Emergence of asset intensive ecosystems

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Abstract:

This paper analysis the emergence of asset-intensive ecosystems. These ecosystems have been largely overlooked in the literature despite their potential contribution to sustainability transition. The paper presents four inherent characteristics of these ecosystems- supply and demand uncertainty, capital intensive, prone to technological lock-in and geographically anchored. It argues that these characteristics strongly influence how these ecosystems emerge. Using the case of the emergence of a regional ecosystem around hydrogen mobility, this paper shows that processes of ecosystem emergence are influenced by two dimensions: a temporal dimension and a spatial dimension. It also discusses a key dilemma for these emerging ecosystems which is to juggle between path creation and path dependence.

Keywords: business ecosystem, emergence, infrastructure, hydrogen

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INTRODUCTION

Due to the ongoing global climate crisis, we observe a growing societal, political and scientific interest on the study of socio-technical transitions to sustainability (Geels, 2019), sustainable business models (Neumeyer & Santos, 2018) and sustainable innovations (Bocken et al., 2014). Many scholars have also pointed that sustainable innovations often materialize through ecosystems of interdependent actors, that need to coordinate their efforts due to their complex and systemic nature (Espinosa & Porter, 2011; Gray & Purdy, 2018; Oskam et al., 2021; Rohrbeck et al., 2013; Schaltegger et al., 2018). Typical examples of such ecosystem are found in the transportation sector where decarbonising mobility requires developing new value chains to produce, distribute and use low-emission fuels.

Following Adner's (2017) definition, ecosystems are "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" (Adner, 2017). This is, to create value, ecosystems rely on the coordination of complementary inputs made by interconnected, yet independent actors with different levels of (technological) distance from the end consumer in order to propose a coherent, customer-facing solution (Adner, 2006; Jacobides et al., 2018). In this paper, we are particularly interested in the early phase of ecosystem emergence and previous literature argued that four processes are central in this phase (Thomas et al., 2022). First, ecosystems needs to go through a process of value discovery in order to identify what kind of collective value the ecosystem can offer to external audience and what kind of individual value it can offer to ecosystem participants (Adner, 2012; Dattée et al., 2018; Williamson & De Meyer, 2012). Second, the ecosystem needs to design a governance regime in order to allocate roles and define rules for participation (Jacobides et al., 2018; Wareham et al., 2014). Thirds, the ecosystem needs to acquire resources to enable ecosystem establishment and growth (Gawer & Henderson, 2007; Shi et al., 2021). And fourth, the ecosystem needs to gain legitimacy and signal itself as worth investing resources in (Thomas & Ritala, 2022).

Previous research on ecosystem emergence mostly focused on ecosystems that revolve around a digital platform (Dattée et al., 2018; Thomas et al., 2022; Thomas & Ritala, 2022). We argue that it is worthwhile to study the processes through which ecosystem emerge when they revolve around an asset-intensive infrastructure notably because such infrastructure are deemed central in sustainability transitions (Bolton & Foxon, 2015; Frantzeskaki & Loorbach, 2010). Ecosystems that revolve on the development of a new asset-intensive infrastructure have four distinctive characteristics. First, they operate in market characterised by supply and demand uncertainties (Frantzeskaki & Loorbach, 2010; Lee et al., 2018). Second, they require large-scale physical assets which are capital-intensive and involve important sunk investments (Frantzeskaki & Loorbach, 2010; Jonsson, 2000; Loorbach et al., 2010; Mori, 2019). Third, they are prone to technological lock-in as previous technological achievements will constrain future technological possibilities (Klitkou et al., 2015; Liebowitz & Margolis, 1995). And fourth, they are geographically anchored meaning that the joint value proposition is only available to users which are co-located with the infrastructure. We posit that these characteristics are prone to impact the processes through which such ecosystem emerge and notably the processes of value discovery and of design of ecosystem governance. In this paper we ask: *do the characteristics of asset-intensive ecosystem influence the processes through which they emerge and if so in what way?*

To answer this question, we analyse the emergence of an ecosystem aiming to deploy an infrastructure of green hydrogen refuelling stations in the Auvergne-Rhône-Alpes region in France. This research is based on the analysis of 36 semi-directive interviews conducted with ecosystem participants over a 2 year period. We find that the four characteristics of asset-intensive ecosystem do influence the processes through which such ecosystems emerge. More specifically, we find that value discovery and governance design are influenced by two dimensions: a temporal dimension and a spatial dimension.

The remaining parts of this article are structures as follows. We start with a review of the literature meant to present the characteristics of asset-intensive ecosystem, introduce what value discovery and governance design are about and how these processes may be influenced by these characteristics. We then present the case study and our research method. Follow a presentation of our results and a preliminary discussion.

1. CONCEPTUAL DEVELOPMENT

1.1. ON ASSET INTENSIVE ECOSYSTEMS

Firms increasingly form business ecosystems to develop complex value propositions (Jacobides et al., 2018). In this paper we build on Adner (2017) who describes ecosystem as "the alignment structure of the multilateral set of partners that need to interact in order for a focal value proposition to materialize" (Adner, 2017). Alignment structure refers to reaching mutual agreement among the members regarding the joint value proposition that the ecosystem materializes, the ecosystem governance and value appropriation (Adner, 2017; Williamson & De Meyer, 2012).

One of the subject of scholarly attention has been to understand how business ecosystem emerge (Ansari et al., 2016; Dattée et al., 2018; Thomas et al., 2022; Thomas & Ritala, 2022). This phase is particularly challenging because perceived potential returns are uncertain and there is a risk that investments outweigh benefits, especially when they target markets characterised by supply and demand uncertainties (Lee et al., 2018). This can make it difficult to convince actors to join the ecosystem and contribute to the joint value proposition which threatens ecosystem birth (Thomas et al., 2022; Thomas & Ritala, 2022). Besides, during the early phases of their development, ecosystems are also confronted with a chicken-or-egg problem as the ecosystem can only create value when it has attracted a minimum threshold of participants (Caillaud & Jullien, 2003).

Previous literature suggests that four processes are central in the phase of ecosystem emergence: value discovery, collective governance, platform resourcing and contextual embedding (Thomas et al., 2022). While previous research on business ecosystem emergence mostly focused on digital ecosystems, this paper proposes to analyse how a business ecosystem emerges around an asset-intensive infrastructure. We argue that such ecosystem have four characteristics that are different from digital ecosystems and which may impact the processes through which such ecosystem emerges. Besides, because they are likely to have a critical role to play as we attempt to transit towards sustainable modes of production and consumption (Bolton & Foxon, 2015; Frantzeskaki & Loorbach, 2010), understanding how such ecosystem emerges has a high societal relevance.

First, they operate in market characterised by supply and demand uncertainties (Frantzeskaki & Loorbach, 2010; Lee et al., 2018). When asset-intensive ecosystem emerge, there is hardly any knowledge and evidence regarding future consumer attitude towards the value proposition. Moreover, technologies may lack maturity and their techno-economic performance may still be uncertain. This implies complicated decision-making and long implementation cycles (He et al., 2015; Zhang et al., 2021), which leads to high rates of failure (Locatelli et al., 2017). Second, they require physical assets which are capital-intensive and involve important sunk investments (Frantzeskaki & Loorbach, 2010; Jonsson, 2000; Loorbach et al., 2010; Mori, 2019). This implies that participating in such ecosystem is not anecdotic but instead demands important financial resources suggesting both high entry and high exit barriers (Eaton & Lipsey, 1980). Besides, it makes chicken or egg problem more important, as it needs large investments to be able to offer value to customers, and it needs large amounts of costumers to reach economies of scale and provide value to ecosystem participants (Caillaud & Jullien, 2003). Third, they are prone to technological lock-in as previous technological achievements will constrain future technological possibilities (Klitkou et al., 2015; Liebowitz & Margolis, 1995). This makes the choice of complementors even more important as they will influence not only the short term performance of the ecosystem but also its capability to evolve in response to changes in its environment. And fourth, they are geographically anchored meaning that the joint value proposition is only available to users which are co-located with the infrastructure. This does not only reduces the number of ecosystem participants but also gives the chicken and egg dilemma a spatial dimension. The ecosystem is attractive when it is able to cover a minimum geographical locations.

In the following sections, we detail two processes which are important during ecosystem emergence: value discovery and design of ecosystem governance. For each we argue why these processes are likely to take place differently in asset-intensive ecosystems.

1.2. THE PROCESS OF COLLECTIVE VALUE DISCOVERY

When the ecosystem is emerging, it needs to go through a collective process of value discovery that concerns both what the joint value proposition could be and how the ecosystem can be source of value for each participant individually. On the one hand, there is a need to establish an ecosystem value proposition that addresses the needs of a certain part of the market (Dattée et al., 2018; Khanagha et al., 2022). In the strategy literature, the value proposition is generally conceptualized as the benefit the consumer experiences from using a product or a service (Anderson et al., 2006; Priem, 2007; Priem et al., 2012), or as the ways in which that product or service can help users achieve their goals (Macdonald et al., 2016). The overarching ecosystem value proposition requires an ecosystem blueprint pinpointing where value should be created why and how to create it (Williamson & De Meyer, 2012). This blueprint may be the result of either a centralized design (Adner & Kapoor, 2010; Dattée et al., 2018), or a multilateral negotiation process (Ansari et al., 2016; Shi et al., 2021).

Under situations of high uncertainty, the ecosystem blueprint is not known ex-ante and ecosystem members need to first engage in the ecosystem and then collectively advance towards the definition of value (Dattée et al., 2018; Thomas et al., 2022). The resulting value proposition will also depend on the availability of complementary inputs from ecosystem members (Ceccagnoli et al., 2012) and this can only be negotiated once the ecosystem members decided to participate in the ecosystem. Given the importance of technical artefact in asset-intensive ecosystem, we can argue that the market segment that can be addressed will strongly be constraint by the technologies that are available at the time of emergence. Moreover, Dattée et al. (2018) also show that the ecosystem can explore simultaneously different alternatives and advance through a reiterative process that aims at delaying resource commitment as much as possible while exploring and narrowing down the options until reaching the optimal value proposition (Dattée et al., 2018). This research, however, focuses on digital platforms that are by definition flexible and adaptive. For asset-intensive ecosystems, simultaneous exploration of alternative is not possible because the required input are capital intensive and there are less possibilities to delay investments because each exploration demands important capital investments.

On the other hand, the value discovery process also requires defining individual benefits, for each of the ecosystem members. Indeed organisations that decide to become members of an ecosystem do it primarily because it allows them to pursue their own self-interested goals; be them financial reward or other strategic goals (Kazan et al., 2018; Wareham et al., 2014) and thus the ecosystem needs for each individual ecosystem member to have a reason to contribute (Dhanaraj & Parkhe, 2006; Kapoor & Lee, 2013). However, because asset-intensive ecosystem have long implementation cycles, it may be especially difficult for the ecosystem to identify how it can be source of value for participants that join the ecosystem during its emergence when the rewards are very uncertain. Besides, because they are geographically anchored, it is likely that value discovery in asset-intensive ecosystems requires understanding local customer culture, needs and preferences (Steenkamp, 2019). Moreover, as we explore more in-depth in the following section, the amount of available partners is limited and, thus, the ecosystem will need to understand and address their interest individually, to ensure their participation.

1.3. The design of a governance regime

Collective governance is the process of regulating participation in the ecosystem (O'Mahony & Karp, 2022). It consists in defining the roles and tasks of each of the participants and finding right incentives to convince participants to contribute to collective value creation (Wareham et al., 2014) despite high uncertainty regarding the possibility to capture value in return (Oskam et al., 2021). Roles may be defined collectively or by the ecosystem focal actor unilaterally (Jacobides et al., 2018). Governance is implemented through architectural design of the ecosystem (Dattée et al., 2018; Gulati et al., 2012) and, additionally to defining roles, it balances the tensions that may appear between the conflicting goals of individual ecosystem members and the ecosystem as a collective (Kretschmer et al., 2022; O'Mahony & Bechky, 2008; Wareham et al., 2014).

When discussing ecosystem governance, literature stresses the need for the ecosystem to find the optimal level of heterogeneity among participants by defining the conditions under which participants self-select themselves in the ecosystem (Wareham et al., 2014). In asset-intensive ecosystems, high entry and exit barriers due to the level of investment needed to participate, imply that participants do not self-select themselves. Moreover, because perceived potential returns are uncertain and there is a risk that investments outweigh benefits (Lee et al. 2017), it is often necessary to convince potential participants to partake. Being able to convince the right ecosystem members to participate is therefore fundamental because the performance of the ecosystem depends on the performance of each of the actors that constitute it (Adner, 2006). Besides, the geographical anchorage of asset-intensive ecosystem may impose some participants by making them not easily substitutable by others (Lee et al. 2017), causing important constraints on the ecosystem.

Second, previous literature highlighted that finding the right level of heterogeneity is crucial for ecosystem to balance the needs to achieve both stability and evolvability (Tiwana et al., 2010; Yoo et al., 2010). We argue that in asset-intensive ecosystem, collective governance will above all be concerned about finding criteria to attribute or refuse a membership to new entrants (Teece, 2016) so as to decrease the risk of being trapped in a sub-optimal technical design. This involves being able to select members that have appropriate resource endowment, knowledge base (Moeen and Agarwal, 2017) and capabilities (Teece et al., 1997) to contribute to the materialisation of the initial joint value proposition and to the evolution of this value proposition as external conditions change.

2. METHODS AND DATA

We follow a qualitative and inductive approach (Edmondson & Mcmanus, 2007) with the aim of building theory (Eisenhardt & Graebner, 2007). More specifically, we rely on the analysis of one embedded case study with qualitative data coming from semi-structured interviews. the case study concerns the deployment of a regional fleet of fuel cell electric vehicles and the necessary refuelling infrastructure and hydrogen production infrastructure for fuel cell users to be able to use their vehicles across that region using only green hydrogen. At the time of the study it represents the largest infrastructural project for hydrogen mobility in France.

We consider this case as suitable to answer our research question because it shows the emergence and development of an ecosystem that depends on the cooperation of multiple public actors (regional authorities and cities) and private actors (large industrial firms and banks, SMEs and start-ups) to succeed. It emerges in a context of high level of uncertainty as it tackles a completely new market with little knowledge regarding future consumer attitude towards the value proposition. Moreover, the ecosystem aims at the development of a new technological path. Finally, low-carbon hydrogen (including green hydrogen) is now part of energy transition strategies of many countries and constitutes an important element of the EU Green Deal. The hydrogen mobility is an emerging sector and therefore its study is particularly relevant.

The premises of the ecosystem started in 2018 when a major a French energy supplier a major international key mobility actor decided to launch a project consisting on the deployment of an infrastructure of refuelling stations for hydrogen vehicles which would be accompanied by a program of public subsidies for hydrogen vehicles. The existence of the infrastructure and the subsidies would reduce the barriers that potential hydrogen car users face when deciding whether to buy (or not) a hydrogen car. To do so they needed to work together with public authorities and they chose the regional level as the most appropriated one. After convincing the regional authorities to endorse and adhere to the project, they applied for some European funding which they won, and they started the implementation of the project.

These two firms together with the regional authorities built a Joint Venture (JV), hereafter referred to as "Hydra", which would be the formal responsible for the deployment of the infrastructure. Two financial institutions joined the JV. Hydra ensures and coordinates simultaneously the deployment of hydrogen production (with electrolysers using exclusively renewable energy) and storage and distribution infrastructures. The regional authorities are in charge of attributing the subsidies for car purchase. Additionally to Hydra and its shareholders, the ecosystems counts on a network of cooperating actors with a variety of functions. These actors include start-ups in charge of the construction of hydrogen stations and electrolysis infrastructures, local authorities of towns who will host the stations, car sellers, and an equipment manufacturer. The following table summarizes the interviews done.

Table 1: summary of interviews

Informer CODE	Organisation pseudonym	Description	(Length in minutes)
HYDRA1	HYRA	Energy supplier & shareholder	100 & 60 & 30& 90 & 59
MOB1	MOB	Mobility industry player & shareholder	65 & 60 & 53
BAN1	BAN	Banc & shareholder	37
BAN2	BAN	Banc & shareholder	68
REG1	REG	Regional public admin & shareholder	52
REG2	REG	Regional public admin & shareholder	35
HYDRA2	HYDRA	Exploitation of H2 infrastructure	42 & 24
HYDRA3	HYDRA	Exploitation of H2 infrastructure	40 & 37
BLUE1	BLUETOWN	Local public administration	58 & 39
CARY1	CARY	Car dealer	62 & 26
GREENTOWN1	GREENTOWN	Local public administration	55 & 39
REDTOWN1	REDTOWN	Local public administration	58
FUEL1	FUEL	Fuel cell producer	53
CARX1	CARX	car dealer	41
WHITETOWN1	WHITETOWN	Public administration	55
STAX1	STAX	Electrolyser and station constructor	62 & 32
STAY1	STAY	Electrolyser and station constructor	62 & 34
STAZ1	STAZ	Electrolyser and station constructor	27 & 30 & 45
IND1	IND	Industrial cluster	54
CONS1	CONS	Consulting company	15

3. FINDINGS

3.1. VALUE DISCOVERY: SIMULTANEOUSLY MANAGING DIFFERENT DIMENSIONS OF TIME AND SPACE

Our first relevant finding is that processes of value discovery in asset intensive ecosystem demand identifying simultaneously two dimensions of value, a spatial and a temporal dimension. Because it emerges under high uncertainty due to high costs and high risk of failure, value discovery will have a temporal dimension, meaning that the ecosystem envisions the value proposition in the long term, but needs a short-term value proposition, which is seen by the ecosystem as a first step towards their long-term ambition. Because the ecosystem is locally embedded, value will have a spatial dimension as well. The infrastructure of hydrogen stations for fuel-cell vehicles that we study needs to discover which global value it can provide as a whole network of stations, and at the same time which local values it can deliver through each individual station locally.

3.1.1. Addressing long and short term value

We observe that the process of value discovery in the asset-intensive ecosystem under study involves discovering the ecosystem value at two temporalities: short-term and long-term.

The ecosystem's value proposition is built on a long-term perspective, meaning that the value that the ecosystem proposes is the participation to a promising technology that will gain relevance during the coming years. Indeed, when asked about the choices concerning the value proposition interviewees explain often that the goal of the ecosystem lies on the long term, and that the short-term value proposition is a first step towards that goal. This first step is seen as one that could allow ecosystem participants to be relevant in that future promising market. The ecosystem we study is built on the premise that mobility is a highly polluting sector, that all European governments want to decarbonize it and that hydrogen technology will have a role to play as it has several advantages compared to its biggest competitor, the battery. The following quotation illustrates this long term focus: "*We are convinced that the battery alone will not be enough and that hydrogen is an essential complementary solution. More than just a supplement, hydrogen is one of the main components of sustainable mobility*" [HRDRA_1]. Shortly after the same interviewee adds, "*We are convinced that this project will create a positive domino effect*". Thus, the ecosystem's value proposition consists on the promise that the hydrogen mobility sector will develop greatly and that this project is a first step towards that development. This is how it is presented to its customers as well, as the following quotation shows: "*We called [the customers] pioneers and we told them: 'If you are present today and participate in this project, it makes you a pioneer. You are one of the first who dare and show the way [to the others].' But it comes from their personal conviction because it remains more expensive and more complicated*." [REG1].

We observe that in terms of individual participant motivations to join the ecosystem, the long-term plays an important role and short-term participation is seen as a first step towards that goal. They believe that hydrogen mobility will grow greatly, and that being present early on will give them a competitive advantage in the future when the sector will be more profitable. One car dealer explains it in the following way: "*I think hydrogen will be the solution in the future. So it interests us, as a distributor and player in automobile distribution, to be able to sell hydrogen-powered vehicles.*"[CARY_1]. Moreover, we observe a strong belief among participants that similar projects will develop in other regions as illustrated by the following quote: "*What is happening here is what will happen in other regions all over France, in Europe.*

So it is a strategic decision to be present on this first deployment." [STAZ_1]. For small entrepreneurial firms, this ecosystem represents an opportunity to show what they are capable of in order to increase their chance to win future similar projects. One manufacturer for instance explained "*ZEV gives us this playground, to develop new technologies, to show we can go much further (than how current station are designed) and be ready when a new EU standard comes*" [STAY_1].

Finally, even though value lies in the long term, the ecosystem still needs to discover which short-term value proposition could be a first step toward this long term value. First, learning from previous similar initiatives abroad, the ecosystem identifies that to create value it needs to overcome the chicken and egg problem. An interviewee explains: "*The genius is to break the cycle of the chicken or egg since car manufacturers could not sell because there was no hydrogen service station which existed. And no hydrogen station maker wanted to install them because there were no vehicles on the road*."[HYDRA_1]. To this end, the value proposition of the ecosystem consists in developing an initial refuelling infrastructure and accompanying it with a subsidy programme to purchase light duty vehicles that commercial actors can benefit from. Another interview explains it in the following way: "*So, the strength of this project is to simultaneously offer a service station infrastructure and the circulation of vehicles. This vehicles cost much more than diesel vehicles today […] so the regional authorities agreed to erase the difference with a subsidy programme*" [HYDRA_2]. Second, the ecosystem also needs to determine to which type of users it can create value considering the technologies which are immediately available. The ecosystem decided to focus particularly on light vehicles because the technology was available for engines as well as for refuelling stations: "*It is an existing vehicle which makes it easier. It's easier to deploy a project with light mobility. It's easier to test*" [IND_1]. Besides, choosing for light mobility also reflected how the ecosystem interpreted the interest for hydrogen among industrial actors at the time of emergence of the project. This is illustrated by the following quote: "*If you look at where the volumes are, the sweet spot is industry. If you look at where the desire is, the sweet spot is mobility*" [ENE_1].

3.1.2. Addressing local and global value

We observe that the spatial dimension also plays an important role in the process of value discovery. There is a need to discover value of the ecosystem globally but also of each of the embedded ecosystems locally. Indeed, as we have seen in the previous section, the value proposition of the ecosystem we study consist of a network of stations. However, each station locally also constitutes a specific and different value proposition.

First, we observe that value discovery process started with identifying which spatial scale would be most ideal for the ecosystem to be able to overcome the aforementioned chicken and egg problem. Ecosystem actors quickly agreed that "*If you have to choose a territory, the right size of territory is the regional geographical perimeter*" [HYDRA_1] and that this would be the minimum and most appropriate scale to create value and convince users to adopt hydrogen light vehicles. Moreover, another important value element is that the ecosystem offers the possibility to move within a region as illustrated by the following quote: "*What's really interesting in this project is that it has 20 stations, we can tell to potential users: 'well, you can buy a vehicle in Chambéry, you can fill it up on the spot and soon in a year, there will be 19 other stations on the territory of the region'. And that is essential for customers, because if they go to Grenoble or to Lyon or Annecy, they must be able to fill up with hydrogen*." [HYDRA_2].

Second, being able to identify how the ecosystem can create value locally also proved very important in the process of value discovery because the ecosystem includes a variety of distinct geographical areas. An interviewee explains it as follows: "*Each territory has its own specificity. That is important to have in mind. A future buyer of a hydrogen vehicle in Clermont-Ferrand does not have the same needs, the same constraints and the same desires as a future buyer in Moûtiers. And very sincerely, that's why we work with local authorities. They are the ones who know the economic actors. They are the ones who know the needs and constraints of everyday life*" [HYDRA_2]. If we take the example of a small town in a touristic area with ski resorts, the ecosystem needs to be a source of value creation for the mountain economy. For instance being able to relate what the ecosystem does to future potential uses specific to ski resorts proved important. An interviewee explains: "*It is still under development, but, typically, the snow groomer, is symbolic[…]. For a snow groomer, a work cycle it's 180 litres of fuel oil. The day you put hydrogen in place of fuel oil… you understand the impact on the carbon footprint*" [WHITETOWN_1]. In larger more industrialized cities, the ecosystem showed it could contribute to an improved air quality and respond to local pollution problem. As explained by the following quotation: "*the city has its own objectives such as the implementation of the low emission zone*" [GREENTOWN_1]. These zone locally establish stricter rules against polluting vehicles. The ecosystem can make it easier for local authorities to introduce such zone by providing impacted users an alternative to fossil fuels.

Finally, we observed that the spatial dimension also influenced the value discovery process that led to the ecosystem's initial value proposition. Beyond focusing on light vehicles, the ecosystem also decided to focus on commercial users (e.g. taxi drivers, local craftsmen) as target audience. The main rational behind this is the need to find captive customers that can above all value the presence of a hydrogen refuelling infrastructure in their locality. The ecosystem was conscious that individual end users would demand a larger infrastructure before purchasing a vehicle. The following quotation illustrates this: "*Today we are not ready for individuals, we are rather ready for companies that move within a town and its surroundings but still need to be able to move within a region sometimes*." [REG_1]. Commercial users represent an interesting first customer target that could value a limited regional refuelling infrastructure.

3.2. Value discovery: simultaneously managing different dimensions of time and space

Our second relevant finding relates to how the observed asset-intensive ecosystem designed a governance regime meant to provide the right incentives for actors to allocate resources and contribute to the ecosystem. The literature often discusses modes of governance that change depending on whether actors are located at the core or at the periphery of the ecosystem (Wareham et al., 2014). In our case, we observe that the governance depends on other criteria namely, the level of substitutability of actors and whether their actions are needed to contribute locally or globally to the value proposition (see table 2). We discuss the governance regime identified for each of the four situations.

3.2.1. Mitigating risks for global non-substitutable actors

By definition asset-intensive ecosystem require important financial resources and because they face a lot of uncertainties, there is a high risk of losing the invested money. This makes it especially challenging to convince actors to become shareholder of the joint-venture that will carry these investments. We found that to overcome this, the ecosystem designed rules to mitigate the risks by shareholders individually and the joint-venture collectively.

First, reciprocity appeared as a key governance mechanism to secure resources and build up commitment. For instance, when building the first stations, the keystone was confronted to a delay as it took longer than expected to formally create the joint-venture. To allow the project to advance, the two industrial partners decided to split the responsibilities and agreed that each of them would be responsible for building one station, each of them in the cities where they had more influence. "We will each build a station in advance of phase: ENE in Bluetown and MOB in whitetown, and Hydra will buy it after". Similarly, the keystone itself is a joint-venture and shareholders agreed that they would each commit certain amount of resources to facilitate the functioning of the joint-venture. This is illustrated by the following quote from the director of Hydra: "*each shareholder commits to put in a certain amount of full time equivalent to facilitate the operation of the company and the deployment*."

Table 2: objective of ecosystem governance depending on actors' role and contribution to the ecosystem

	Non- Substitutable	**Substitutable**
Global Contribution	Shareholders of the Joint-Venture Mitigating risks	Station manufacturers Ensuring long-term techno economic performance
Local contribution	Big cities and car dealers Minimizing resource allocation	Small cities and small users Enabling embedded sub-ecosystem

Second, rationalising resource allocation is another important governance mechanisms to mitigate risks by showing that ecosystem resources will be used wisely and spent with parsimony. For instance, Hydra included two strict criteria that have to be met before each station is built to reduce the risk that refuelling station would be built without users present to buy hydrogen and therefore pay for the station.: the existence 50 letters signed by local actors that commit to purchase a hydrogen vehicle and an economic criteria consisting on the expected consumption of hydrogen of the local fleets associated with one station. As explained by one interviewee: "*50 vehicles does not mean anything because if 50 vehicles traveling 5,000 km / year versus 50 vehicles traveling 250,000 km, we will not have the same turnover at the station*" [HYDRA_2].

3.2.2. Minimizing resource allocation for local non-substitutable actors

The second group concerns actors that are not easily substitutable and have an important role to play to ensure the success of the refuelling station locally. This includes car dealers considering that few of them are capable to propose hydrogen vehicles and big cities given that the ecosystem would lose credibility if it was incapable to build stations in the largest regional cities. Convincing them to allocate resources and contribute to value creation is complex yet decisive for the success of the ecosystem. We found that the ecosystem designed rules to minimize resource allocation of this group of actors by internalizing some of the tasks.

First, in the initial allocation of roles, cities were expected to identify and convince potential users to commit to buy a fuel cell hydrogen car. However, we observed that in big cities where political support for hydrogen was limited, local project managers were not comfortable with this role as illustrated by the following quote "*you have to have the soul of a salesman and I am not a salesman. Hydra often talks about a pioneering spirit, but it's hard to convince. It's hard to carry this message you see*." [WHITETOWN_1]. In order not to discourage this local contacts and show commitment, the joint-venture decided to modify the distribution of role and internalise the commercial activities. "*Hympulsion has invested from a commercial point of view because we have two people who dedicate 100% of their time to the commercial activities*" [HYDRA_3].

Second, another strategy we observed is to provide tailored support and training. We observe that often the main reason for ecosystem members to be reluctant to allocate resources to the ecosystem is their lack of knowledge regarding hydrogen vehicles and their market. For instance, car dealers fear that selling a hydrogen car would require significantly more time than selling a traditional car or even a battery or hybrid one. The following quotation from the keystone illustrates this problem "*A good salesperson sells six cars a day. If he tries to sell a vehicle that he doesn't know and to customers who don't even know [hydrogen cars], it is going to take three hours, four hours and maybe he is not going to sell it. So that doesn't interest him*." [HYDRA_2]. To compensate from this barrier to the allocation of resources, the keystone provides with tailored support so the car dealers gain knowledge in hydrogen and can find clients. The keystone explains it in the following way "*We are the ones who will bring them knowledge, skills and know-how around hydrogen*." [HYDRA_2].

3.2.3. Ensuring long-term technico-economic performance of global substitutable actors

The third group concerns actors that are easily substitutable and contribute to the ecosystem globally. This includes station manufacturers that will build the infrastructure around which the ecosystem revolves. Before entering the ecosystem, these actors are easily substitutable - many manufacturers exist worldwide. However, because they contribute core physical assets, once chosen, the ecosystem cannot easily cast them out if their turn out not to have the desired performance and lock the ecosystem in a suboptimal technical design. This makes it extremely important for the ecosystem to develop governance mechanisms to ensure that these members are able to contribute to the ecosystem. We ecosystem we studied did that by carrying out a strict selection at the entrance based on techno-economic performance.

First, when choosing station manufacturers a call for tenders was organised where competition included strict economic criteria. One of the station manufacturers explains it as follows: "*We knew that it was an open call for tenders, large groups do not give gifts to SMEs, the market is fully open. They received offers from the United States, they were on the verge of receiving some even from Japan. It was a tough fight in the game! […] Price was indeed a major issue*" [STAY_1]. Unsurprisingly this objective was to minimise the financial resources needed to develop the infrastructure.

Second, the selection criteria also demanded specific technical performance and notably the capability to develop very different types of refuelling stations. The call for tender required manufacturers to be able to design small and big stations (between 40kg and 200 kg), stations where hydrogen is produced on site and stations where hydrogen is imported in tube trailers from elsewhere and stations that could be easily upgraded to welcome larger vehicles if needed. The rationale behind this was the high uncertainties about what the most optimal technical design would be in order to be able to respond to local demands in terms of hydrogen uses in an economical way. This governance mechanisms was meant to give the ecosystem the possibility to adapt as technical and market conditions change.

3.2.4. Enabling embedded sub-ecosystem through local substitutable actors

The fourth group includes non-substitutable actors that have a local contribution to the ecosystem. Here we find small cities and small users of fuel cell cars. While the ecosystem made a lot of compromises to align large regional cities, it had the possibility to be more demanding for small cities that are much more numerous. Similar to the previous category of actor, the governance mechanism for this fourth category also includes gatekeeping to only align actors that have the capabilities to provide a relevant contribution to the ecosystem. However, the governance mechanisms do not focus on securing the ecosystem's technical-economic performance but on enabling the creation of embedded sub-ecosystems that are coordinated by a focal local actor and operate partly autonomously from the global ecosystem.

This local coordination allows the join-venture to delegate some activities thereby minimising its own allocation of resources.

First, one example of gatekeeping is that small cities are only accepted in the ecosystem if they are able to convince that local politicians are able to show a high degree of willingness to participate in the ecosystem. This willingness is often referred to as political commitment and described as the enthusiasm of authorities and their promises regarding resource engagement. As explained by an interviewee cities are chosen when "*there is a willingness, a political commitment which is manifest and well presented*". [HYDRA_1].

Second, gatekeeping also concerns the willingness of a city to animate local networks in order to find local businesses that could adopt hydrogen vehicles and facilitate the identification of land where the station could be built and which is often problematic to find. This is illustrated by the following quote "*In fact, what we ask of a city is [...] to get involved and take charge of the piloting of the deployment of the project at the local level*" [MOB-1].

4. DISCUSSION AND CONCLUSION

4.1.1. Asset-intensive ecosystems are shaped by temporal and spatial dimensions

We contribute to research on ecosystem through our analysis of the emergence of a type of ecosystem that has been overlooked by scholars so far: asset-intensive ecosystems that revolves around a large infrastructure. These ecosystems have a central role to play considering that addressing humanities grand challenges often demands developing new or transforming existing infrastructures (Bolton & Foxon, 2015; Frantzeskaki & Loorbach, 2010). Asset-intensive ecosystems have four characteristics that constrain ecosystem emergence and necessitate specific attention: they emerge under supply and demand uncertainties (Frantzeskaki & Loorbach, 2010; Lee et al., 2018), are capital intensive (Frantzeskaki & Loorbach, 2010; Jonsson, 2000; Loorbach et al., 2010; Mori, 2019), are prone to technological lock-in (Klitkou et al., 2015; Liebowitz & Margolis, 1995) and are geographically anchored.

Our results show that the processes of emergence for these ecosystems have to conciliate two dimensions: a temporal dimension and a spatial dimension. The temporal dimension relates to the fact that emergent ecosystems build on the promise to create value in the long term as/if the infrastructure starts to serve a growing pool of captive users. At the same time, emergent ecosystem still need to show short term achievements in order to gain legitimacy and be able to convince participants to allocate resources to the ecosystem today (Thomas & Ritala, 2022). The spatial dimension relates to the fact that the processes that lead to ecosystem emergence take place at different scale simultaneously. The global ecosystem consists of multiple embedded ecosystems that mobilise a partly site-specific set of participants, that each develop at their own pace and with their own objectives.

We show that these two dimensions are central in explaining how value discovery takes place and how the ecosystem governance is designed. One the one hand, value discovery demands findings out how the long-term collective global vision of the ecosystem can resonate with multiple short-term local goals of individual participants. On the other hand, ecosystem collective governance is designed to balance short-term local achievements and long-term global performance.

4.1.2. On the challenge of convincing the right actors to participate

In the emergent ecosystem analysed, ecosystem governance is concerned with attracting participants that are both willing and capable to contribute to the ecosystem. Instead of a hierarchy based on whether actors operate at the core or at the periphery of the ecosystem, we observe a hierarchy of actors depending whether or not their contribution can easily be substituted by another actor. For non-substitutable actors, the main aim of the governance mechanisms is to convince participants that the ecosystem's value proposition is acceptable, plausible, and credible (Ansari et al., 2016; Dattée et al., 2018; Thomas & Ritala, 2022) so that these actors agree to allocate resources to the ecosystem. For substitutable actors, the main aim will be to make sure to select actors that have the capabilities needed to contribute to the ecosystem's emergence and to the ecosystem's dynamic capabilities (Linde et al., 2021).

We observe that a key challenge is for the ecosystem to convince non-substitutable local actors to participate. This proves especially difficult when these actors cannot easily find resonance between the global objectives of the ecosystem and local objective for themselves. In our case, large cities and car dealers have been very difficult to convince to partake in the ecosystem. The main strategy of the joint-venture has been to allocate additional resources to the ecosystem in order to signal strategic interest. If this strategy does not prove sufficient, this will put ecosystem emergence at risk at it compromises the capacity of the ecosystem to create value. In this case, the ecosystem may have to make additional efforts in order to discover what kind of value it is able to create with the pool of actor it is able to attract.

4.1.3. Limitations and future research agenda

The research is a first attempt at studying the emergence of a large-scale asset-intensive ecosystem. We believe that the results presented here may be of value for other similar ecosystems that may emerge for instance around hydrogen infrastructure for mobility or CO2 infrastructure meant to enable carbon removal (Jagu & Massol, 2022). Nevertheless, this research has limitations linked to our research design based on a single case-study. We believe that future research is needed to further confirm our observations.

ACKNOWLEDGEMENTS

This research has been made possible thanks to the support of the Chaire Energy for Society. We would also like to especially thank all of interviewees for accepting to participate in the interviews and share their insights on our case study.

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