (Lim, 2018). This 'universalization' reflex is particularly remissive of supply chain justice concerns, whereby increased demand for rare earth minerals and metals leverage economic asymmetries between resource-rich and financially wealthy nations (Dunlap & Laratte, 2022). It is clear "no country in the world currently meets the basic needs of its citizens at a globally sustainable level of resource use" (O'Neill et al., 2018, p. 1). Prosperity or progress is not an isolated translation of knowledge to product, and critical attention must be given to planetary boundaries which problematize the viability of normative 'triple win' models between people, planet and economy (Ramcilovic-Suominen et al., 2022). The 'green growth' agenda, bent on tying economic prosperity with sustainability through innovation, is a dominant governmental logic; The Netherlands recently announced the creation of a Green Growth & Climate Ministry (Hylkema, 2024).

2.8. Multi-Level Perspectives on Socio-technical Transitions

The Multi-level Perspective to Socio-technical trajectories (MLP) is a cornerstone of technology, innovation, sustainability, and transition studies (Bilali, 2019; Kanger & Schot, 2019). This framework has three core analytical dimensions: niches of radical innovation, socio-technical regimes, and socio-technical landscape (See Figure 6). Niche initiatives emerge out of localized practices and concerted initiatives deviating from or transforming existing arrangements. Socio-technical regime(s) are path-dependent, established and locked-in constellations of interdependent actor coalitions, industry relationships, legal frameworks, material infrastructure, and socio-cultural patterns of adoption or use. The landscape encompasses relevant exogenous, macro-economic, geopolitical and ideological dynamics (Geels, 2012; Geels & Schot, 2007). Historical patterns of siloed and incremental adjustments are reckoning with the emergence of disruptive, advanced, and interoperable technical initiatives necessitating a more intense conjunctions of competencies and resources between private and public actors (Goyal & Howlett, 2018).

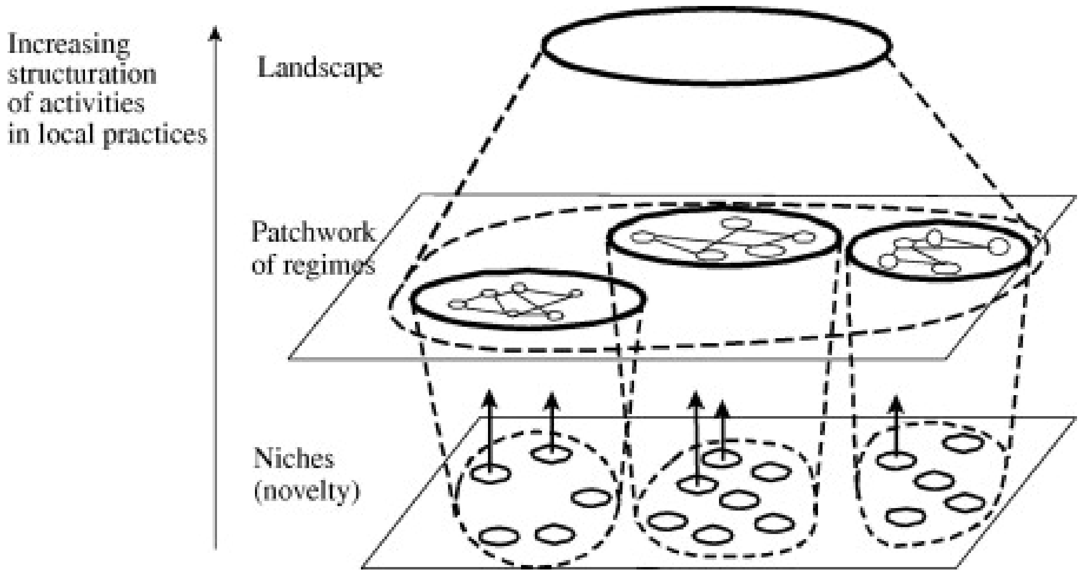

Figure 6. Socio-technical Trajectories (Geels, 2012)

Geels (2012) emphasizes that the multi-layer model is a non-linear, co-produced and contextual framework for mapping socio-technical development and revealing points of uncertainty, causal effect, and contestation, heeding to interconnected social, cultural, ideological, economic, and political processes. This substantiates the methodological approach of this thesis in building mutual understanding of the empirical state and prospects of the hyperloop alongside the socio-imaginative guiding visions and conditions. The academic task is to analyze the conditions and tendencies by which mobility discourses and technologies compete, coalesce, and contribute into a coherent 'sustainable' mobility landscape (Ruhrort, 2023).

Geels (2002) has outlined the transition from niche to regime throughout history; What is clear is that a niche technology will grow in awareness, utility, and feasibility as the artefact is trialed, deployed, developed, and subsidized in a favorable governmental context. This trajectory from niche to regime is an incremental, non-linear, and long-term process requiring interdependence of the technology with companies, supply chains, and regulatory competencies in the socio-technical system (Geels, 2007, 2010; Sorrel, 2015).

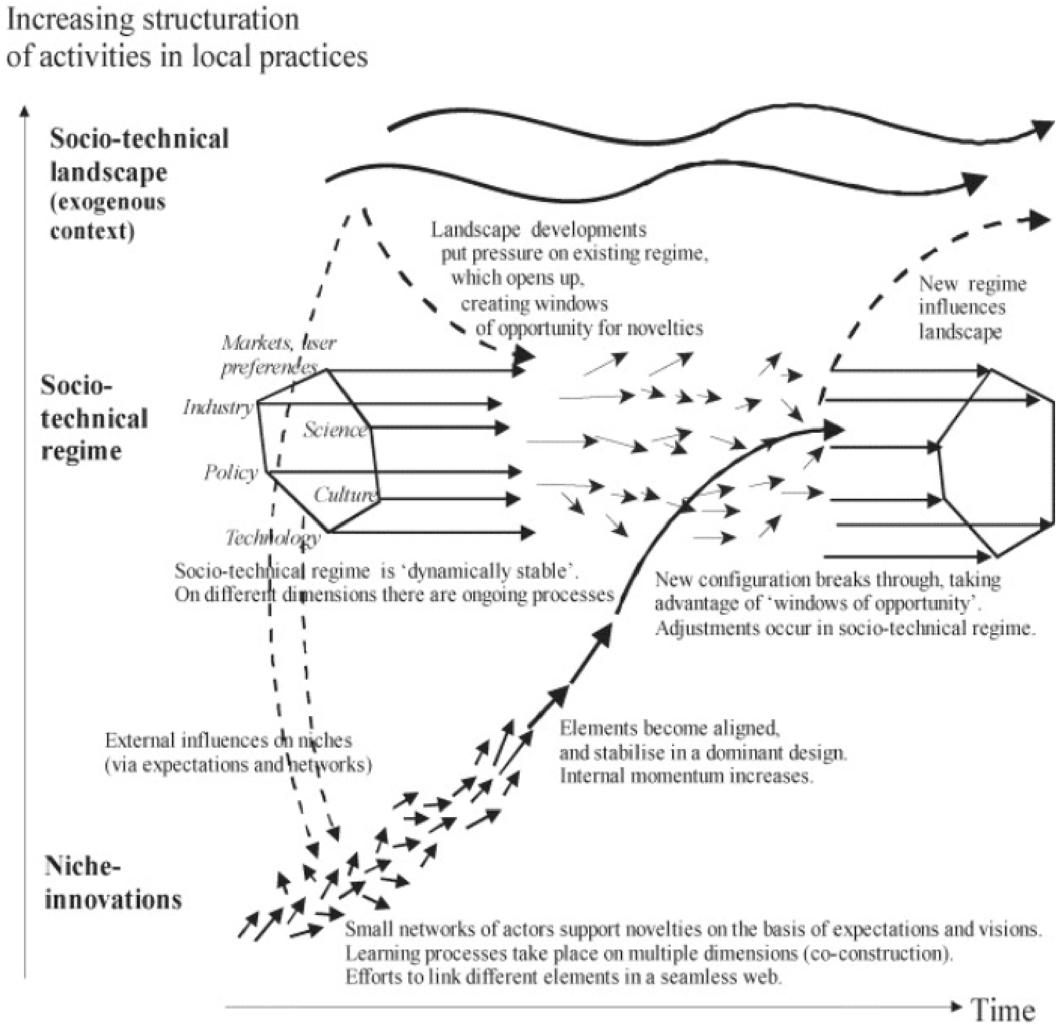

Figure 7. Niche Assimilation in Socio-Technical System (Geels & Schot, 2007)

These trajectories are propelled between stabilizing forces and destabilizing forces, these being interactions that reinforce or deter the continuation of existing regimes interactions between niche innovations and wider landscape, detailed in Figure 7 (Moradi & Vagnoni, 2018). The hyperloop can be conceptualized as a niche innovation prospectively competitive with incumbent regimes. This entails the hyperloop will navigate the theorized challenge of instilling niche technologies to a regime patchwork and landscape of fiscally and regulatorily protected incumbent mobility modalities (Marcon Nora and Alberton, 2021; Nold & Corman, 2024). There are exigent power dynamics in the MLP model of innovation, and attention must be given to how incumbent socio-technical regimes stabilize themselves and deter niche regimes, and inversely how niche regimes engage against incumbent regimes and resist destabilization (van Rijnsoever & Leendertse, 2020). Scaling innovative niche technologies into regimes requires a growing market position, institutional support and cultural adoption. Technologies also do not necessarily substitute incumbent regimes, but can integrate, merge, and complement them (Schot & Geels, 2008).

2.8.1. Current Mobility Regimes and Landscape

Socio-technical systems in mobility are a key focus in transition studies, and ample attention is given to how niche technologies are articulated amidst established mobility regimes. Incumbent regimes destabilize when extraneous circumstances, upheavals, fallouts in policy support, or internal dysfunctions impede systemic stability (Aarhaug & Tveit, 2023). There are three distinct regimes the hyperloop will contend with: road, rail and aviation. Regarding road and rail, austere conditions negatively impact political preferences for mass transit initiatives. Rail investment is 30% of what has gone into roadway investment in the EU (De Freitas & Blum, 2023). Policy preferences towards sustainable automobility, while still an improvement, are fundamentally ineffective at fulfilling sustainability aims (Gallardo et al., 2018; Watson, 2016). Rail is advancing as improvements in automation and various technical optimizations improve efficiency and lower costs, but benefits are capped without an expansion of new tracks and corridors (Nold & Corman, 2024). In the meantime, the European railway network has lost 3,300 kilometers since 2008, and rail investment has been stagnant and significantly less than road investment (Rudolph et al., 2023). While road has taken central attention in budgets, EU wide-rail network plans are stuck in between rhetoric and realization, and ambitions differ between member-states.

Throughout Europe at large, rail has suffered the most from withering investment, while road benefits from increasing stimulus, and aviation holds an unbothered ‘business as usual’ position through unfaltering subsidization and investment (Islam, 2018). There are strong policy levers available to member states in reconfiguring mobility. Introducing kerosene or carbon tax schemes would work to divert funds from aviation to alternative mobility arrangements, albeit this is an unpopular and decisive approach (Krenek & Schratzenstaller, 2016). This is a key issue in the tradeoff between aviation and hyperloop or HSR, as aviation is far more profitable and a relatively less capital-investment heavy industry (Pareschi et al., 2023). Growing research reinforces the overlapping benefits in collaboration, patent creation, innovation and sustainability within rail, specifically when connected to peripheral or regional stations between larger cities (Hanley et al., 2022). The preferrable rail egress times provide a seamlessness not there in aviation (Moyano et al., 2018). The hyperloop will spatially, fiscally, politically and socially contend with the incumbency of road, rail and aviation regimes, outlining the inevitable tensions around pursuing one trajectory without destabilizing another.

3. Literature Review: Socio-technical Hyperloop Characteristics

Having theoretically contextualized the hyperloop as a niche innovation enmeshed in the MLP framework, it must be understood as a prospective discrete mobility system. Canitez (2019) forwards a typology of socio-technical urban mobility systems. This will be drawn from to expound upon key dimensions within the prospective hyperloop system. This theoretical framework accounts for tangible dimensions of entities and relations, namely supply chains, infrastructure, and markets, and stakeholders (Nora & Alberton, 2021). It also gives insight into intangible cultural, social and organizational characteristics, such as practical rules, routines, and expectations (Forbord & Hansen, 2020).

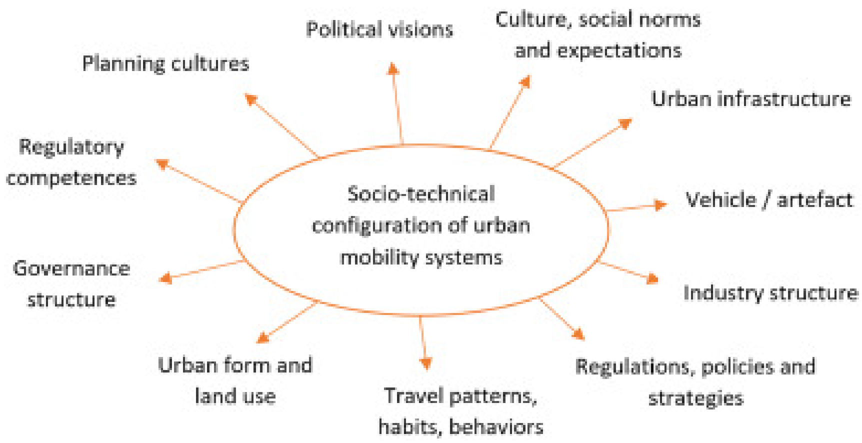

Figure 8. Socio-technical Mobility Systems (Canitez, 2019)

3.1. The Hyperloop Artefact

NASA's Technology Readiness Level is a useful indicator for the current state of a technology system. It is ranked between 1 to 9 levels. High-speed rail (HSR) exists at a level 9, defined as an "Actual System … 'proven' through successful mission operations," reflecting operability and stability of the system. On the other hand, the Hyperloop would be best classed at TRL 6, defined as "System/subsystem model or prototype in a relevant environment" (NASA, n.d.). This reflects the different involvement of relevant actors; TRL 4-6 technologies require more strenuous involvement of policymakers and regulatory oversight bodies to facilitate further development, while TRL 9 technologies focus upon a running business model and aligning with social needs and demand segments (Moretto et al., 2016). There are various hyperloop prototypes (Nøland, 2021), but Delft Hyperloop is utilizing a magnetic field system with a coil system integrated within the pod itself (Museros et al., 2021). As of present, the hyperloop remains in technical infancy, requiring substantial experimental proof for technical feasibility and safety (Nøland & Bird, 2024). The ongoing experimentation over what materials and design choices are made are a dynamic part of the innovation process with fundamental implications on the feasibility and future of the technology.

3.2. Planning Culture

As outlined by Ward & Skayannis (2019), sustainable development approaches to mega-transport projects require the removal of organizational barriers, integrated thought-action channels, and demonstrated understanding of available alternatives. More difficultly, megaproject struggle to meaningfully operationalize social and ecological considerations, tending to suffer from the short-sighted reflex to write-off feasible long-term projects, or inversely and irresponsibly underassess risks when opportune (ibid., 2018). As explained by Flyvbjerg (2011), these seemingly irrational tendencies arise within two caveats of overlapping incentive and bias. Firstly, 'strategic misrepresentation' occurs when politicians and planners deliberately misconstrue their project's feasibility to out-compete alternatives and garner positive political clout. Secondly, 'optimism biases emerge when planners undervalue rational analysis amidst optimistic enchantment with the idea itself. Either case demonstrates how megaprojects are sensitive to the sentiments, priorities and political culture they are deliberated within.

In mobility planning, the Netherlands implements transit-oriented development policies between national and regional levels, furthered through a multi-level system of co-governing authorities. It allows for consensus-formation when overcoming institutional barriers, bridging short and long-term interests, deliberation over all viable trajectories, and mitigating ill-evidenced overzealousness or strategic misrepresentations of an initiative (Tan et al., 2014). The precedence and consensus around transit-oriented planning in the Netherlands weaves existing and emerging mobility solutions together (Van Lierop et al., 2017). HSR has become a central megaproject in the Netherlands, reflecting economic willingness and political competency for long-term and large-scale mobility projects geared towards intra-European connectivity (Van Marrewijk, 2017). This reflects the Netherlands context-specific capacity for exploring mobility alternatives and managing strenuous planning challenges. The innovation-friendly and consensus-oriented policy process underlines how the hyperloop concept has gained momentum in the Netherlands.

3.3. Governance & Industry Scopes

The Netherlands has consistently and proactively outlined progressive visions and policy goals for transport and movement regulation, both within national and EU contexts (Scholten et al., 2018). This is reflected in the integral role of innovation in Dutch mobility policy, evident in early adoption of Mobility as a Service (MaaS), EV and AV initiatives (Gironés et al., 2020), as well as the centrality of well-integrated mobility hubs in Dutch transit planning (Rongen et al., 2022). The high density of electric infrastructure, albeit still a mix of sustainable and fossil energy sources, enables a national policy approach amenable for renewable technologies (Gürsan et al., 2023). Urban mobility policy is a multi-level negotiation in the Netherlands between municipalities, regional and national stakeholders. The national governmental body (Rijkswaterstaat) is the party most concerned with inter and intra-national mobility developments, such as HSR, or a prospective hyperloop system (van de Velde, 2009).

Critical to realize is the regulatory benefit derived from the absence of any historical precedent for a hyperloop. HSR in Europe is contingent on national standardizations and existing conventional rail infrastructure (De Freitas & Blum, 2023). The European Court of Auditors (2018) describes TEN-T as an 'ineffective patchwork' of systems and standards between EU member states. EU provisions and grants amass around only 11% of the total construction cost that would be required for the TEN-T HSR network. The Hyperloop will likely begin development upon consistent EU-wide standardization, relinquishing concerns of retroactively integrating infrastructure and struggling to form compliance between EU nations.

Two notable international hyperloop contexts are the United States and Saudi Arabia. The United States department of transport has identified the Hyperloop in large infrastructure bills (U.S Department of Transportation, 2021), however the largest American hyperloop company, Hyperloop One, shut down operations at the end of 2023 (McBride, 2023). Proponents of the Hyperloop identify the Middle East and China as catalysts for establishing working hyperloop pilots, likely before a system is deployed in Europe (Rob et al., 2019). Saudi Arbia has included prospective hyperloop corridors in plans for the Line city in the NEOM megaproject (Systra, n.d.), and the technology has been studied in light of the Kingdom's 2030 development goals (Balabel & Almujibah, 2022). This illustrates that the hyperloop has a varied but tangible presence in a variety of national contexts.

3.4. Land Use

Hyperloop land-use is a critical dimension of the development process. The hyperloop is being bult from blank slate, likely to service dense urban areas, thereafter connecting these points via one or two-way tubes that are built as to balance system integrity, speed, energy access and suitable geographic integration (Premsegar & Kenworthy, 2023). It lacks the precedent or existing ground network of HSR (De Freitas & Blum, 2023). Transparent citizen involvement in land-use decision making is tied to ensuring procedural justice, resolving conflicts of interests, and ensuring necessary benefits or incentives are provisioned (Delft Hyperloop, 2019).

The hyperloop track will require a continuous route of tubes and ancillary supports accompanied by recurring vacuum-pumping stations. The immovability of the tube once planned entails terraforming and public acceptance, a more serious concern in complex natural environments outside of the Netherlands (Van Den Brink et al., 2006). Furthermore, many models presume the hyperloop will be built alongside or near already existing rail and road transit corridors. This would ensure minimal intervention into non-necessary residential, commercial or public space. The hyperloop will also require integration with established and multi-function transport hubs to promote public accessibility and integrate with other modalities (Loukaitou-Sideris et al., 2012). Managing disruption and displacement wrought in constructing the hyperloop will furthermore be an essential part in cultivating positive public support (Premsegar & Kenworthy, 2022) and anticipating protests or resistance against development (De Barbieri, 2018).

3.5. Industry Structure and Cost

The hyperloop is being realized in a nexus of universities, public organizations, private companies and joint-private public partnerships (Mitropoulos, 2021). Various scenarios balance the hand between venture capital, grant schemes, government oversight and profitability; the only clear consensus is that the government will be involved in some capacity, carrying a vested interest for an equitable realization (Van Goeverden et al., 2018). While the government subsidizes for broader socio-economic benefits, private stakeholders ascertain an early-stage trailblazer or pioneer position. The "irrational exuberance of the private sector" in innovative willingness, matched with risk management through public-private partnerships (PPPs), have shown merit in HSR development (Preston, 2013, p. 30). This indicates private-public collaboration will be indispensable for any prospective European hyperloop project.

As established, the Hyperloop is an expensive megaproject. Lowest predicted costs are €37,923,655 per km (Delft Hyperloop, 2019), with other estimates around €47 and €59 million per km (Borghetti, 2023; Pareschi et al., 2023). Some estimates range up to €76 million per km (Almujibah, 2023). These costs are largely given to buying materials and constructing the tube and vacuum infrastructure (Mitropoulos, 2021). Exponential costs could arise if terraforming or tunneling is required, and the cost of building hyperloop stations is also sizable, depending on the corridor length and the degree of integration into existing mobility networks (Borghetti et al., 2023).

In terms of financial sustainability, comparative research is largely convinced that the system is less financially feasible compared to HSR due to novelty and high infrastructure costs (Araghi & Wilmink, 2022; Guerrieri, 2012). Given high initial capital investment, there are concerns the cost per ticket could rise to a high 'break-even' price that limit the accessibility of the mobility (Nikitas et al., 2017). A demand analysis on a Rome-Milan hyperloop connection, priced at 125 euros a ticket, would take 44 years to reach break-even (Borghetti et al., 2023). Hyperloop ticket prices are likely at the order of magnitude of HSR, but may struggle to compete with short-haul aviation ticket prices without policy intervention (Araghi & Wilmink, 2022). The need to balance affordability and recuperate costs with low passenger capacity will necessitate connecting pods or rapid turnover times, increasing complexity and risk (Hirde et al., 2023). It was furthermore predicted the hyperloop is broadly economically disadvantageous; consistent price underestimation by hyperloop stakeholders obfuscates meaningful estimations (ARUP et al., 2017; Premsegar & Kenworthy, 2022; Guerrieri, 2022; Yavuz & Öztürk, 2022). The prospect of its cost is also mediated by proposals to balance passenger and cargo haul in the hyperloop, promising high-speed transport of sensitive materials. The road-air cutoff point at which air becomes preferable for cargo transit is around 240km (Samimi et al., 2011), a distance primed for Hyperloop substitution. Hyperloop could gain revenue through cargo, especially if able to completely offset risks of collisions (Werner et al., 2016). Balancing cargo and passenger tradeoffs can prove beneficial, but long-term cost recuperation and short-haul aviation price advantages prove to be significant challenges to affordability.

3.6. Public Perception

High-speed mobility also gives rise to questions of what speed reaps the most optimal benefit for the population. Comparatively, HSR demonstrates equal benefits and preserved costs when comparing 250 km/h to 160 km/h scenarios (De Freitas & Blum, 2023). The hyperloop will be partly perceived through the ease it can be accessed and interconnected with existing modes. It is found that door-to-door trip speeds are more significantly influenced by improvements in access and egress trip times than pure on track travel times (Brezina & Knoflacher, 2014). This finding is endorsed by estimations of Froehlich et al. (2013) who estimate that improving access to rail stops has a potential of increasing rail demand significantly. There is also a difference in how the public will conceptually accept and practically utilize hyperloop technology (Ward & Skayannis, 2019). Perception can also differ between endorsing the concept and tolerating its construction and presence, akin to not-in-my-backyard (NIMBY) resistance (De Barbieri, 2018). As established, premium or highly priced schemes will result in equity issues – a concern emphasized given the tendency for megaprojects of this scale to overshoot budget (Flyvbjerg, 2011). The hyperloop will struggle to balance high costs and ticket prices with an accessible and diversified network. Rail is better oriented to service areas where demand requires subsidization to be actualized (De Freitas & Blum, 2023). Verifiable feasibility for an accessible and harmonious realization will influence the degree of public resistance, skepticism and disbelief likely to emerge (Premsegar & Kenworthy, 2022). It is empirically difficult to ascertain reliable predictions for public perception, both because of the hyperloop's current obscurity, but because preconceived and tangible benefits may change over time, and differ between people. Its quick, low-security egress times may prove both desirable and effective for riders, but the scope of whom would access the network will be defined by its relationship with rail and how peripheral access points are prioritized.

4. Methodology

4.1. Methodological Approach & Justification

A qualitative approach to socio-technical systems will be taken. MLPs are historically contingent arrangements constructed by clusters of interconnected social and technical entities dialectically constituting economic and political dynamics (Geels, 2002, Geels, 2012). This framework is explanatory and illustrative of how mobility systems will evolve and consolidate over time, discerning the relation of physical artefacts, social groups and intangible, normative and ideological rules and conditions (Sorrel, 2015). The MLP theoretical framework is suitable for a qualitative and analytically potent multi-level research approach (Schot & Kanger, 2018).

Qualitative analysis is well-suited for connecting the technical to social. Qualitative approaches are suitable and empirically rewarding within the MLP framework (Fern, 2012), geared for dissecting existing institutionalized arrangements (Quist, 2007), tracing the maturation of emerging niche innovations (Geels, 2010), and illustrating interactions between stakeholders (Fuenfschilling & Truffer, 2014). It can uncover evolving dynamics and characteristics defining an emerging niche (Johansen & Johra, 2022), as well as revealing the discourses or narratives which legitimize the niche between individual and organizational levels, illustrating how niches are re-structured through the interaction of technical developments and social practices (Simoens et al., 2022). Qualitative analysis delineates the plurality and potency of imaginaries within the socio-technical landscape (Bechtold et al., 2017), identifying narratives and 'guiding visions' between actors, establishing the contextuality and contingency of technical development upon socio-technical imagination (Geels, 2019). Discourses also have a significant function in framing how mobility practices are interpreted, naturalized and accepted in public life, instilling the preconditions for systematic transitions (Endres et al., 2016). Discourses are fundamentally context-specific, emerging from and appealing to certain actors and groups; Discourse analysis ascertains reliability through acknowledging origin, positionality, audience and influence of stakeholders in how data is collected and analyzed, as so findings are not overestimated or generalized beyond the merit and relevance of the texts they are produced within (Ulrich, 2003). Within highly technical fields, like the hyperloop, it is pertinent to understand technical texts can be discursively potent, revealing organizational practices, challenges and procedures (Couture, 1992).

In accordance with a critical realist perspective, a reflexive 'retroductive' analytical approach is taken that oscillates between the theoretical, the systemic and the situation, combining theoretical insight and empirical evidence towards analytically rich and explanatory understanding (Belfrage & Hauf, 2017). This approach is useful for interconnecting systemic mechanisms and characteristics with their contextual and theoretical backdrop. Critical realism is vulnerable to over assuming the potency of social structures, poor identification of causal effects in favor of interpretive postulation, and prioritizing theoretical versatility at the cost of conclusive findings (Sorrell, 2018). To ensure validity and veracity of qualitative findings, a methodological resilience is inbuilt through blending inductive and deductive approaches interlinking theory, social and empirical reality (Alexander, 2013). This enables a constructive and pertinent application of theoretical heuristics to uncover relations, narratives, dynamics and trajectories within complex socio-technical systems (Geels, 2022). Furthermore, critical realism instils an analytical rigor maintained by denying claims to exceptionality, and counterbalancing or validating data from employees, associates and organizations harboring vested interest (Tokatli, 2015). In understanding the development of the hyperloop, this is critical for discerning speculation from practice, or differentiating perceived and feasible trajectories.

4.2. Research Design

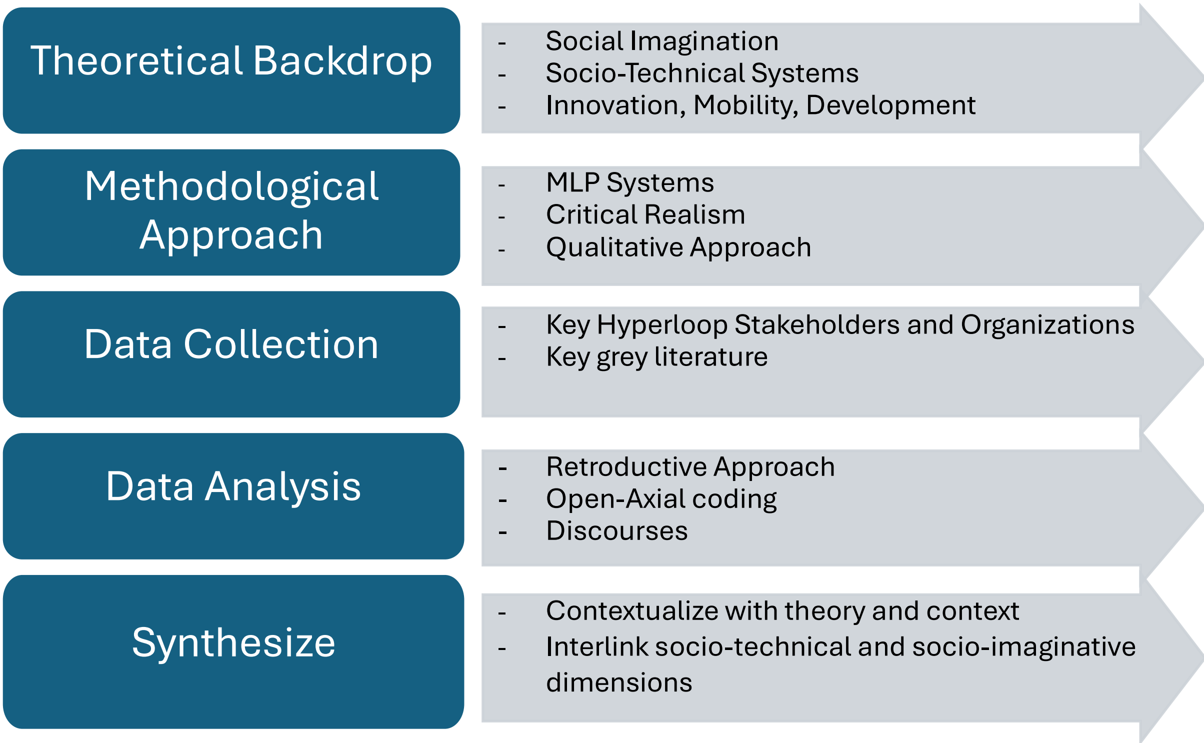

Figure 9. Research Design. Made by Author.

This paper will conduct a qualitative analysis of the hyperloop within the socio-technical landscape of the Netherlands and the EU. A qualitative multimethod approach of semi-structured interviews and content analysis was conducted. Semi-structured interviews allow insight and perspective into the findings, beliefs, and perspective of key individual agents. Content analysis of organizational grey literature allows an meso-level organizational understanding, revealing the strategic approach, relationships, and vision of key hyperloop stakeholders. The comprehensive literature review will supplement insight into macro-level trends and dynamics relevant to the landscape.

4.3. Data Collection

Interviewees were selected to obtain varied insight from within the hyperloop, broader mobility and policy sectors. Two Delft Hyperloop members, and the co-founder of Hardt Hyperloop, represent the hyperloop space. Two Dutch government employees with specific experience with the Hyperloop and mobility innovation were interviewed. Two non-hyperloop mobility professionals, from rail and public transit backgrounds, were interviewed. Recorded consent and relevant written consent was obtained. When conducting interviews, it was already a prerequisite that questions were particularized to their position and experience.

Table 1. Interviewees

Name	Position	Organization	Stakeholder Type
Jorg Scheepens	Full-Scale Engineer	Delft Hyperloop	University Team Hyperloop
Julian Koot	Lead Scalability	Delft Hyperloop	University Team Hyperloop
Mars Geuze	Co-Founder, Chief Commercial Officer	Hardt Hyperloop	Private Company, Hyperloop
Eric Mink	Afdelingshoofd Innovatie (Head of Department Innovation)	Ministerie van Infrastructuur en Waterstaat	Dutch Government
Edoardo Felici	Policy Coordinator for Innovation in Mobility	Ministerie van Infrastructuur en Waterstaat	Dutch Government
Arjen Jaarsma	Mobility Expert at Modancia	Modancia	Private Sector, Public Transit & Mobility Consultant
Valentijn Vlek	Project Leader Train	QBuzz	Private Company, Rail

Documents were selected purposively and with preconceived intent to develop a holistic and varied corpus of texts. Multiple text types, ranging from comprehensive reports, scenario case studies and 'vision' documents about the future of the hyperloop were selected. 5 organizations, aside the EU-wide Hyperloop Development Program, come from Dutch stakeholders, specifically the well-established Hardt and Delft Hyperloop. This selection process produced a corpus of 10 texts.

Table 2. Grey Literature

Stakeholder	Document Name	Document Type	Date
BAM	Hyperloop: Let's Join This Ride Together	Vision Paper	2022
Berenschoot	Speeding Up swiftly	Vision Paper	2021
Hardt Hyperloop	Cargo-Hyperloop Holland	Report	2021
Hardt Hyperloop	Pre-feasibility Schipol Hyperloop	Scenario Paper	2020
Hardt Hyperloop	Amsterdam - Frankfurt	Scenario Paper	2018
Delft Hyperloop	The Future of Hyperloop	Report	2019
Delft Hyperloop	A Hyperloop Handbook for Public and Private Stakeholders	Report	2022
Delft Hyperloop	On The Future Development of	Report	2022

	Hyperloop Infrastructure		
Delft Hyperloop	The Community Acceptance of the Hyperloop Infrastructure	Report	2023
Hyperloop Development Program	Hyperloop Connected - A Vision for the European Hyperloop Network	Vision paper	2022

4.4. Data Analysis

A preliminary understanding of MLP systems, social imagination, the hyperloop landscape and mobility establishes a starting point for meaningfully interpreting and dissecting interview material and grey literature.

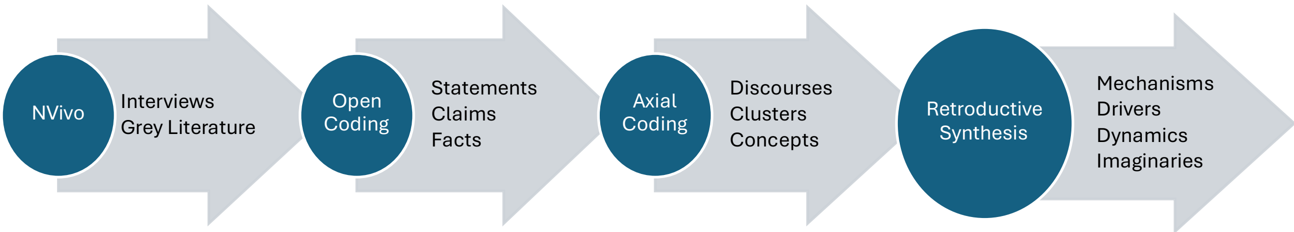

Figure 10. Coding Process. Made by Author.

After having built a base of theoretical and empirical knowledge on the hyperloop, and conducting and transcribing all interviews, interview transcripts and grey literature were analyzed in separate NVivo files. A critically-realist informed qualitative coding scheme was utilized. The coding scheme facilitated open-ended axial coding of the texts and interviews. This allows for identifying, categorizing, postulating and grouping concepts and discourses. This then allows for the subsequent retroductive synthesis of codes, categories and discourses in the scope of relevant theory and existing literature (Fletcher, 2017). This works to identify conditions, relations and mechanisms rendered visible in the hyperloop niche; delineating where systemic exogenous and endogenous dynamics meet, accounting for dynamics of power between scopes and stakeholders, and concomitantly linking discourses and imagination to the hyperloop's development. This process is illustrated in Figure 10. The codebooks for grey literature and interviews are accessible in Appendix A and B.

5. Results

5.1. Hyperloop in Socio-Technical Landscape

The question of how the developing hyperloop niche is conceived as a prospective socio-technical mobility system will follow the parameters of the MLP framework. Firstly, results will be structured along the lines of a prospective mobility itself, spanning technical artefact, planning culture, regulation and governance, land use, public acceptance and funding structure, demonstrating the contingencies and interconnections between characteristics. Secondly, there is analysis as to how the prospective system will foreseeably interact with incumbent mobility regimes. Finally, considerations are given to critical dynamics within the mobility landscape. In all, this three-dimensional approach details the conception of hyperloop as niche innovation and prospective mobility system evolving within a regime patchwork and broader landscape.

5.1.1. Artefact Development: Materials for Scalability

The hyperloop is itself an 'uncharted' trajectory, and key decisions regarding its design will carry implications in its feasibility and sustainability. Currently, steel-reinforced concrete is the most optimal material-mix identified. Steel offers a mix between durability, price point, scalability and existing supply chain competencies. (Delft Hyperloop, 2022a). The decision-making matrix is visualized in Figure 11.

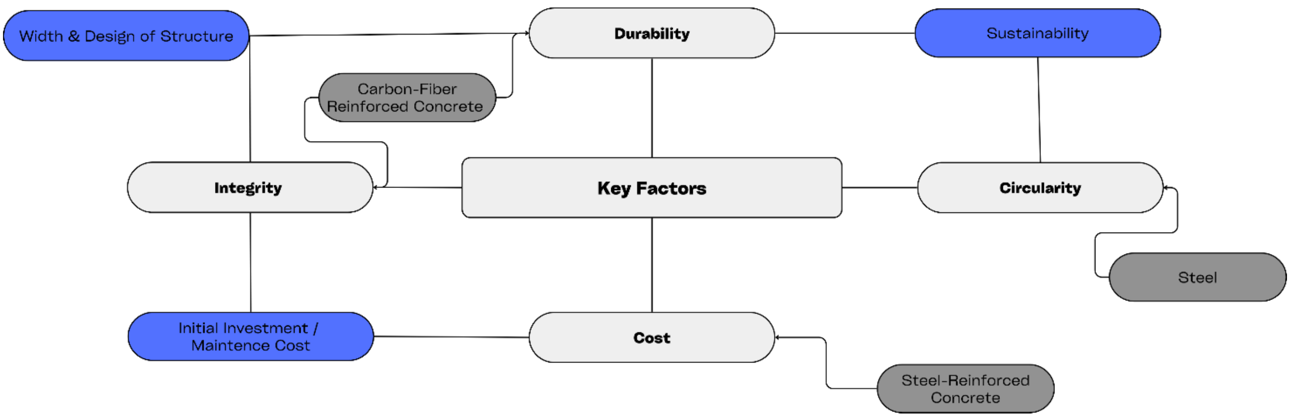

Figure 11. Material Decision Mapping. Made by Author.

Although initial costs may be high in whatever case, key decisions in how the system is designed will need to ensure scaling the system remains relatively affordable. This pertains specifically to the tube-pilon structure, as the pod design is a smaller part of the system's resource use (Bam, 2022). This was explained by Jorg Scheepens of Delft Hyperloop:

> *"How do we actually make it a scalable system ... not using all the coils and copper, that is what we are trying to eliminate ... that is what we are eliminating to make it cheaper ... maybe more steel, but way less costly materials."* (Scheepens, Delft Hyperloop)

This scalable network aims to maximize utilization and minimize opportunity cost. The emphasis on the earlier adored high speeds has changed, as further noted by Jorg:

"*It's more efficient for a little lower speed, we are estimating a system of 600-700 km/h. It is not comparable to the 1200-1300 km/h … Elon Musk was really concentrated on speed.*" (Scheepens)

The tradeoff between low-passenger capacity and aviation-level speeds is managed by efforts to maximize turnover between pods, departing every 2 minutes at max operation, operating 16 hours every day (Delft Hyperloop, 2019). Hyperloop stakeholders want to "*avoid creating a security scheme like airports have*" (Felici), allowing rapidly efficient egress times. Evidently, a prospective high rate of pod departures and rapid passenger inflow demonstrates scaling the hyperloop system will induce high loads upon system integrity. A dually scalable and durable system is necessary. One aspiration shared by Eric Mink, head of the Department of Innovation, is in developing a low-impact material alternative:

"*Currently, it is more expensive … work on scalability and lowering costs. Very difficult to grasp, would be nice if they didn't use steel, but something that could be made on-site*" (Mink)

Further innovation will be required to ensure high-complexity resilience and affordable, sustainable scalability in a prospective network. Decisions or consensus on its central characteristics should consolidate as its TRL increases; a TRL level of 8 will require coordination between regulation and developers and at TRL level 9 begin construction and integration with existing transport modalities (Hyperloop Development Program, 2024).

5.1.2. Planning Culture

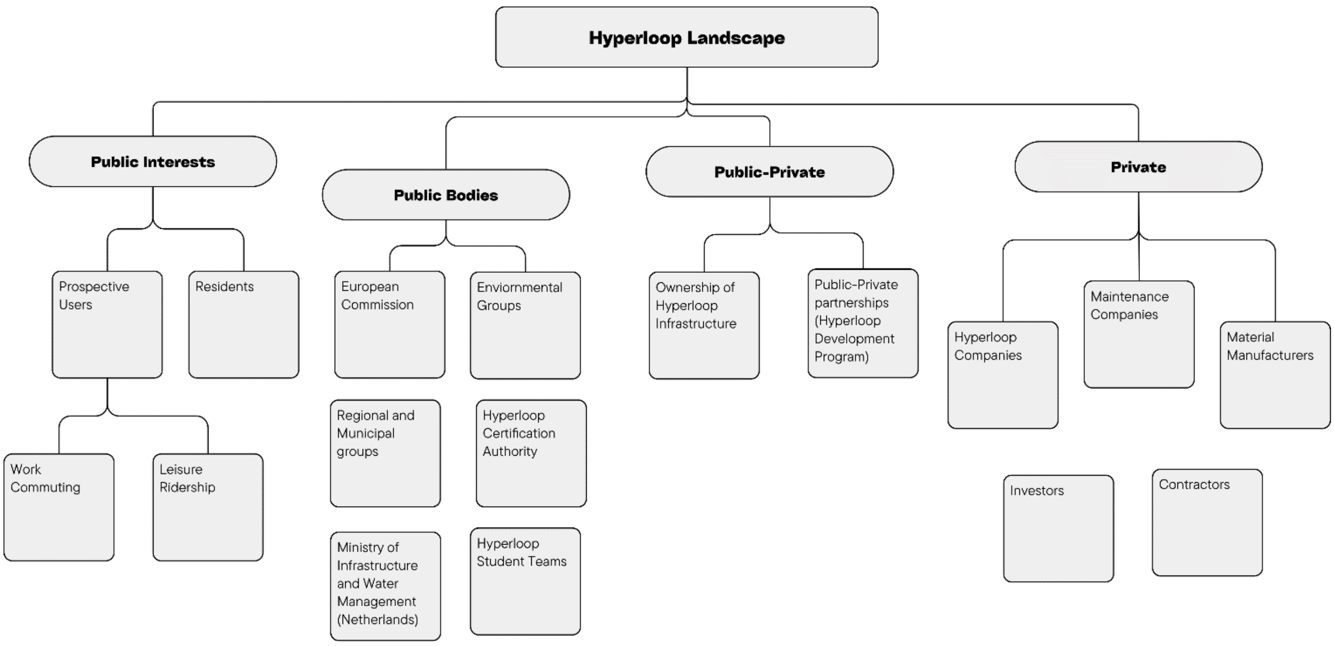

Figure 12. Stakeholder Mapping. Adapted from (Delft Hyperloop 2022a, b)

The stakeholder landscape of the hyperloop involves public stakeholders in governmental agencies and university groups, and private stakeholders for investment. University groups and private hyperloop companies deal mostly with technical development and allocating investment. The future of the hyperloop will necessitate public and private collaboration.

“A public-private partnership is most likely needed, as it is not expected that governments will fully finance the system. However, they will contribute to the project, as a hyperloop offers socio-economic value to society” (Delft Hyperloop, 2019, p. 61).

There is a tension between distributing capital risk to private stakeholders and oversight and subsidization responsibilities upon public stakeholders. What became abundantly clear is that the hyperloop cannot be expediently driven to market. This was noted by Hardt Hyperloop co-founder Mars Geuze:

“(*Hyperloop One) Had venture capitalists in their portfolio ... required them to get to market a lot faster ... we are focused on building relationships with the public sector that can sustain the vision. You must put a lot of energy into building the ecosystem around it to enable our long-term potential. ... They will always choose a technology with multiple providers*” (Geuze)

Geuze highlights here that interorganizational relations need to be resilient, varied and long-term. Describing the hyperloop space as an ‘ecosystem’ reflects the symbiotic relation of private and public actors. Europe’s more ‘defensive’ approach speaks to the hyperloop’s hefty cost and risky business case for investors, requiring prudent governmental oversight and support. The Dutch government is not a primary financier, but a critical yet cautious incubator awaiting to see how the technology develops:

“*We (Dutch Government) are not the big spenders on hyperloop ... industry is investing. We have some innovation subsidies, maybe 10-15% of what is going on*” (Mink)

Public-private partnerships are therefore a necessary bridge; The Hyperloop Development Program is the most comprehensive example of such in the Netherlands, as shared by Julian Koot of Delft Hyperloop.

“*There is the Hyperloop Development Program, and we are one of the stakeholders ... within them ... Tata steel, Hardt Hyperloop, NS, KLM, Prorail ... there are all kinds of companies that want to be involved ... we’re not one of the big players, but we have the ideas and like to be creative with what we’re doing*” (Koot)

It became clear that open, non-exclusive and good-faith collaboration is key to innovation. This was also reinforced by policymaker Eduordo Felici, noting a tentative network will necessitate collaborative engagement:

“*To create a network ... You will need to collaborate with your competitors ... it is not a winner-takes all*” (Felici)

This applies to innovation within the hyperloop, but also other contexts, like HSR. This was highlighted by Valentijn Vlek, informed by his experience in HSR business development:

“*You cannot regulate innovation or further development, that is trust and cooperation between government and private carriers*” (Vlek)

The assortment of such large firms and government ministries collaborating on a relatively niche technology reflect the centrality of innovation in mobility policy and business in the Netherlands. As noted by Eric Mink in the Ministry of Infrastructure:

“*When we started in 2017 ... our goal was to accelerate innovations in all mobility fields .... The Netherlands is a strong country when it comes to engineering, but most of the smart mobility was not designed by our engineers ... Having a new concept like Hyperloop in your country attracts new talent .... Not yet the Silicon Valley of Europe, but* *could be a bit of Silicon Valley for mobility within the Netherlands … maybe in Europe, depending on success of Hyperloop and spillover companies*" (Mink)

Evidently, innovations like the Hyperloop in the Netherlands are perceived as magnet for talented labor and a driver for developing agglomerations of strategic firms. This highlights the economic benefits wrought in the development process itself prior to deployment. This demonstrates a plausible benefit to national economic aims. There was an observed consensus that the hyperloop is not a 'winner take all' field. The differing vested interests, capabilities and responsibilities of stakeholders must be cooperative adjoined and attended to when facilitating public-private collaboration. Efforts to quickly reach the market and establish a provider monopoly, or inversely a rescindment of governmental support, will ultimately undermine any prospect of a scalable network.

5.1.3. Regulation and Standardization

Regulation remains a necessary and unfulfilled prerequisite. The question of what the timeline will look like varies. Estimations from policymakers placed predictions in around 5 or 6 years:

> *"Gut feeling … within 5 years there could be certification and standardization in place"* (Mink)
>
> *"6 years will bring clarity on certification and the pool of money available to build something"* (Felici)

Hyperloop standardization is largely discussed as a European-wide certification, a necessary regulatory scope to enable international network expansion. Arjen Jaarsma, experienced mobility industry professional, has worked closely with the concept:

> *"There is interest in the European Commission … we need more of the vision, how to transition from a high-speed rail network to a hyperloop, will they coexist, freight or passengers … I saw a vision from the Dutch government last summer, it was very vague"* (Jaarsma)

This exemplifies that regulation is tethered to the clarity, or lack thereof, of the hyperloop vision. The distinction between what components are necessary, and what aspects have margins for adaptation, will make clear boundaries as to not only how the technology will optimally and safely operate, but what freedom developers and government bodies have in designing and implementing the technology:

> *"The technology is going to be there … but having a modular system, that will take a while … what are the soft things behind it … it is really moving towards how do we use this thing, but now it is what we do with the European system … where do we put this system"* (Scheepens)

Regulation will necessitate answers to the questions posed by Jorg about how it will work and where it could go. The key regulatory barrier lies in the creation of a "European Hyperloop Agency" that will be "essential for the standardization and certification within the European hyperloop network" (Delft Hyperloop, 2022b, p.20). Mars Geuze, co-founder of private developer Hardt Hyperloop, explains that the regulatory process will involve the pooling of knowledge of expertise of organizations within Europe and abroad:

> "*Were working with … international hyperloop companies … to integrate into a single system …my perception on our collaboration with other companies makes me very comfortable that we will be able to organize*" (Geuze)

It is also clear that prospects for standardizing the hyperloop could also look to existing standards for reference:

> "Legislation can be derived from (Maglev) trains and aircraft, as these share various similarities with the hyperloop" (Delft Hyperloop, 2019, p. 63).

The necessary regulatory direction is understood, but the steps to it are unfulfilled, although this is expected to change relatively soon. The lack of concrete regulation does not hinder speculation around the technology's timeline. Predictions range from a hesitant 2080 or end of century market, as Arjen expressed, or alternatively optimistic accounts predict 2030 for a pilot and 2050 a network thereafter (Berenschoot, 2021).

The hyperloop, in its conceptual and technical immaturity, galvanizes optimism and dedication through refining the synergy, interest and vision of actors onboard. It was clear that 'hype' around the hyperloop is a substantial factor in attracting policymakers:

> *"There was so much hype around it, and there was quite a momentum a few years ago, but now a few years further down the road, but now we see quite … a lot of people are losing interest in the concept … Many people who are decision makers in the mobility and transport field consider this as a nice toy, something for the future … put some money in form of pilot project, but nobody really sees it as a promising network for the coming decades"* (Arjen)

The hyperloops prospects for realization are tied to its legitimacy in being seen as more than a 'toy' or 'something for the future.' Policymakers, especially those not working formally with innovative technologies, have seemingly lost novel adoration for the concept, and do not currently observe immanent opportunity for its implementation. The government has subsidized a test track, and the 2013-era of momentum will not be reincarnated through promises. Arjen earlier shared the Dutch government has a vague vision for the technology. Any tentative hype from the present forward will need to exhibit feasibility and demonstrable opportunity to revitalize interest.

5.1.4. Land Use

Land-use is also an important legitimizing characteristic. The hyperloop is assumed to necessarily overcome a latent and widespread "fear of the unknown consequences of innovations" (Delft Hyperloop, 2023, p. 2). In terms of spatial implementation, the hyperloop has been consistently posited to integrate with existing road or rail corridors:

> "*In a country like the Netherlands … it is quite easy to Implement with existing rails, over existing highways … its on tubes, its on pillars. Anything that takes up land takes time*" (Felici)

This vision was further explained by Julian:

> "*The vision delft hyperloop has … integrate into systems in place already … we see it the same as a train track … build it along a highway, perfect*" (Koot)

This would allow an unobstructed and above-ground tunnel to mesh within already established rail or road corridors. However, the desirable spatial manifestation of the hyperloop differs between urban and rural contexts. Within urban contexts, the hyperloop is conceptually geared to integrated and multi-use deployment. One model below illustrates how underground tunneling would allow for public space to exist above.

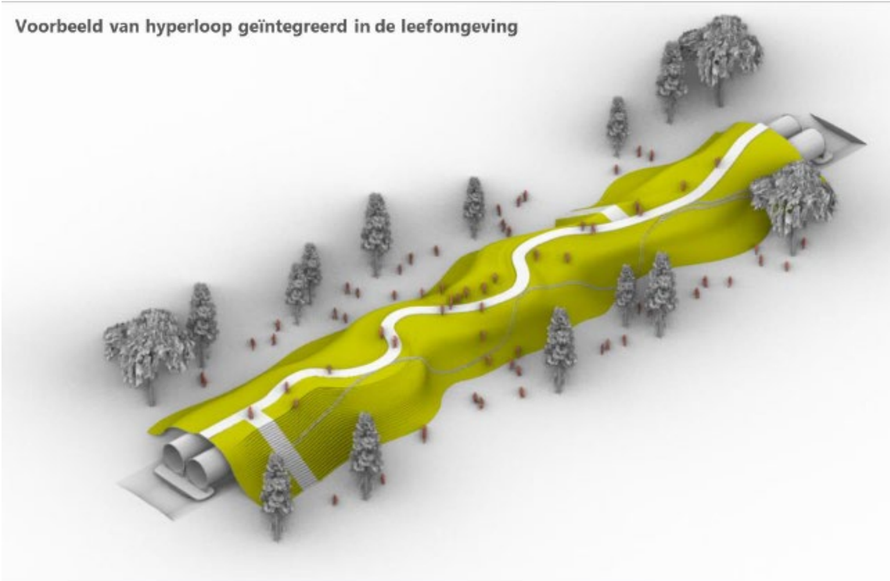

Figure 13. Mixed-Use Public Space (Hyperloop Development Program, 2024)

As the hyperloop is already economically intensive when built unobstructed above ground, terraformed or specialized segments could present substantial cost increases (Delft Hyperloop, 2022a). It remains clear there is a focus on connecting and reclaiming value through residential, commercial and leisure facilities (Delft Hyperloop, 2023). See below a rendered vision by Hardt Hyperloop of Amsterdam Central station as hyperloop hub:

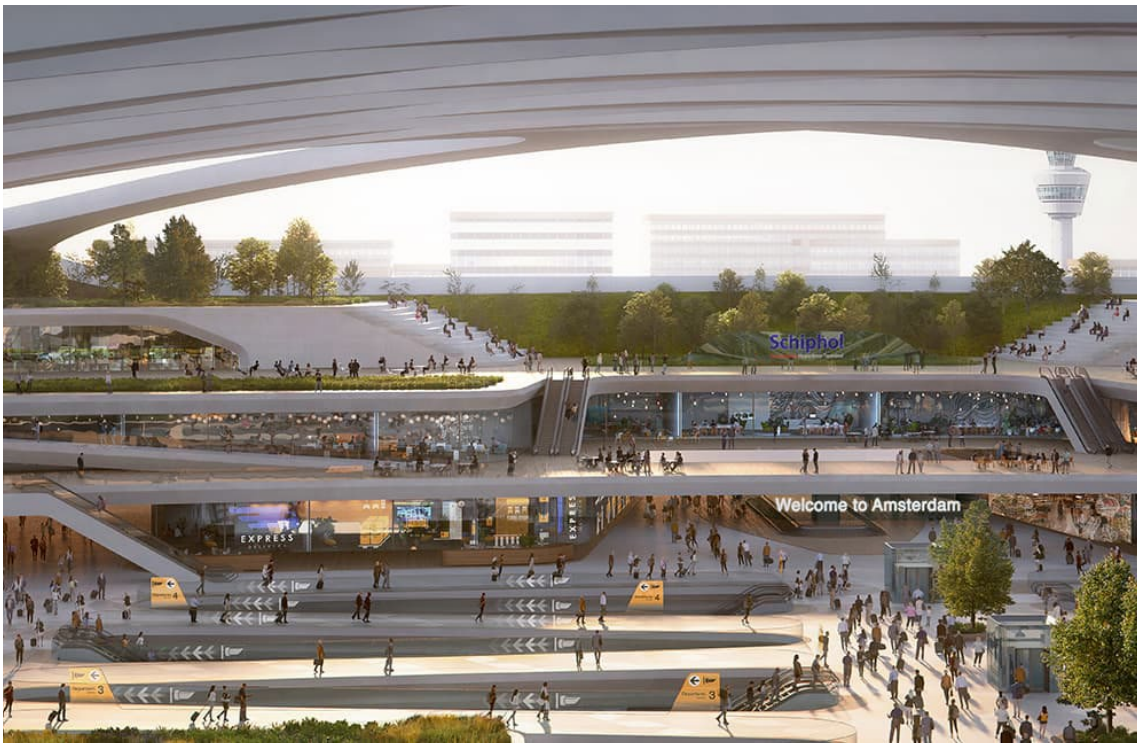

Figure 14. Amsterdam Centraal Hyperloop (Hardt Hyperloop, 2020)

This projection includes complimentary shops, greenery and vendors. Within urban areas, it is expected the Hyperloop would spur land value, and by extent value-driven urban development:

> "Property value increase that can typically be seen when transportation infrastructure is being built ... higher attractiveness of properties ... connected to hyperloop hubs" (Hyperloop Development Program, 2021, p. 47)

Rural areas present the difficulty of circumscribing or penetrating local communities and settlements in an amicable manner. Similar to Figure 13, masking or camouflage strategies could "cover the tube with soil and vegetation" in rural areas (Delft Hyperloop, 2023, p. 15). Additionally, there are speculative innovations that could increase utility of hyperloop infrastructure, such as relieving overloads in the power grid and lining the tube with solar panels and advertisements (Delft Hyperloop, 2023). The attention to integration, unobstructive design, and multi-use purposing reflect efforts to attention to "avoid social and natural segregation" (Delft Hyperloop, 2022a, p. 12). Procedural justice through land-use deliberation would be additionally difficult given the technologies obscurity in public discourse. Thus, these land-use predictions are speculative and untested in arenas of public opinion. Furthermore, the hyperloop is primed to exist as a network of 200-300 km distances, as "*over 800km there is a lot of cost in infrastructure*" (Koot). A growing hyperloop hub network will increase the complexity and importance of multi-level stakeholder arrangements and citizen involvement between increasingly varied contexts.

5.1.5. Public Acceptance

Public perception is being increasingly researched (Delft Hyperloop, 2023). The will and want of people are simultaneously uncertainty, driver and barrier of realization. Uncertainty around the technology is a prime concern, and planned to be mitigated through research and knowledge diffusion:

> "Potential hyperloop travelers care the most for travel costs and time, sustainability, and safety ... The market acceptance of the hyperloop can be enlarged through the user's knowledge... through the provision of additional information" (Delft Hyperloop, 2023, p. 3)

Furthermore, positive public perception was tied to criterion of affordability, timeliness, sustainability and safety (Delft Hyperloop, 2023). The hyperloop's public-facing challenge is in enlarging knowledge around how the technology will deliver on its promised use-cases. However, even with the identified significance of positive public perception, this was not a current focus of current hyperloop stakeholders:

> "*We are not really looking into how we will get the public involved ... people when confronted with it, everyone is positive and supportive, but when confronted with consequences of it, you can see it in your backyard, and there needs to be construction, then they get against it*" (Scheepens)

This highlights a recurringly expected issue of 'NIMBYism', where awareness and familiarity with a technology struggle to translate into acceptance and support in its realization. It is seen Hardt Hyperloop has begun efforts to make the hyperloop concept visible, such as through an experience center, but this is directed more towards onboarding partners:

> "*We have things like an experience center, so anyone who is interested can learn more about the hyperloop, but we mostly use that to target more direct partners to get on board*" (Geuze)

So, cultivating awareness and interest in strategic private or public stakeholders, rather than the public at large, appears more necessary at this moment. The public perception approach most evident is that self-interested protectionism (NIMBYism) will decrease, and positive perception will increase as knowledge around it is disseminated its advantages in price, safety and timeliness are recognized in line with people's transit needs.

5.1.6. Funding Structure

As explained earlier, the costs largely reside upon private stakeholders in investing in the technology. Valentijn Vlek outlines the centrality of private stakeholders in providing finance and expertise:

> "*I think we need more PPP, we need cooperation of the EU. You need money from private parties, expertise from private parties. The government doesn't know anything … you need private parties*" (Vlek)

From an HSR perspective, Valentijn affirms the impetus for EU and Private-Public collaboration, but aggrandizes the role of private stakeholders in both capital and knowledge. The hyperloop arrangement differs, as university working groups are formative in hyperloop research and development (Delft Hyperloop, 2019). So, research expertise is not solely a private competency, though operational expertise may be down the line. As of now, cost estimations are notoriously difficult:

> "*In terms of cost, really, the construction costs, the figures vary a lot … we've heard estimates they match HSR … but there have also been some signals it could be cheaper … We will need more test tracks … it's all over the place*" (Felici)

This uncertainty was repeated by Delft Hyperloop engineers, albeit also optimistic about signals the price could decrease:

> "*Every research says something different, but there are indicators it can be affordable*" (Scheepens)

Nevertheless, the largest strain that will be faced upon funding the hyperloop is in scaling it. Socio-economic benefits only become significant when a network is established. Reports found that single routes struggle with feasibility, while international routes prove more viable:

> "… the entire Amsterdam-Frankfurt route is technically and financially viable, the standalone Dutch segment doesn't align with feasibility" (Hardt Hyperloop, 2018, para. 36)

The possibility of forthcoming contributions to the Hyperloop model reflects the positions held by Hardt Hyperloop co-founder that stakeholders must have a long-term vision for the project's success:

> "*One thing that has changed is the perception of when it will be there … when venture capital is driving, it always seemed it was two years away every year … the market at general has now taken a more realistic approach it takes time to develop something like this*" (Geuze)

This 'realistic approach' avoids speculative and bad faith promises that spur sensationalized attention or hype. More so, stakeholders attune their capacitates and needs to that of the technology. Such is reflected in Tata Steels arrangement to develop the high-grade and resilient steel tubes, those of which are currently under use in the Groningen test facility (Bam, 2022). Companies like Tata Steel (material provider) and Schiphol (possible client) are active stakeholder in the Hyperloop Development Program (Berenschoot, 2021). Schiphol is also a key partner as the airport exhibits interest in a hyperloop route that could release passenger volume burdens (Hardt Hyperloop, 2020). The immaturity of the technology presents an opportunity for stakeholders to solidify an early position in reaping unforeseen benefits down-the-line.

5.2. Competing Mobility Regimes: Rail and Short-Haul Aviation

The next relevant dimension of the hyperloop system is in how it will develop in relation to existing mobility regimes as the technology translates a niche technology into a prospective mobility system. It is necessary to establish the projected cases for how the hyperloop interacts with each mode differently. In regard to rail, it is primed for complimentary capacity:

> *"We want to shift more towards rail, but the hyperloop would simply an additional modality that has additional capacity that will integrate into the rail network" (Geuze)*

However, regarding Aviation, it is promised that the hyperloop could supplement short haul aviation.

> "*HSR will never really compete with short-haul flights … the main (hyperloop) substitute case is short haul aviation*" (Geuze)

Evidently, the hyperloop aims primarily to complement rail transport and substitute short-haul aviation, bringing about a more sustainable shift in transit from emitting to electrified European transit. The hyperloop's push to integrate with existing mobility hubs will likely differentiate and enrich opportunities for ground-zero transit decisions:

> "*Something on top, sort of the fifth modality … might replace some (continental) flights, some long-distance trains, but really optimize the way you differentiate between transport modes*" (Felici)

It is furthermore important to acknowledge existing EU-wide initiatives. The TEN-T proposal is the most comprehensive EU-wide directive, guiding member states to contribute to a two-part roadmap for HSR rail throughout Europe. The progress made on this proposal, originally codified in 2013 (EU Monitor, n.d.), is not as envisioned:

> "*TEN-T deadlines … I have no confidence at all we will make those deadlines … the problem is there is no money to build that high-speed infrastructure … lots of infrastructure investments needed to get it on time … for example connections with Netherlands (and Germany), there are routes they don't want to put money in, they (Germany) start lobbying to get those routes removed"* (Vlek)

Vlek identifies key problems that hinder the success of HSR as laid in TEN-T guidelines. This speaks to the ostensible advantage of the hyperloop in transcending the patchwork problem, as touched upon by Arjen, who is well-versed in European mobility predicaments:

> "*The railway network in the east, it really is a patchwork … every country still has its own national operator … this patchwork is there, and we need out of the box solutions … the nice thing about the hyperloop is that it is building forward without looking at national systems*" (Arjen)

Challenges in funding and organization of the TEN-T HSR network, leveraging an already existing technology with an established market of vendors and operators, brings to question what capacity the EU would have to effectively realize a parallel and complimentary megaproject, especially being its largely posited to be operating by 2050 as well (Berenschoot, 2022). Although, upon standardization, presenting an easier cross-border mobility solution could plausibly increase competitive advantageousness. Sourcing a funding vehicle capable of affording a trans-European hyperloop network while HSR struggles to do so would require ample venture capital and likely spur tensions with HSR investors and advocates.

5.2.1. Emerging Innovations

The nebulous hyperloop timeline is susceptible to innovations in competing regimes. Valentijn Vlek framed the hyperloop as contingent on the ill-suitability of existing modes to meet sustainability demands.

> "*In 50 years' time I think we can fly electrically between European Countries. It is only a temporary discussion we are having that people should not fly. If flying was sustainable, why would you buy infrastructure for HSR, or hyperloop*" *(Vlek)*

On the other hand, Mars Geuze did not perceive developments in sustainable flight as a concern.

> *"We will be able to fly electrically or have sustainable fuels ... if you look at the numbers required to do that, where Lufthansa says they would require half of the sustainable energy in Germany to fly their own planes, that won't allow us to become sustainable"* (Geuze)

The tension here is in the credulity of innovations in aviation, whether biofuel or electric aviation, to cement the industry's standing and inadvertently constrain the business case of alternative modes like the hyperloop.

5.3. Landscape Considerations

5.3.1. International Efforts

The hyperloop concept was identified to have a unique potential for realization in the Middle East. Regional advantages could suit quicker deployment. Comments of such belief were captured by one professional with specific experience working in the region:

> "*I think to a certain extent it will happen ... in the middle east ... oil-sponsored project with all these huge megastructures, one of these structures is called the line, 1km wide ... I kind of believed a few years ago the first hyperloop would be built in that region. Decisions are made from the topic there is no democracy, land acquisition outside the cities ... one big dessert* "(Arjen)

As explained above, natural benefits to the region in land-use, available funding and top-down governance provide strong suitability for realization. Although an opportunity to demonstrate feasibility, it presents clear ethical considerations as well:

> "*The middle east may not be an ethical project, with all the oil money, but it will be nice to have to show you can implement elsewhere*" (Koot)

This tension between an ethical and efficient development will evolve as the undergoing hyperloop projects in Saudi Arabia formalize. The degree to which non-European projects could establish transferable precedent and expertise is uncertain, but could prove useful to demonstrate its feasibility.

5.3.2. European Geopolitics

It is critical to consider how political landscape dynamics influence how the hyperloop is evaluated. As the hyperloop aims to connect Europe through a modular and interoperable structure, the question remains as to if member stays prioritize the investment, and furthermore deem an EU-wide system as desirable amidst rising euroscepticism. Russia's invasion of Ukraine, spurring increase in NATO funding, could decrease interest in non-strategic development opportunities.

> "*The rise of populist movements in Europe is not good for infrastructure, that is definitely the case ... I think Europe is strong enough to overcome separate nationalist movements, populism, and still strive for a European community ... The geopolitical situation is a much bigger threat in my view. If we need to increase our budget for NATO, ... different countries in Europe are changing from a regular economy to a war economy*" (Arjen)

Arjen explores here how growing fervent nationalism and security investment needs could deter the budget and political will behind new international transit initiatives. Populist political triumph could put efforts for a connected Europe at risk. Nevertheless, disadvantageous shifts in the landscape are not necessarily an existential threat:

> "*Being on your toes, and being perceptive of what is happening in the world... when the times are bad ... there is a focus on other things and maybe there is less funding available, that isn't a time to grow, but a time to focus on making the right partnerships that are needed, ... so you have a superplan with the right team to start executing that*" (Geuze)

The responsibility of adapting to a changing landscape of energy, national politics and policy priorities is not necessarily a 'death sentence' to innovation, but more so an indicator that hyperloop stakeholders need to organize and await an opening for realization, reinforcing the importance of resilient, well-partnered collaboration.

5.3.3. Energy and Material Intensity

The implication of hyperloop construction upon global supply chains is left underexplored. The ecological impact in upstream segment of the supply chains are a recognized concern, as noted by Jorg Scheepens of Delft Hyperloop:

> "*It's a paradox ... one of our main selling points is it is very sustainable, very little energy, very high speed, but the construction is very bad for the environment, lots of steel ... but it is a tradeoff"* (Scheepens)

This exemplified an oft-overlooked dimension of the system in its wider material constraints, the tradeoff here is in if those material costs are justified on the basis that "*In the long run you will gain on it*" (Koot). The social implications around sourcing a high volume of materials from abroad, and the ecological intensity of its construction, highlight the tensions around prospectively asymmetrical benefits and burdens favorable to those who are proximate and endowed enough to utilize it. Although procedural justice is briefly mentioned in hyperloop literature (Delft Hyperloop, 2023, p. 19), the hyperloop's spatial obstruction and material or fiscal intensity are more easily rationalized as a short-term tradeoff for a desirable long-term vision.

5.4. Hyperloop in Social Imagination

The hyperloops construction within social imagination is innately bent upon notions of the future of mobility. These notions are revealed in discourses which illustrate desirable characteristics, values and opportunities enabled in its realization. This research question will be answered through expansion upon the preconceived potential of the hyperloop and its imagined prospects for shaping life and mobility.

5.4.1. The Hyperloop's Potential

The hyperloop, from inception, has held weight as a radical idea, yet to be seen, with the capacity to change the world. Edoardo Felici notes that "*Elon Musk … promised the world*", highlighting the impact of Musk's 2013 white paper. It can be seen foremost that the hyperloop is perceived as a harbinger of a new transport paradigm:

> "*The public transport world is quite a boring sector … and what you see over the last 10 years, with opening the market, or operators with hyperloop, is shaking the sector up, and bringing new talent in, and keeping the transport sector modern, and relevant"* (Arjen)

The insistence on keeping transport 'modern' insinuates our current mobility arrangements struggle to remain relevant and contemporary. The perceived revolutionary potential was furthermore reinforced by Mink, referring it as a defining attribute of the 21st century:

> "*Trains is 19th Century, Maglev is 20th century, and Hyperloop is 21st*" (Mink)

It was seen the hyperloop, at most conceptual, is framed as a product of belief and action within a broader journey:

> "Futuristic, innovative and ground-breaking, according to believers. Obsolete, unfeasible and surrealistic, according to nonbelievers. All these, sometimes conflicting, messages are part of the journey to a completely new mode of transportation" (Bam, 2022, p. 3)

However, hyperloop proponents largely defined their involvement upon rational postulates for its need and positive potentiality. Hardt Hyperloop co-founder clearly explains:

> "*I was personally quite skeptical about hyperloop, so I fully understand the way in which skeptics think about this. I wasn't going to spend my life working on something that was just a technology push. I spent some time looking at what the challenges are facing transportation, and what the business case of the hyperloop would be. I basically came to the conclusion that I don't see any other option to have a sustainable way to allow us to keep travelling the way we do*" (Geuze)

Mars Geuze cites his own skepticism as his original starting point and justifies his change in perspective along rationally informed process of identifying problems in sustainability and transit, and perceiving innovation through the hyperloop as necessary solution. This coincides with the motivations outlined within Delft Hyperloop reports, whereby:

> "The capacity of existing infrastructure does not suffice for the growing demand … current modes of transportation are energy inefficient and thereby large contributors … climate change … A promising solution for these problems is the hyperloop" (Delft Hyperloop, 2019, p. 1)

This reasoning is grounded in a mix of fact and assumption; the foremost fact being the undeniable realities of climate change and the impact of mobility within that. Facts form assumptions when accounting for the predicted increases in transit demand. A driving justification of the hyperloop is that transit is a "*derived demand*" (Vlek) and "each year, people tend to travel further and further" (Delft Hyperloop, 2019, p.1), bearing an increase in the "growth of consumers and their level of consumption" (Delft Hyperloop, 2022a, p.2). These predicted inelastic increases in demand and consumption are to be met and facilitated by the hyperloop.

5.4.2. Shaping Life and Society

The hyperloop, in conceptual formulation, is unrestrained by any geographic constraints, and largely articulated as realizable in any context the drivers for its construction are in place. As shared by Jorg Scheepens, the "*goal is to really make it for everywhere around the world*." Within Europe, this manifests in the often-repeated goal of realizing a European hyperloop network (Delft Hyperloop, 2022a; Hardt Hyperloop, 2020; Hyperloop Development Program, 2023). Nevertheless, the current lack of real implementation escapes practical interrogation and permits technological optimism for what has yet to be done and what could emerge, a state-of-imagination that is attempting to translate speculation to certainty through a process of innovation.

The radical space-time compression forwarded by the hyperloop is unexplored territory. It is understood our ability to move is fundamentally effective upon whom we interact with:

> "*We are greeting different people from different backgrounds, and mobility is playing a big role in that sense, because if you don't have the possibility to travel, where if you can, you can discover new worlds, new friends"* (Arjen)

As outlined in hyperloop literature, some key urban corridors would be rapidly connected. Amsterdam to Frankfurt would take 50 minutes (Hardt Hyperloop, 2018), Amsterdam to Paris would take up to 22 minutes (Delft Hyperloop, 2022b), or 1 hour 36 minutes to Berlin (Hyperloop Development Program, 2024). This form of speed changes the nature of a trip completely. Where a large part or entirety of a day is needed now, the Hyperloop would make a morning and midday commute. Outside of time-savings considerations or attributes around modal selection (Delft Hyperloop, 2022a, b), the embodied impact upon travel habits remains underexplored. Mars Geuze noted:

> "*In countries like the Netherlands … we have a big challenge in housing people and additionally people (entering the labor market) … that could open up a lot of possibilities for the housing crisis*" (Geuze)

Considering domestic stops are needed to make the hyperloop attractive and accessible, the prospect of how people could bridge farther distances between work and home validates the advantageousness of the hyperloop. Similar to how the hyperloop is responding to transit and sustainability demands, it is poised to resolve social and economic concerns as a function of space and time compression.

The mobility utopia whereby market equilibrium meets radical space time compression, ensuring "*everyone can travel anywhere for the price they can pay*" (Vlek), valorizes the hyperloop's vision as plausible mechanism for radical mobility access. The hyperloop vision is constructed not solely through its contained technical or systematic characteristics, but by the society which ascribes it with utility and frames this space-time compression as desirable. The articulation of space and time happens prior, framing and signifying desires for mobility the hyperloop is poised to fulfil. Furthermore, the inscription of value upon speed and hyper-connectivity through material investments in new infrastructures requires a contention with the broader impetus for growth and space management, as elaborated upon by Eduordo:

> "*We're considering eternal growth possibilities … more private cars to the network, adding more flights to the network – there are physical boundaries, whether in terms of nature, emissions … we need to start preparing, mentally as well, where we will approach the system in a different way … trying to optimize the way we use the system. We know there are limits to the system, and we are not yet adjusting them*" (Felici)

Policymakers exhibited understanding that mobility systems must contend with where these "physical boundaries" exist, driving new awareness around assumptions of eternal growth and the role of mobility systems in configuring sustainable living arrangements.

6. Discussion

In abidance to the critical-realistic approach, theoretically and contextually substantiating qualitative findings is necessary. Now that key systematic makeup of a the hyperloop technology as mobility system have been expounded upon, it can be analyzed within the MLP framework as a niche underway to become prospective mobility system, substantiating the findings which answer RQ1.

6.1. The Hyperloop as Socio-technical System

It is important to understand how socio-technical niches are stabilized and contested, and identify what dynamics and drivers are conducive or constrictive towards further development and realization (Geels, 2012). In like with the three-dimensional MLP framework, the hyperloop's trajectory and developmental momentum is formulated within iterative interaction with the broader landscape, existing mobility regimes, and the systems own characteristics.

6.1.1. Green Technologies: Supply-chain and Infrastructure

The hyperloop cannot render invisible the material costs and impacts wrought in its manufacturing and construction. As established in 5.3.3, hyperloop construction would be the most materially intensive part of the process. As explained in 5.1.1, hyperloop scientists are aiming to minimize the amount of strategic materials utilized, specifically by ensuring copper is not lining the entire tube. The overall logic in development now is to develop a high-integrity, scalable and sustainable material that is competitively affordable, durable, safe and reliable. The continued optimization of the system's scalability and resource intensity are a prime focus area. Increasing the affordability, scalability and multi-functionality within energy storage and production aligns with the needs of governments, transit authorities and contractors (Borrás & Edler, 2020), while minimizing rare-mineral (copper) use and optimizing energy consumption align with global supply chain justice aims and renewable energy infrastructure constraints. Socio-ecologically sustainable supply-chain practices are furthermore increasingly tied to organizational resilience and adaptability within the sustainability transition (Di Paolo et al., 2023).

The hyperloop's sustainable potential is reliant on the penetration of renewable electrical penetration, given the hyperloop is much more efficient than an airplane, it still is three times as energy intensive as bullet train or maglev alternatives (Hirde et al., 2023). Albeit Europe is increasing production of renewable energy, having doubled the share of renewable energy sources between 2005 and 2022, share of renewable energy in total energy use throughout the EU in total was averaged 23%, with the Netherlands only ranking 23/27 of the member states at 14.97% penetration, a third of the 45% goal set by the renewable energy directive (European Environment Agency, 2024). This raises concerns for greenwashing real sustainability concerns and highlights the dependency of a prospective system upon existing energy infrastructure. The hyperloop's aggrandizement of sustainable movement and green growth are intricately tied to extraneous supply chain impacts and available renewable energy. Technological innovation cannot be narrativized as a rational arbitrator of unyielding sustainable growth (Gross & Sampat, 2020), but instead a critical mechanism for ensuring a global sustainability transition, attentive to oft-ignored supply chain externalities and increasing energy consumption patterns (Wells, 2018).

6.1.2. Economic Feasibility and Impact

Economic analysis of alternative transit modes predicts the hyperloop to be financially disadvantageous or ambivalent compared to existing modes (Guerreri, 2022). Seen in 3.5, existing research proposes costs between €37 and €59 million per km. It was found that policymakers perceived the costs in the Netherlands as high, and both policymakers and hyperloop advocates see further innovation as necessary to lower costs (See 5.1.6). Existing literature aligns with findings that price estimations are uncertain and context specific. A comparison to the economic feasibility of HSR is useful here. HSR costs can differ vastly depending on land-acquisition costs, geographical challenges, terraforming, and existing electrical infrastructure (Nash, 2015). It is clear many HSR lines do not operate at their technical max potential due to high operation costs or diminishing benefits after certain speeds (Fröidh, 2014). The hyperloop aims to maximize the volume and speed its network is utilized at, and its modular and standardized structure could enable more expedient construction and deployment than rail. An unobtrusive land-use approach (see 5.1.4) would also be necessary to mitigate social opposition. Efforts to ensure a matching or cheaper price relative to HSR include leveraging discounts from scale, innovations upon tube structure, and limiting copper only to the pod (See 5.1.1). This aligns with findings that economic feasibility will follow technical developments in optimizing tube design, pod-linkage and propulsion mechanics (Nøland & Bird, 2024). Notably, innovations into multi-use purposes for energy storage or solar energy production could lower operating costs and prove a public benefit (Delft Hyperloop, 2022b).

It becomes clear the hyperloop will be extremely costly, and returns on investment will take significant time to recuperate (Guerreri, 2022), which is specifically relevant given the significant role of private capital. Furthermore, the hyperloops urban-centric network vision is likely to reap externalities that are tied to the transit of citizens possessing high socio-cultural capital. This entails a plausible rebound effect in sustainable gains through intensifying rates of conspicuous consumption and perceived value of positional goods previously mediated by spatial dispersion (Wiedmann et al., 2020). Regional inequality has increased in the EU, and informs a situation “too politically dangerous to ignore,” whereby there is diverging real incomes, prices and rates of labor force participation within and in between regions (Iammarino et al., 2019, p. 1). While the hyperloop subverts the European patchwork problem in a regulatory dimension (See 5.1.3), it cannot avoid the patchwork of economic differentiation; connectivity between unequal regions can exacerbate a centralization of wealth (Puga, 2002). Given the prediction that the hyperloop would exacerbate hyper-urbanization (Premsegar & Kenworthy, 2022; Delft Hyperloop, 2019), this would also entail it would only be economically advantageous and empowering to denser urban areas. This is stark difference from the HSR TEN-T vision geared towards more holistic intra and interregional accessibility, reinforcing the finding that the hyperloop must complement HSR (See 5.2).

6.1.3. Protest and Public Opinion

There is historical precedent for backlash and protest against HSR megaprojects that are relevant to acknowledge. There has been substantial backlash against HSR in Italy, where a complex array of ecological and locally oriented political movements have taken a strong stance against new corridors (Porta & Andretta, 2006). This protest against the expansion of HSR infrastructure is less tied to private property protectionism and traditional NIMBY-concerns, but is grounded in a rationale of the megaproject’s social and ecological injustices (Esposito et al., 2022). This socio-ecological injustice lies in how megaprojects are conceived through market and political imperatives disconnected from the realities of local communities, creating a perception that collective demands are overwritten or underrepresented, and are ultimately powerless to influence or resist these developments (Strauch et al, 2015). A resentment is built when natural or public space is made exclusive, especially considering the long-term, expensive and imposing nature of the megaproject construction process (Zucchetti, 2022). The resentment is fundamentally one of imbalanced power dynamics. It is clear the structural agency of residents is paramount, and developments without channels of dialogue or mediation face the most intense backlash (Esposito et al, 2022). As so, prospective hyperloop realization would have to contend with the risk of socio-ecological and political resistance from citizens who stand opposite to fiscal and ecological costs or social exclusivity. In terms of planning culture, the process must not rely on the prospects of post-hoc distributional justice (see 5.1.4, 5.3.3), but institutionalized procedural justice. Procedural justice can be ensured through democratized citizen-stakeholder initiatives, and socio-ecological concerns can be remedied by prioritizing multi-purpose land-use integration, assuring sustainable upstream sourcing, and provisioning schemes for accessible and affordable ridership.

6.1.4. Boundaries of Hypermobile Lifestyles

Hyperloop literature at large frames its use through the discernable benefits and expected positive externalities of facilitating leisure and business travel (Delft Hyperloop, 2019). As established, it also assumes public opinion to be a matter of transmitting the technologies advantages into public awareness (see 5.1.5), forwarding a concrete rationale for adoption grounded in the desirability of sustainable and high-speed transit. Notwithstanding broader socio-ecological critiques, the hyperloop prompts exploration into what a hyperconnected Europe would look like, and questions of what groups would utilize it the most.

Mobility modes are in part defined and lived through the lifestyles they enable, bringing attention to the impacts of consumption and production facilitated through mobility. Tourism, for one, has outpaced the growth rates of the entirety of international trade, driving increased draw on transit demand alongside the production tourism-centered goods and services. Growing mobility demand has a significant carbon multiplier, accelerating emissions in various industries simultaneously (Lenzen et al., 2018). The existential imperative to consume, as explored in theories of conspicuous and positional consumption, is a socio-cultural interlink between material affordances, socio-economic positionality and identity construction. Highlighted in 5.4.2, the hyperloop must contend with the material and spatial limits of our world – the hyperloop's promise to facilitate increasing "growth of consumers and their level of consumption" (Delft Hyperloop, 2022a, p. 2) needs to contend with the fact that "*we know there are limits to the system, and we are not yet adjusting them*" (Felici). Furthermore, there is a disproportionate increase in biophysical resources driven by consumption. The predicted sustainable level of consumption emissions per capita is 0.2 of our world's average, with Europe rating 2.1 above the average (Chancel & Piketty, 2015). The core challenge is in imagining a decoupling of our consumption habits and lifestyles from economically rooted imperatives of growth, and consumption-driven notions of affluence (Wiedmann et al., 2020), lest we deceive ourselves that sustainability is achieved by electrifying asymmetries in our status-quo.

6.1.5. Regime patchwork: Air Travel

It is evident the Hyperloop is primed to compliment and disincentivize air travel. This was found in both key documents and interviews, as seen in 5.2. Aviation is responsible for 2.5% of total carbon emissions, threefold more intensive per passenger than bus and rail, but similar to automobiles (Capaz et al., 2023). The EU remains steadfast in a standardized and preponderant 'open skies' policy that developed in the 1980s, congruent to the role of aviation in facilitating neoliberal economic development. Sustainability interventions in aviation, such as mandated emissions trading, remain heavily opposed by the industry (Dąbrowski, 2014). While aviation demand has tripled over the last 30 years, and emissions doubled since 1990, there is political inefficiency of regulating international industries through discrete national policy framework, further encumbered by explicit resistance against regulating and curtailing aviation (Lai et al., 2022). National policies that ban short haul flights, as France has done recently, can prove effective at reaching net-zero transit sector objectives extremely quickly (de Bortoli & Féraille, 2024). Albeit unpopular, directives to tax or scale-down short haul aviation could mobilize financial resources and incentivize alternative and grounded modalities. This would prove extremely beneficial for a prospective hyperloop substitution of short-haul aviation.

6.1.6. Regime patchwork: Road & Rail

As established in 3.3, The European Court of Auditors (2018) highlights that the EU lack enforcement mechanisms for ensuring member states comply with set mobility goals, contributing to the patchwork predicament. This aligns with findings in 5.2 that express uncertainty over the feasibility of the proposed TEN-T HSR network. Firstly, the funding and construction necessary for the TEN-T vision are not as desired. Some member states have failed to follow through on provisions for shifting away from road traffic (Pape, 2020; Thaler, 2024), and continued disproportionate investment into automobility-oriented roadway expansion and maintenance could draw funds away from alternative infrastructures (De Freitas & Blum, 2023). Secondly, there remains a substantial lack of financial instruments contributing to pay the estimated €500 billion and €1.5 trillion necessary for 2030 and 2050 rail visions. Priority of cross-border corridors have fallen due to bottlenecks of complexity in cost and management (Luica, 2018). While the TEN-T vision is aiming for 65,000 km of rail by 2030, and 119,078 by 2050 (European Commission, 2021), the hyperloop network is predicted to be around 19,700 km of bi-directional tube between urban nodes (Delft Hyperloop, 2019). In this way, a direct comparison is difficult, as HSR costs per/km are being invested to a fundamentally more comprehensive ends with increased scope of service. It also reinforces the position of hyperloop stakeholders in complimenting rail in key corridors, while could substitute short-haul city-to-city flights. Nevertheless, the follow through behind the TEN-T corridors will impact emerging hyperloop business cases when computing passenger demand and route planning, and both TEN-T and continued roadway work will draw away funds or subsidies.

6.1.7. Landscape: International Collaboration

The high-initial costs, uncertainty and urgency around standardization necessitate a collaborative organizational ethos to innovate effectively and mitigate risks. At this point, no single provider can or could succeed by taking a monopoly position, evident in 5.1.2. Whether this will hold true in the future remains to be seen; patents and intellectual property claims on hyperloop technology in the EU are not yet clarified. American company Hyperloop TT has filed up to 60 global patents as of 2023 in the objective to standardize and crowdsource innovation (Securities & Exchange Commission, 2023). There are also large patents being made by companies and universities in China and Korea (Spencer & Whitfield, 2020). As outlined in a report conducted for the Dutch Ministry of infrastructure, down-the-line exclusive rights or payment schemes to key mechanisms in the Hyperloop could incur additional costs or spur second-best decisions around its design (ARUP et al., 2017). How European and international hyperloop stakeholders will go about delineating rights and ownership of key hyperloop mechanisms will drive or hinder its prospects. This driving discourse of coordinated and inter-reliant collaboration is susceptible to change as the technology matures and stakeholders etch out secure positions or profitability within its future.

6.1.8. Landscape: Fungible Innovation

As outlined in 5.2.1, the prospect of radical innovations in alternative modes of transit could drastically impact the feasibility of a hyperloop, the most notable being progress in electric or sustainable fuel for short-haul flights. Aviation particularly is undergoing a coordinated push to evaluate and consider sustainable fuel alternatives that could meaningfully mitigate emissions (Capaz et al., 2019). These fuels are not widely used, and are commercially unviable due to high price and limited volume. Hybrid or electrified aviation are furthermore gaining taction, albeit still in extremely early stages. However, these innovations would likely be utilized for short-haul purposes far before long-haul use (Bauen et al., 2022). While biofuels remain commercially unfeasible, they are expected to be piloted by 2030 and develop thereafter given policy support and incentives are in place, while electric aviation remains farther away (Ansell, 2023). The hyperloops potential of supplementing short-haul aviation in Europe could be jeopardized if incumbent aviation stakeholders accelerate and facilitate development and implementation of new fuels. This innovation would be 'fungible' in relation to the hyperloop – that meaning the beneficial properties of the hyperloop can be upended and overwritten in the face of an interchangeable and more preferrable innovation in aviation. The challenge of ensuring the hyperloop grows beyond a "*temporary discussion*" (Vlek) resides within how fast the timeline is realized to resist destabilization, and how its innovations compound to not solely compete with but systematically overshadow incumbent mobility regimes.

6.1.9. Landscape: International Actors

Evident in 5.3.1, the gulf region is a particularly ripe context for hyperloop development. Firstly, Gulf States are more inclined to invest large sums into transformative megaprojects, well-evident in the region's rapid urbanization approach (Aoun & Teller, 2016). Secondly, the project would evade the challenges innate in a stakeholder consensus approach due to top-down governance (Hertog, 2013). At this current stage, the UAE and Saudi Arabia have both expressed concrete interest in the technology, and are partnering with European hyperloop firms (Zeleros, 2021). Saudi Arabia has already taken decisive action to construct a hyperloop system in Jeddah (International Trade Administration, 2021), as well in the NEOM industrial city, two urban settlements under construction (Systra, n.d.). This exemplifies the relation of European Hyperloop companies with the project's realization in the Gulf States, and highlights that the hyperloop's cost burdens and testing constraints be resolved through a reverse spillover from other areas. Gulf actors work emphatically to uphold a specious and sterile image of being "transparent, humanitarian actors with efficient funding mechanisms" (Yaghi, 2024, p. 1). Collaboration may spawn critical discussions pertaining to underlying ethical and political implications.

6.1.10. Landscape Interactions: Geopolitical Forces

Furthermore, The EU policy landscape is shifting amidst the Russian-Ukraine war, whereby 'peace policy' dividends and military divestment is no longer guarantee of national security. There is an urgently growing reprioritization towards defense spending and energy independence (Borrell, 2024). The energy security push could prove to incentivize renewable energy resilience (Hosseini, 2022). Renewable energy policy will also embolden military related energy applications. This elicits another site of discursive struggle, where national security needs are forcing an energy transition, but at the same time reinforcing historically rooted imperatives for economic competitiveness and national security that undermine efforts to democratize and facilitate long-term developmental aims (Sovacool et al., 2019). Megaprojects can inversely be utilized to feign consensus and convey the solidarity of dominant political organization in austere and conflicting conditions (Vento, 2024). It is clear this macro-level shift in political priority may spur energy independence, but the prioritization of security investments may induce fiscal constraints for subsidizing niche innovations (See 5.3.2). It remains currently uncertain if the hyperloop could deliver a politically attractive megaproject. Furthermore, Euroscepticism and reactionary political forces could delegitimize and erode visions and momentum for inter-European mobility (Jensen, 2013), as expressed in 5.3.2. Striving for a hyperloop-enabled 'connected Europe' would necessitate and animate imaginaries and actor coalitions directed towards European integration.

6.2. Hyperloop in Socio-technical Imagination

The 'imaginary' of the hyperloop and the vision around its realization is both a legitimizing and illustrative social artefact beholding a particular aesthetic and catalyzing extant socio-cultural notions and ideals around movement, prosperity and the future (Jasanoff & Kim, 2015; Wiig, 2019). The hyperloop is a dynamic innovative anchor point by which scientific knowledge is being translated into prototypes fabricated for wider prospective implementation (Wesselink et al., 2013), preconfiguring our sensitivity and sensibilities to the technology through social imagination. In answering RQ2 and understanding how the hyperloop is constructed in social imagination, one must understand how the hyperloop imaginary functions as political resource, conceptual vehicle, subjective catalyst, and mechanism attesting trajectories of economic prosperity and experiential fulfillment.

6.2.1. Imaginaries as Legitimizing Force & Political Resource

As found in 5.1.5, Hardt Hyperloop has largely oriented experience centers and outreach efforts to onboard possible partners in industry and government. This fulfills a strategic purpose through including key stakeholders with relevant influence and means. It was also found to be lacking attention and 'hype' it held few years prior in policy circles, as seen through Arjen Jaarsma in 5.1.2. This effort would need to be developed to inspire policy entrepreneurs capable of persuasively and authoritatively advocating the hyperloop proposition and vision.

As the legitimacy of the market as a just and equitable adjudicator of development is dissipating, trust in the prospects of market-driven technological innovations will fragment (Beckert, 2016). The hyperloop imaginary anticipates a future just as much as it embodies a toolkit on how to understand the present. Its political legitimacy and public legitimacy may diverge; the former will be cultivated upon the basis of what it can feasibility contribute to national interests, while the latter will render visible heterogenous and geographically differential needs, concerns, and attitudes to how the imaginary intersects with lived experience (Upham et al., 2015). The question is not just 'is the hyperloop a reasonable solution,' but also 'is the world investing in the hyperloop structured in a sustainable and just way.' This is reflected above in 6.1.3 in acknowledging growing backlash and resistance against transit megaprojects. There will be a horizon of visions around the future that emerge from epistemologies critical of accelerating the velocities of movement, privileging the capabilities of the hyper-mobile, and emboldening the purview of private stakeholders over strategic infrastructures.

6.2.2. Conceptual and Contextual Articulation

The question of how high-speed networks are desired is a function of material or fiscal surplus, immediate needs, and the distribution of prospective benefits relative to the capability of whom can afford it. The hyperloop is emerging within a long-term vision of scaling beyond Europe, prospectively servicing mobility needs wherever applicable (See 5.4.2). The hyperloop is tentatively suitable within the European context due to the political will and competency of member states and supra-national guidance provided by the EU, as exemplified in existing TEN-T efforts and the political and cultural precedent for cross-border transit and connectivity (See 3.3 and 5.2). High-speed transit is contextually rooted within the infrastructural precedent, political competency and economic capability of national actors to invest and maintain these technologies; This makes a universalized 'global' perspective around mobility difficult, as high-speed transit is not an inalienable human right but a configured privileged and achievement (Cranston & Duplan, 2023). The promise of a 'flattened' geography of speed is irreflective of disparities and differences in wealth and opportunity between and within regions (Ochungo, 2021). While the hyperloop imaginary is conceptualized as an interoperable and transferable technology, its feasibility remains tied to context-specific political competencies and funding vehicles not afforded in global asymmetries.

6.2.3. Creating Subjectivity

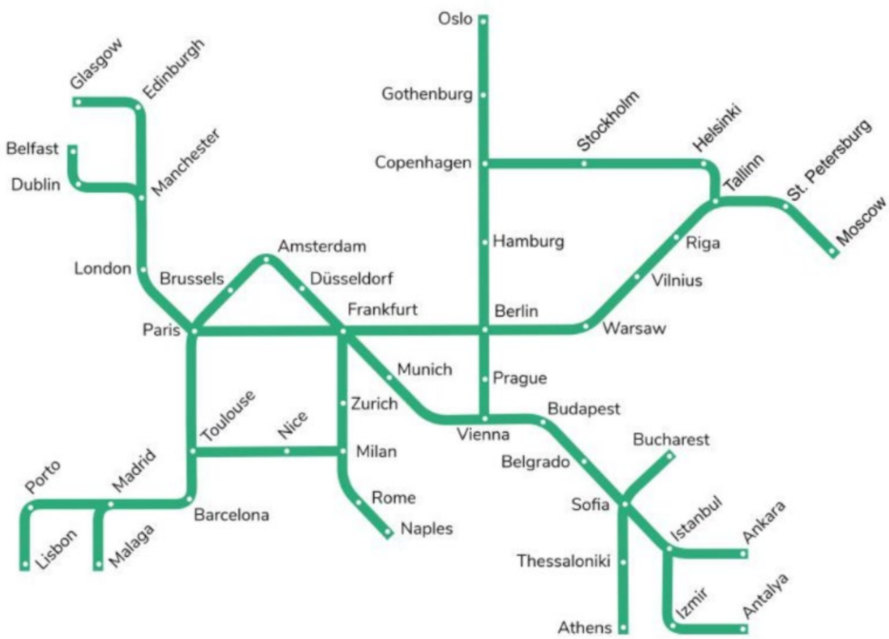

Figure 15. European Hyperloop Network (Delft Hyperloop, 2019)

The aforementioned 'privilege' of high-speed transit is innate in both construing visions of the world and framing the experiences of subjects within them. As shared in 5.4.2, the guiding vision of the hyperloop is for it to be a global transit medium, a reality enabled by its modular and networked structure. The hyperloop worldbuilding formula is conceptualized more access for more people at higher speeds; That is illustrated in Figure 15, projecting a network with 48 cities ranging Ireland, Turkey and Russia. This arrangement would foreseeably valorize social and cultural capital, where individuals with the socio-economic dispositions necessary to navigate, enjoy, and leverage these mobility arrangements both utilize and thrive the most from their affordances (Igarashi & Saito, 2014). Hypermobile arrangements invertedly match the virtual immanence of digital connectivity to our corporeal mobility practices; a subjectivity of 'post-national' cosmopolitan citizenship is evoked in discourses of hypermobility, where a new frontier of digital workers, entrepreneurs and knowledge workers circumvent geographical boundaries with ease (Molz, 2005). While transit developers establish a business-case around travel as meeting derived demand to move and consume (see 5.4.1), hypermobility as a modality will imbue immediacy into the nature of how business, pleasure and experience are instantiated and structured. Desirable 'speeds' of movement are socially constructed and grounded in technological affordances and hegemonic logics of intensifying the volume and velocity of social activity and productive opportunities (Pelgrims, 2019).

Figure 16. Hyperloop Interior (Hardt Hyperloop, n.d.-a)

High-speed transit, whatever the modality, evokes sensory experiences. The hyperloop's desirability is not just formed by prospective benefits, but through imagining an unforeseen and unprecedented mobility experience. Landscapes of movement are fundamentally experiential, embodied and lived (Jensen et al., 2011, 2013). The aesthetic dimension of space-time compression are essential products of how these modes of transit are socially engrained and culturally significant (Harvey, 1990). The 'death of distance' utopia is embodied in rationales of speed and accessibility underlying the hyperloop (See 5.4.2). The 'sense-scape' of the hyperloop is tantalizingly seamless, sleek, and futurist. Illustrated in Figure 16, it is geared for a smooth, ergonomic, and enjoyable passenger experience with limited security interference (See 5.1.1). Due to its containment within a tube, virtual technology is deployed to emulate scenery; isolation from natural environment is the cost paid for speed. Movement in this imaginary is a practice of utility and curiosity. Much of the imagery around the hyperloop, illustrated in the reimagination of Amsterdam Centraal (See 5.1.4), invokes a futurist architectural style, neglecting historical or contemporary architectural integration. These visual codes are key for allocating aesthetic makeup to socio-technical transformation (Pedata, 2017). This is not mere practical mock-up, but a symbolic effort to illustrate the transformative potential of the hyperloop in inducing new self-contained futurist sensescapes built upon, not within, a landscape.

6.2.4. Desirable World Building

It was found the hyperloop is largely designed to respond to demand segments and use-cases; when mobility is conceived as a derived demand, questions around how mobility need take form are precluded by the fact people are expected to move at higher volumes and rates in the future (See 5.4.1). As explored in 5.4.2, mobility has shaped how we "*discover new worlds, (and) new friends*" (Jaarsma). The availability of these opportunities, as established in 2.2, are context-specific; more so, the premise of expanding the scope and rate by which one maintains inter-cosmopolitan social networks will have a radical impact on how opportunities are distributed and how people structure their time. Evidently, one cannot imagine high-speed mobility as a sterile conduit of people and goods, but as an embedded mechanism within lived experience, subject formation, cultural practice and the global distribution of opportunity, expertise and wealth. Whether a promise of allowing new circuits of high-speed infused tourism (Pagliara et al., 2015), or matching skilled workers to new opportunities over greater distances (Feng et al., 2023), these are promises for increasing consumption and widening scopes of opportunity repackaged with higher speeds.

The desire to travel faster and effectively is not a universal sentiment, but one rooted in promises of economic productivity and social cohesion. The material vehicles of movement in our epoch evoke conceptions of idealized society, ideal life and desirable modes of living (Jensen, 2011). The modernist proposition of the automobile is no longer the staple of individual movement, and complex high-speed mobility infrastructures widen the horizon of movement beyond the individual and towards the network. Through these transitions, economic imperatives set quantifiable benchmarks and normative stipulations of advancement as filters through which desires are modulated to embody feasibility. A hegemony of what is rational in movement – faster, smarter, electrified and efficient – establishes imaginative anchors our technologies abide by (Pellizzoni and Ylönen, 2012). There are imperceptible orientations towards constructing the future that manifest in how we imagine it, be it the valorization of human will and ingenuity, and yielding merit to the imaginaries that engender a desirable future. Furthermore, the hyperloop is not a zero-sum endeavor, meaning its localized affordances in urban regions may induce disparities elsewhere. The widening difference between the capabilities of peoples within and between regions to indulge in hypermobility will become another vector of displacement and differentiation (Mensah, 2008; Ochungo, 2021). The desires in which the technology is framed are geographically contingent and hegemonic by nature. The findings of this research illustrate the rationales and dynamics within this frame, but a contextualized and critical framing of the hyperloop and imperatives around the mobility transition reveal the instability of path-dependence bent on intensification and acceleration. In predicting how our systems can optimize to meet the challenges we face, it is found that "the expansion or optimization of existing socio-technical systems will not be even remotely enough … neither the stimulation of radical niches to promote transitions in single systems, nor even the emergence of the next surge, will be sufficient. What is needed is to challenge the fundamental features of industrial modernity: we need a new theme, not another variation on the existing one "(Kanger & Schot, 2019, p. 19).

7. Conclusion

7.1. The Relationship of Socio-technical Systems & Imagination

RQ1 and RQ2 are answered to the extent that the hyperloop imaginary and hyperloop system remain innately connected. Answering RQ2, it becomes evident the hyperloop is grounded in tacit premonitions and orientations towards accelerating and intensifying the speed and volume of movement. Within a landscape emphasizing the interrelation of innovation and green technologies in the mobility transition, the hyperloop imaginary is innovation par excellence; an unprecedentedly futurist, sleek, and seamless modality facilitated by a modular, scalable and sustainable transit system. The imaginary is dialectically related to the society that imagines. At a point where the hyperloop will gain fidelity and formulation in public thought, its imaginary and associated worldbuilding scheme will calcify; the imaginary will interact with the perceived desirability of existing modalities, and be negotiated by the broader public relative to their socio-economic and spatial proximity to the prospective system. This imaginary, rich with an intangible sense of the future, compels speculation, curiosity and engagement necessary to source funds, form stakeholder coalitions, and attract policymaking interest, as has been evolving within the Netherlands. This process is illustrated below in Figure 17.

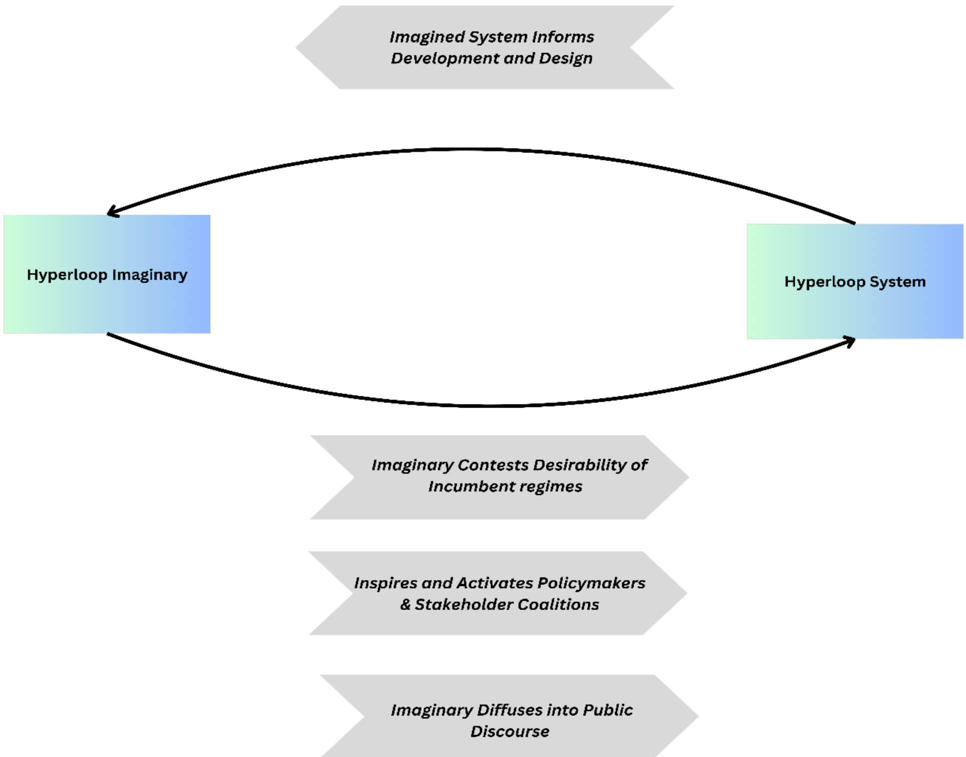

Figure 17. Hyperloop Socio-Technical System and Imagination Relation. Made by Author

Answering RQ1, the prospective hyperloop system will be stabilized or destabilized through contention with regime developments and macro-level landscape dynamics. As development continues, key technical mechanisms are clarified, and regulation emerges, pathways for residential or citizen involvement and education will become paramount. Mobility is both a symbolic and cognitive practice; speed or price-point benefits are important, but not all-encompassing drivers behind our mobility practices. The nature of our lifestyles interfaces our movements with our profession, status and identity. If sustainable technologies maintain disproportionately high travel patterns of wealthy people in a sustainable manner, the technology has answered an ecological challenge, not a social one. If the hyperloop imaginary becomes widely digested, its reception will fragment along the fault lines of socio-economic and regional differences. Hyperloop stakeholders question the basis for realizing the system; the wider disaffected or disadvantaged question if the system is needed. Hyperloop opposition will not be luddite-like or dogmatic, but reflective of discursive negotiations around how equitable and procedurally just our sustainability transition is.

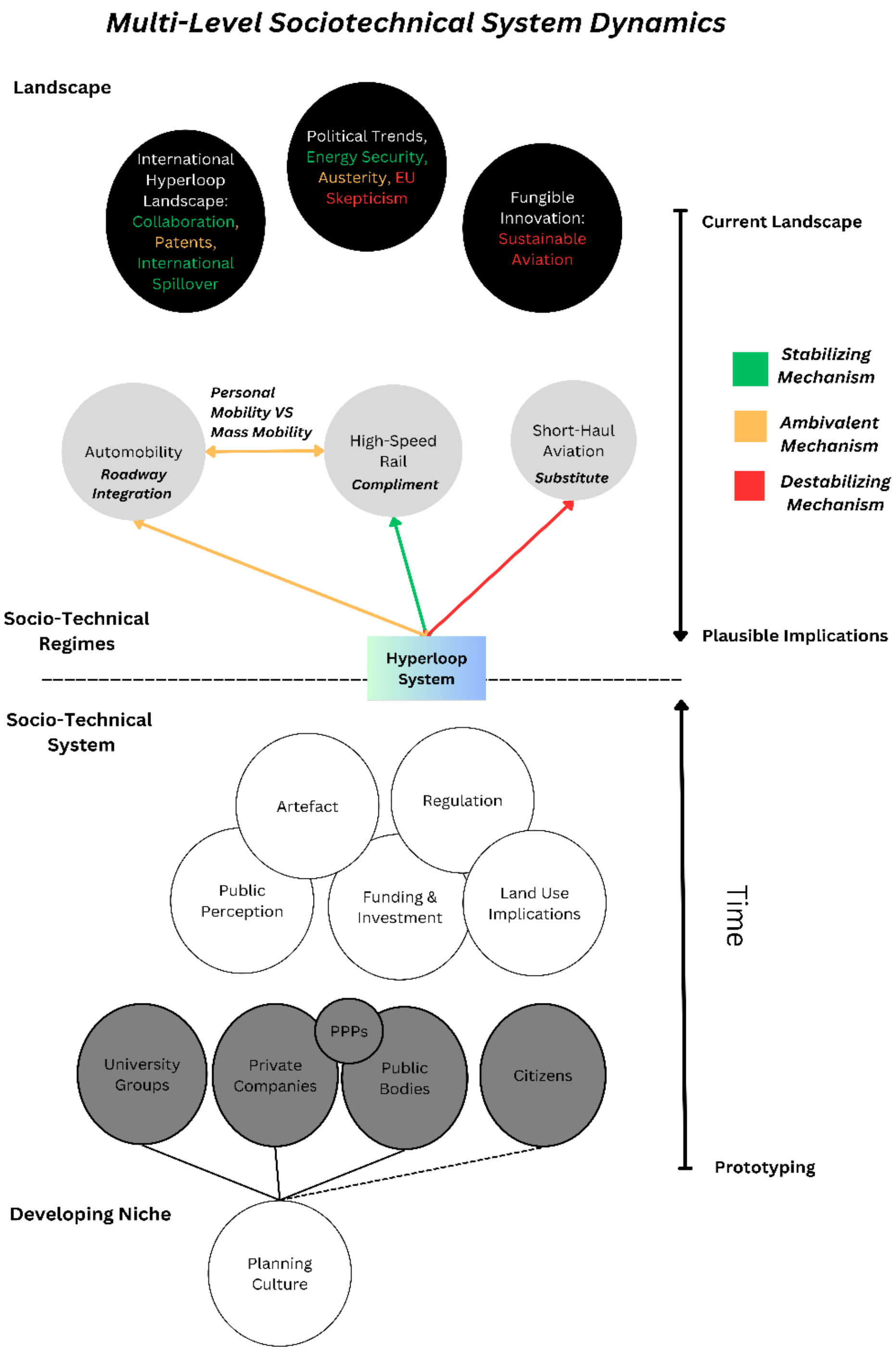

Figure 18. Hyperloop Socio-Technical System and Imagination Relation. Made by Author

The challenge ahead is multifaceted; international collaboration, successful multi-modal integration and increasing renewable energy security will stabilize the niche. Ambivalent mechanisms denote the uncertainty in unforeseen possibilities around incumbent preferentiality, that being increasing austerity, foreseeable patent exclusivity, or prioritizing innovations and expansive infrastructure for automobility. Innovations in aviation and EU skepticism will plausibly destabilize the niche. These key tensions are illustrated above in Figure 18. The prospective hyperloop system will emerge relative to assuring continued prototype development, increasing the TRL, while simultaneously preempting the makeup and competitive position of a prospective system. There is a political calculus to scaling innovation or protecting existing systems; increasing niche viability necessitates a politically desirable proposition that inspires prudent political hype. There are growing calls for differentiating growth and development; whereby growth has relied on appropriating and reabsorbing surplus' in productivity and increasing consumption, development should be a question of initiating positive change within the human condition. The hyperloop may hold a place in that future; but the conditions in which it is built and for whom it benefits must not comply with contemporary arrangements, but reconfigure possibilities for future ones.

7.2. Stakeholder Recommendations

The approach taken by this research in critically contextualizing the technology alludes to a perspective that may be necessary for its own realization. A progressive development of the hyperloop must preempt dynamics extraneous to the prospective system. Notably, the disconnect between legitimizing megaprojects along the lines of their benefits and growing efforts to protect procedural justice highlight that the hyperloop's future rests more in how it is built than what capabilities it can offer. Hyperloop stakeholders should develop frameworks for an early, inclusive and involved onboarding of citizens to understand and deliberate the technology. Additionally, stakeholders should preemptively mitigate plausible intellectual property conflicts to ensure a foreseeable prototype remains utilizable between contexts. Furthermore, while a rapid hyperloop timeline may prove difficult, noting difficulties in immaturity and feasibility, this is not a death sentence for the technology. Continued attention to diversifying use-cases and land-use opportunities can increase relative advantageousness. Hyperloop stakeholders should conceptually reorient from framing the hyperloop as a unilateral solution to increasing mobility demand, but instead as an enhancement bound to a vision of a multifaceted sustainability effort. Expand the frame of the hyperloop to include a concomitate vision of a world it could benefit; package it alongside calls for adjacent improvements in renewable energy infrastructure, European and international cooperation, supply chain justice, radical mobility accessibility and meaningful place-making.

7.3. Limitations & Future Research

The MLP framework's interpretive and versatile methodology compensates for limitations in precision by incentivizing further research to build upon and enrich understanding of the empirical field systematized within the framework over time (Geels, 2011). The critical realist approach utilized establishes theoretical precedent for further work analyzing mobility systems as material and discursive constructions. Recognizing this theses' qualitative primacy, the analytical rigor of future research can benefit from mixed-method approaches (Schot & Kanger, 2018). Further hyperloop niche research must follow the technology's maturation. Notably, research into how the hyperloop could leverage sustainable sourcing, construction, or production techniques would benefit both development and desirability. Research into prospective PPP vehicles should preemptively outline long-term approaches to manage risk and private-public incentives.

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