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Sustainability and Resilience in Alliance-Driven Manufacturing Ecosystems: A Strategic Conceptual Modeling Perspective

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Abstract

The challenge of sustainability rests on the ability of organizations to change their practices to meet the needs of current and future generations. To date, most research on organizational change has focused on how to change within a single organization. However, an increasing number of sustainability challenges require changes across multiple organizations. In this paper, we summarize strategic challenges faced in such a setting and outline a conceptual modeling approach for strategic analysis of alliance-driven solutions. We illustrate our ideas with a case study in digital agriculture, a field particularly relevant to sustainability, and end with the identification of issues for further research.

Keywords: conceptual modeling, alliance-driven platform ecosystems, sustainable manufacturing, case study, coopetition

1. Introduction

Industry has a particular responsibility to transform the current economy into a more ecologically and socially sustainable one. The COVID-19 pandemic demonstrated how unexpected events can disrupt entire global logistics chains in a short time. The resulting demand for change poses significant challenges for industrial production. A core challenge in this context is to consider sustainability and resilience in a much larger extent as before.

Environmental *sustainability* emphasizes environmentally conscious manufacturing processes, the reduction of energy usage, resources consumption, and harmful emissions, but also the development of new sustainable business models and value chains (Hauschild et al., 2020). Social sustainability is concerned with the wellbeing of the humans who work in these systems and the quality of their work. Economic sustainability implies a good balance between the cost of manufacturing and profits to ensure business continuity. It drives efficiency, waste reduction, and productivity (ElMaraghy et al., 2017). Strategies for achieving sustainability in production are discussed, e.g., in ElMaraghy et al. (2021).

Resilience is the capacity of an organization or supply chain to recover quickly from disruption. Resilience is more than robustness, which is fault-tolerance, i.e., the ability to withstand disruptions. In a more recent understanding, resilience should be understood as adaptability, i.e., the ability to adjust to new conditions and to be modified for a new goal, use, or purpose. Adaptability is multifaceted; it includes static, dynamic, cognitive, and extreme adaptability (ElMaraghy et al., 2021).

The ongoing digitalization and networking of industrial value chains, often referred to as the fourth industrial revolution (Industry 4.0), offer new opportunities and capabilities to reach these objectives. Digital Twins and their related data views, so-called *Digital Shadows* (Bauernhansl et al., 2018; Liebenberg & Jarke, 2020), are main drivers of this vision. A digital twin is a "digital representation of a unique asset such as a product, machine, service, product-service system or other intangible asset that compromises its characteristics, condition and behavior by means of models, information and data" (Stark et al., 2017). Digital Twins allow future spaces to be explored and appropriate decisions to be made (ElMaraghy et al., 2022).

A digital shadow can be seen as "a task- and context-dependent, aggregated, multi-perspective, and persistent dataset computed from measurements of the physical system, external data, or simulations by a

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digital twin" (Becker et al., 2021). Digital shadows provide multi-modal views with task-specific granularity offering high performance, low latency, security, and privacy at the same time.

While previously rather discussed in the context of operational efficiency and process engineering, a recent Delphi study identifies digital twins and shadows as core enablers of sustainability and resilience in future manufacturing (Piller et al., 2022). On the technical side, data-enriched views on processes and a higher information capability improve the efficiency of processes and avoid waste throughout the complete life cycle of products and industrial assets. In this regard, digital twins could become "sustainability twins", i.e., digital models that are networked with the real products, and provide information about performance, repair requirements, and possibilities for more efficient use. A sustainability twin would continuously improve operations, help the product or asset adapt to the required performance, and provide important insights for more sustainable engineering of the next product generation. One example of this are combined model-based and machine learning-based optimization methods in the steel-based hot rolling process, which result in not only more flexible high-quality processes but also considerable energy and CO2 savings (Liebenberg & Jarke, 2020). As another example, adding sustainability indicators, such as pollution or energy usage, to cross-organizational digital twins enables flexible process chain configurations in normal, low-emission production as well as resilience to unexpected disruptions (Vitali, 2022).

Reducing resource consumption and more efficient production setups are just the beginning. We also need new business models which focus on prosperity with resource recovery and less resource consumption. While increasing efficiency remains undisputedly important, a dual paradigm shift is required: Digitalization and sustainability must move into the center of the value proposition, and sustainability must be generated from the digital value creation structure itself. Examples of the former are digital platforms for second-hand goods; examples of the latter are "as-a-service" or sharing models, where new forms of sustainable value creation take place in the usage stage (Piller et al., 2021). These new approaches achieve sustainability and resilience with value co-creation and value sharing in collaborative networks (Camarinha-Matos et al., 2021), enabling cross-company, open ecosystems (Capiello et al., 2020). This requires data not just on final products, but also on semi-finished goods, raw materials, production, usage, and disposal or refurbishment.

Here, the idea of a *data space*, enabling the sovereign exchange of data and services from digital twins and shadows, comes into play (Otto et al., 2022). However, all too often, the lack of willingness to share and use data hinders achieving the best-case scenarios. Establishing and maintaining such data spaces hence requires careful and continuous requirements management (Otto & Jarke, 2019). This involves the identification of actor goals, the design of balanced interdependencies structures as the basis for fair cooperation and trust, and early recognition of relevant bottlenecks or disruptions.

In the remainder of this paper, we first discuss conceptual, technical, and organizational aspects of such interdependency structures. We use experiences from a multi-year case study of an agricultural industry alliance to illustrate a conceptual modeling approach, which extends established conceptual strategy modeling techniques and illustrates its application and implementation.

2. Platform Ecosystems: Technical and Organizational Aspects

A challenge for many companies is not only handling big amounts of data, but also creating and capturing value from them. Hence, organizations increasingly rely on external data and service exchange within business ecosystems. Examples are service-oriented business models, enabling new interrelations between companies as well as value co-creation (Pfeiffer et al., 2017). In this context, platform ecosystems emerged that connect various stakeholders, from established business partners to emerging market entrants (van Alstyne et al., 2016).

Compared to purely digital platforms in consumer markets (e.g., social networks), physical boundaries and complexity hamper value capture from such platforms in industrial settings. Technological complexity results from connected physical components such as industrial assets and their association to information systems, business processes, and smart services (ElMaraghy, et al., 2012; Schermuly et al., 2019; Sisinni et al., 2018).

These complexities lead to several challenges. First, potential needs must be recognized in time, so that firms can take strategic decisions in advance. Second, data sovereignty, i.e., self-determination with regard to the use of data, must be considered. This is particularly valid for emerging alliance-driven platforms (Otto & Jarke, 2019), where multiple players cooperate to create value jointly. At the same time, exactly these (complex) multi-player, alliance-driven platforms hold the largest opportunities for more sustainability and resilience (Piller et al., 2021).

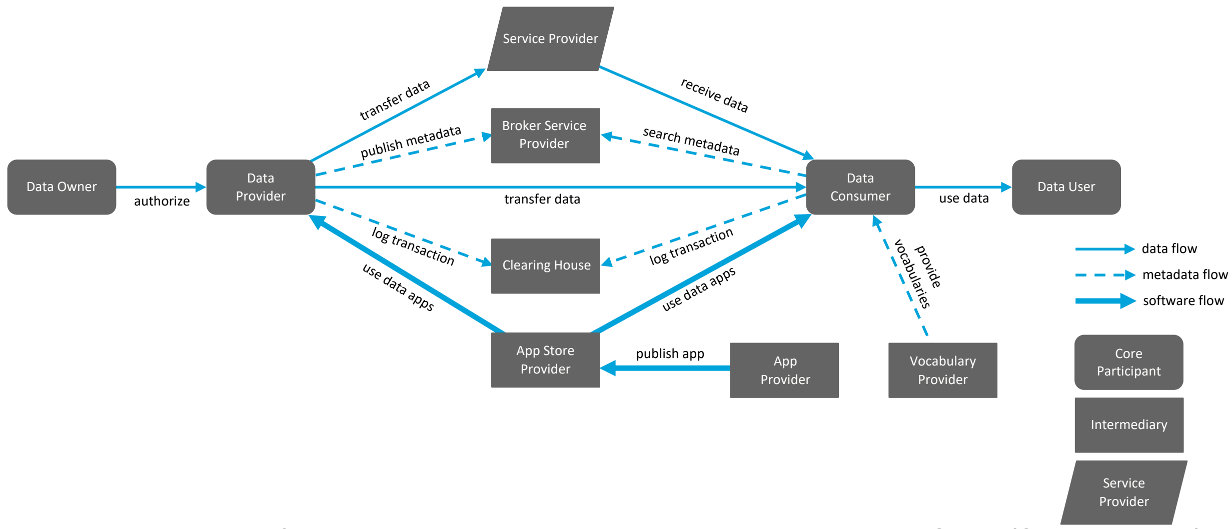

Figure 1. Actor roles & data exchange task dependencies in an Industrial Data Space (Otto et al., 2017)

2.1. Platform Ecosystems: Economic Perspective

Integrating engineering, production, and usage data in the form of digital shadows is the underlying foundation of new data-based industrial ecosystems. Conventional value chains are transformed into platform-based business ecosystems mediating data and connected assets with third-party complements (Kopalle et al., 2020). The vision of these ecosystems is an open network of sensors, assets, products, and actors that continuously generate data. This data is utilized to enhance operational efficiency, but also provides new opportunities for sustainability and resilience. The rise of platforms within industrial eco-systems where these data are being exchanged and enhanced by dedicated "apps" (i.e., complementary digital offerings and services) is one of the most significant economic developments of the last decade (Adner, 2017; Gawer, 2014). In the context of industrial manufacturing, the term IIoT (Industrial Internet of Things) platform denotes such a platform.

Platform ecosystems consist of a central platform with multiple peripheral firms connected to it. Thereby, platform orchestrators hope to benefit from network effects, achieving a winner-takes-all (WTA) position (Eisenmann et al., 2011). Therefore, in many ecosystems, a dominant industry platform arises, where the orchestrator becomes the de-facto leader. But not all platform ecosystems follow this WTA logic. In integrated platform ecosystems relying on a modular architecture and open data spaces, openness is key (Baldwin & Woodard, 2007) as the core value proposition (Cusumano & Gawer, 2002). The underlying innovations are created jointly by platform owners and third-party contributors (Adner, 2017), and the value created is fairly distributed among the participations. When sustainability and resilience become the core value proposition, this second structure of open, integrated platforms around an alliance of actors becomes the role model (Otto & Jarke, 2019). As in a natural (biological) ecosystem, a business ecosystem can only thrive when all actors perceive a "win-win" and balance between value creation and value capture.

2.2. Platform Ecosystems: Information Systems Perspective

From an information systems perspective, openness is enabled by standardized interfaces and autonomous data exchange, connecting formerly isolated companies (Brettel et al., 2014). The platform thereby embraces technology standards that support the integration of offerings and manage the interdependency in the ecosystem (Thomas et al., 2014). A premier example of such an open data ecosystem is the *International Data Space* (IDS).

The IDS Association has introduced an architecture blueprint and standards for data-sharing among member organizations in a reliable, trans-parent, compliant and accountable manner (Otto et al., 2017). The main idea behind the IDS is that actors can trustfully, and with full sovereignty over data usage, exchange data without knowing each other. Technically, it is an open system, but the connectors, brokers, and cross-party security mechanisms among participants must be certified to exchange data. Significant effort has been invested in creating a coherent standardized metamodel for the IDS reference architecture (Bader et al., 2020). Actor roles and subtask dependencies among them for sovereign data exchange in the IDS model are depicted in Figure 1. IDS itself does not offer a conceptual abstraction for the actual valuable data objects to be exchanged. In the context of Aachen's large-scale research initiative *Internet of Production,* we consider digital shadows to be these valuable data objects (Jarke, 2020).

2.3. Modeling Strategic Relationships in Data Ecosystems

App providers and other contributors to an ecosystem often face the challenge of relying on third-party interfaces, libraries, and resellers, leading to numerous dependencies on technical and business levels. A well-known example is the need for app developers who contract with the two leading mobile platforms, iOS and Android, to pay a 30% commission on app sales. A clear view of technical dependence on integrated libraries, their licenses, and update policies regarding, for instance, security aspects hence are essential.

Analytical tools in this context are, e.g., visual modeling languages and software supply network (SSN) diagrams, including material and monetary flows (Jansen et al., 2007). In contrast, product deployment context (PDC) models focus on the software in the running architecture (Lucassen et al., 2012). A case study comparing these two approaches is presented by Boucharas et al. (2009).

Our approach to modeling data ecosystems extends a tradition of research on goal-oriented conceptual modeling around the goal- and actor-oriented visual modeling language i* that has been widely adopted in requirements engineering and business modeling since its invention by Eric Yu (1996). It focuses on the intentional (why?), social (who?), and strategic (how?) dimensions to show goal hierarchies of individual actors, who may be natural persons or organizations. These goal-task hierarchies, visualized in *Strategic Rationale* diagrams, reflect different alternatives for actions as a framework within which decisions can be made.

Since not all goals can be achieved by one actor alone, so-called *Strategic Dependency* diagrams show how actors depend on other actors to reach their goals or fulfill subtasks of their tasks. The IDS actor network shown in Figure 1 can be interpreted as such a dependency network where the nodes are the actor (roles), and the annotations of the links indicate the dependencies among them.

Often, i* modelers combine both kinds of sub-models in one graph, which shows the goal-task hierarchies within a larger bubble that represents one actor. This integrated view enables a more detailed understanding of dependencies among actors. However, this visualization creates very busy figures. For this reason, many i* tools employ a background model and reasoning facilities for i* and even for some extensions, e.g., addressing special kinds of goals such as socio-technical systems aspects or security (e.g., STS-ml (Dalpiaz et al., 2011) or security (e.g., Secure Tropos (Mouratidis & Giorgini, 2007)). By analyzing such formally supported dependency networks, strategists can identify possible win-win situations or dangerous dependencies in the value chain structure.

Yu & Deng (2011) formalize software ecosystems by modeling the strategic goals of their stakeholders. By comparing traditional versus open ecosystems, the authors perceive that “the relationships between the software vendor and its buyers and suppliers evolve from a simple linear configuration to a more complex network of relationships”. Addressing one of the world’s major sustainability issues, Baier et al. (2015) report on a project on the planning and analysis of *water management* in complex urban megacities. Here, the agents to be simulated are not just IT and human organizations but also semantically enhanced geodata with associated strategic “intentions” such as maintaining air and water quality, protecting affordable housing, and decent traffic connections.

The need for dynamic complements to i* model concepts has been recognized at least since the early 2000's. In cooperation between computer science and sociology (Gans et al., 2003), the dynamic nature of trust in networks was recognized and modeled by linking i* dependencies to workflow or AI planning models through which trust could be built up by kept commitments and distrust monitored by suitable controls. In a complementary approach, Jureta et al. (2014) study adaptive information systems engineering. This approach is particularly suitable for studying the resilience of ecosystems, as it explicitly models “alternative” links within Strategic Rationale.

Closest to our approach is Pant and Yu's recent study of an i* extension for modeling coopetition, i.e. how the combination of competition and cooperation can be modeled and analyzed (Pant & Yu, 2018b, 2018a). Their extensions include novel link types and literature-based knowledge catalogs for analyzing key aspects such as inter-dependence, complementarity of capabilities, mutual trustworthiness, and reciprocality.

In particular, *reciprocality* offers an interesting dynamic concept for our current research question. Pant and Yu (2018a) combine Game Trees with i* dependencies as an operationalization of this dynamics. Valuable, Rare, Inimitable, and Non-substitutable (VRIN) resources are of special importance for all aspects, as they can lead to *contentions* between actors (Pant & Yu, 2018b)

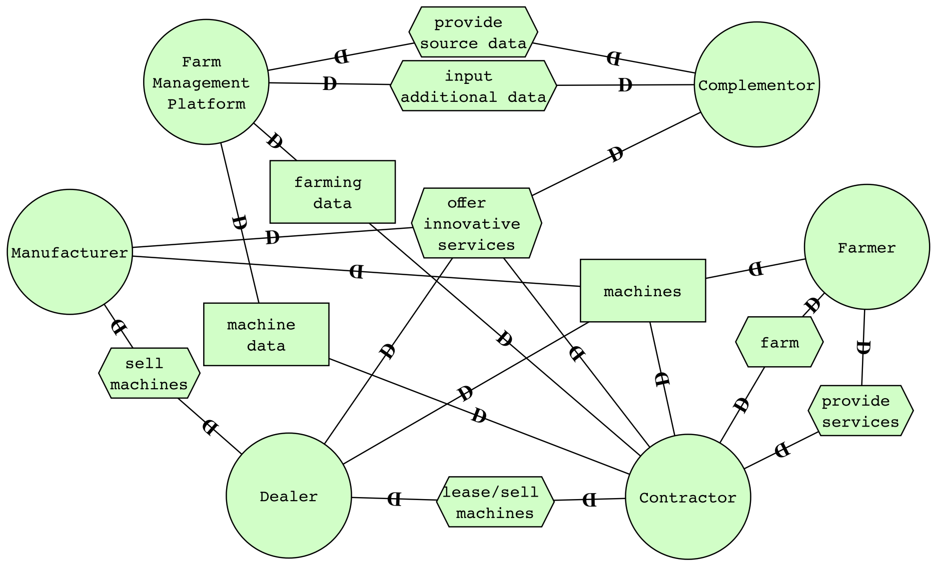

Figure 2. Strategic Dependency view of stakeholder relationships.

3. An Integrative Approach to Dynamic Ecosystems Modeling

Pant's case studies focus on binary coopetition, possibly facilitated by an abstract platform actor like the IDS infrastructure and regulations. In alliance-driven settings, the more general case of multi-sided coopetition applies. It is clear, that actions from inside and outside the ecosystem will constantly challenge and not rarely change this structure. For companies in such a platform, it is of strategic importance to anticipate their future role at an early stage and plan appropriate steps along the way.

In prior work, we utilized this modeling approach to investigate strategic positioning decisions of incumbents and competitive dynamics (Koren et al., 2021; van Dyck et al., 2021). This research identified, for example, a number of control points, i.e., active strategic decisions that platform participants can exercise to achieve a certain ecosystem behavior; examples of such control points include economic decisions such as pricing, but also technical decisions such as the decoupling of product and service offers. Organizations can set up control points by adhering to more or less open technical standards, signaling different levels of willingness to cooperate.

In the sequel, we illustrate the usage of i*-based conceptual modeling for supporting sustainability and resilience, using excerpts from a large-scale, multi-year case study of the evolution of an alliance-driven platform ecosystem in the agricultural sector, aiming at both economic and ecological sustainability. For more details on this case, refer to (Van Dyck et al., 2021; Van Dyck & Lüttgens, 2019).

3.1. Case Study: Analysis and Dynamic Modeling of a Smart Farming Ecosystem

To illustrate the opportunities of using this modeling approach in order to design better industrial ecosystems, we studied an emerging ecosystem around farming equipment. Events like severe weather, draughts, but also new demands and regulations regarding sustainability make the *agricultural sector* a perfect case to study the impact of digital platforms on sustainability and resilience.

The farm equipment industry is dominated by a few large manufacturers, with two strong market leaders in Europe and North America. The European leader, under pressure from potential threats by market participants in other parts of the traditional supply pipeline (e.g., seed companies) as well as generic web-based marketing platforms, began in the 2010s by setting up its own platform-based ecosystem as a broad alliance-driven network including players in its supply chain as well as customers (farmers and their supporting contractors), service units, and the like. Recently, even competitors have been joining forces such that coopetition is becoming a vital element of the alliance.

The case study included 55 interviews with key actors from the agricultural sector, e.g., manufacturers, input firms (seed, crop protection), and other relevant members (customers, suppliers, complementors, competitors, dealers, or new entrants), which we model as platform actors. Extensive secondary data like information on connected machines, digital service usage, strategy documents, or annual reports were analyzed. Based on these insights, we modeled the interactions between ecosystem members. The models were created using the recent iStar 2.0 notation (Dalpiaz et al., 2016). The version reported here extends a sketch presented in (Koren et al., 2021).

Error! Reference source not found. depicts such a view of the stakeholder relationships in the smart farming ecosystem. Of strategic interest is a comparison between the conventional value chain and the positioning within the platform ecosystem. The actors in both settings are slightly different: Market participants present in the conventional ("pipeline") structure, as well as a platform ecosystem, are **Manufacturers**, **Dealers**, **Contractors**, and **Farmers**. When changing to a platform ecosystem, a **Farm Management Platform** and **Complementors** join as new actors.

The i* strategic dependency model shows these actor types and typical goals, as well as the dependency relationships between them.

Manufacturer: Produces agricultural machines and sells them. Is interested in after-sales business with the customer and delivers products and services linked to the machines. Collects data about how machines are used, e.g. to increase OEE, but also sustainability of equipment as part of its value proposition.

Dealer: Sells or leases agricultural machines and corresponding services to farmers or contractors. It buys machines from the manufacturer.

Contractor: Operates farming processes for a farmer. It obtains its machinery from the dealer or manufacturer.

Farmer: Owns land for crop farming or animal produce with the goal to profit from the sale of goods. Wants to efficiently use labor and machine resources as well as the inputs for seed and crop protection. Intrinsic motivation for more resilience and sustainability, but also using the latter more and more as a market differentiator.

The previous participants are present in a pipeline business model as well as a platform ecosystem. The following two participants join when changing to a platform ecosystem.

Farm Management Platform: Integrates all data from the manufacturer, dealer, contractor, and farmer. Additionally, it provides data-based services on other data streams (e.g., weather). It can be operated by a single player (Adner, 2017) or governed by an alliance of different stakeholder organizations (Otto & Jarke, 2019). It is a new actor in the agricultural value chain.

Complementors: Contributes services through the farm management platform, working on data obtained through the platform. It provides insights via the platform and sells them to Farmers and Manufacturers. Especially in this actor group, a large dynamic could be observed by the market entry of dozens of startups specializing in sustainability and resilience for the agricultural sector, many with data-driven business models.

3.2. Strategic Dependency Model

The farm management platform is an information system that may be operated by either a manufacturer or another entity. The platform relies on the resources farming data and machine data, which it obtains from the contractor. It provides the required data to the complementor for the development of services. The complementor develops new services, which are made available via the farm management platform. The users are the contractor, the dealer, and the manufacturer.

Most notably, the dependency direction of the new data services goes from bottom to top (Figure 2). The production dependency cycle (i.e., the machine dependency cycle) starts on the left, traversing the bottom to the right before finally ending in the top. These two dependencies are clearly distinguishable. However, there is a link between the two, since the actors manufacturer, dealer, and contractor depend on the data service early in the production cycle. In contrast, the new data service depends on the last participants of the production dependency. In total, thus, they form one big dependency cycle, an essential prerequisite for inter-dependence.

3.3. Strategic Rationale Model

Figure 2 shows the hybrid strategic dependency and strategic rationale view for part of the smart farming ecosystem, also emphasizing sustainability aspects. It refines **Error! Reference source not found.** and details the internal views of the actors: For each actor, the main goals are associated with sub-goals necessary to achieve the main goals; goals are in turn associated with tasks that contribute to the respective goal.

In the figure, the lower three actor types show classical players in the farming systems, whereas the upper two actor types describe the new platform and its complementors. Their goals and tasks relate to digital data-based services, connecting the other actors. The lower actors pursue goals and tasks dealing with the central theme of the use case, i.e., farming, and additionally the concept of integrating the services provided by the upper two actors, whereas the upper two actors, in turn, provide the "smartness" for the smart farming. We included a sustainable fertilizer producer to demonstrate how much its business model is based on data availability. In this case, the producer offers fertilizers optimized for specific soils, which is

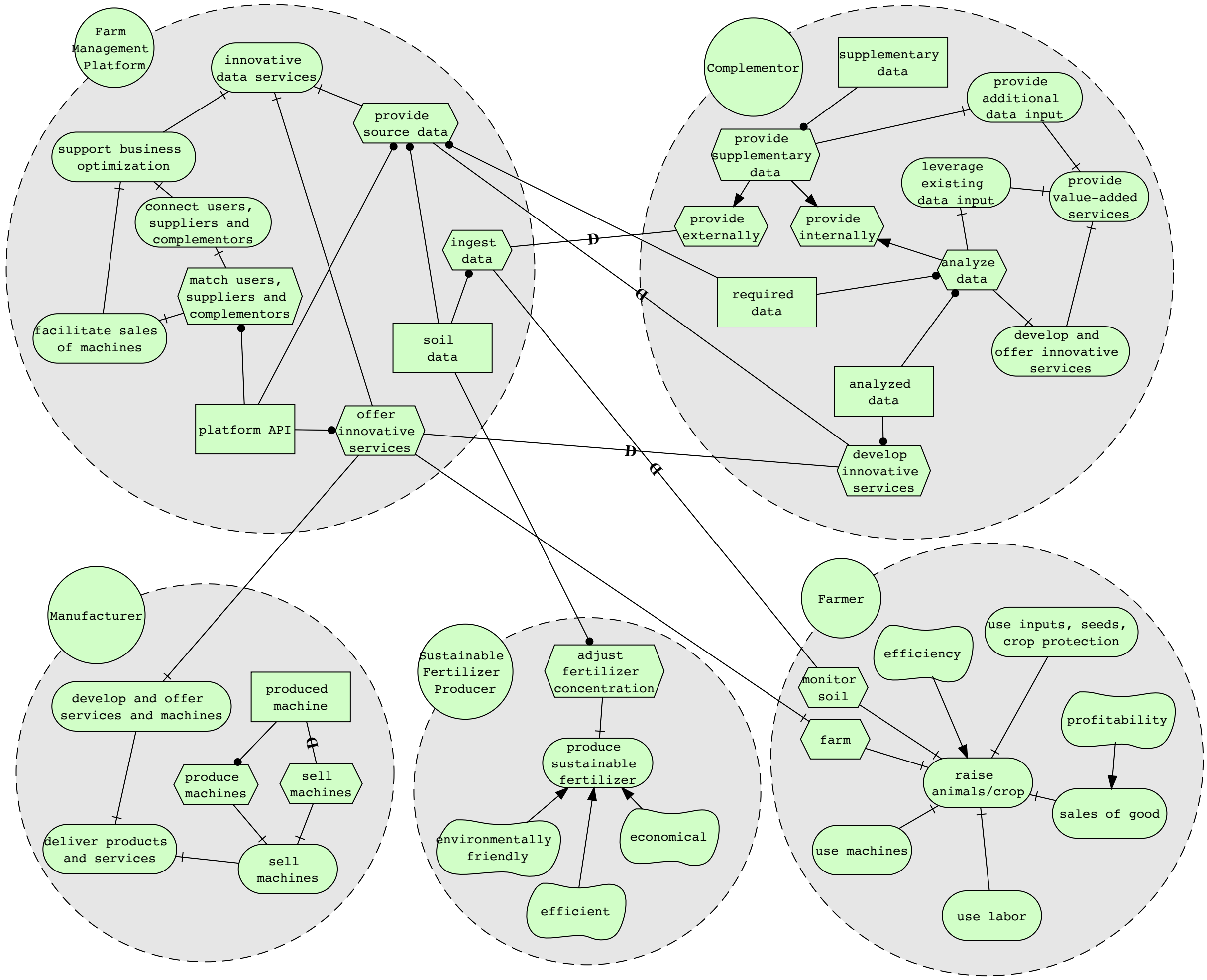

Figure 2. Hybrid Strategic Dependency and Rationale model of agricultural platform.

why it relies on corresponding soil data available on the farm management platform. These reciprocal offers render it possible to improve the overall sustainability jointly.

The consideration of the inner details of actors allows for a better understanding of the context in which the interaction of the actors takes place, as well as for a more granular description of the intended benefit of the actors. Note that in this model, the resources, tasks, and goals are all assigned to unambiguous actors, emphasizing that there are interdependencies between the actors but that still, each goal, resource, or task is in the domain of and of most interest to one specific actor.

There is a clear interdependency between the emerging market participants (on the upper part) and the existing participants (on the lower part): The emerging market participant provides innovative services and the matching of market participants. Both tasks rely on an interface for the new services and system, i.e., the platform(s). On the other hand, the new participants are dependent on the old participants providing farm and machine data. Therefore, we have a cyclic dependency, where each participant relies on the other. For analysis of the abstraction, the interior of the abstracted actors is depicted, emphasizing the most important newly introduced changes within the relationship between the existing market participant and the emerging market participant.

3.4 Coopetition on connected data in the ecosystem to enhance sustainability

Our previous analysis of emerging ecosystems and the underlying data exchanged across organizations predominantly focused on the creation and capture of economic (monetary) value (Dattée et al., 2018). But as the model shown in Figure 3 also illustrates, data sharing across organizations is also a core enabler for sustainability and resilience. Cross-company data spaces contribute to this capability. Sustainable business models use these data spaces and offer transparent information as part of their value proposition (Piller et al., 2022). In this way, data spaces foster organizational decision-making for more sustainable value creation, as they contain information that was not previously collected (or at least not systematically).

While building a data space enabling this visibility is technically possible today, motivating all actors to share the required data is much more difficult and requires a complete reversal of thinking in "lock-in effects". The goal is not to bind customers and their data exclusively to one company but to provide customers full access to their data so that they can use this visibility to design more sustainable processes. At the same time, also asset providers (like the manufacturers of agricultural equipment in our case) or complementors (like crop protection companies or digital service providers for precision farming) can enhance the sustainability of their offerings by getting access to the pooled usage data of the entire ecosystem.

This is exactly what happened at the end of our case observations, when the largest providers of agricultural equipment (John Deere, Claas, Case IH, Steyer, and New Holland) established *DataConnect*, a first step toward such an open data space in the form of a direct, cross-manufacturer and industry-open cloud-to-cloud solution (ClaasOfAmerica, 2022). Most farmers use a fleet of agricultural machinery from different manufacturers. Accordingly, multiple IT systems were required to control and monitor their machines. With DataConnect, all data can be exchanged via one interface so that farmers can see all machine data in their preferred data portal at a glance. DataConnect currently only links technical information. In the future, however, the system will also share agronomic data, such as fertilizer maps or information on soil conditions.

The sovereignty over the data remains exclusively with the farmers, who use it to realize sustainable precision agriculture. In contrast, the manufacturer side is confronted with two challenges: Firstly, technical standards needed to be agreed upon how data sharing can succeed effectively, securely, and transparently. Secondly, there was the fundamental strategic decision about how the solution could be implemented, as the participating companies continue to compete as part of the cooperation. Hence, the most important criterion when setting up DataConnect was that users are free to choose the platform for the user interface and can switch at any time if they perceive that one cooperation partner succeeds in generating greater added value for them from the shared data than the competition. In turn, other participants are under pressure to follow suit as quickly as possible. The result: A constant competition ensures a steady improvement of the offering – and the overall sustainability of the connected farms. The system develops organically and is driven forward jointly by all stakeholders – who, in this case, realized that for a sustainable future of agriculture, such a coopetition in a data-driven ecosystem is the only way to proceed.

4. Conclusions

Industrial platform ecosystems are highly complex in terms of technology layers (Schermuly et al., 2019) and relationships (Sisinni et al., 2018). The ongoing digitalization, together with the requirements of economic, social, and ecological sustainability, poses enormous challenges for manufacturing companies. Data-driven approaches are the core driver to tackle them. However, it is impossible to satisfy many of these demands within a single company. Hence, cross-organizational cooperation within networks of stakeholders is required. Stakeholders need to position themselves optimally and strategically to better plan collaborations in the evolving data ecosystems.

Our i*-based formalization helps to compare scenarios concerning, e.g., centralization, the structure of the data system, and required interfaces. Innovative possibilities can be pursued together with Control Points as strategic business parameters ranging from decisions about openness to choices of technical implementation. As the IDS actor model is consistent with the i* modeling approach, the i* model offers a starting point that can be elaborated, technically and socially, to other aspects of data ecosystems, taking into account further aspects of the IDS, such as data ownership and privacy. For example, participants could restrict data use to only certain sustainability KPIs like energy consumption, enabling a shift from local to global benchmarks (ElMaraghy et al., 2017).

The core of further research is additional validation of the approach in other case studies and a formal integration of the control point and coopetition concepts observed in the DataConnect extension into the background formalisms of i* support and reasoning tools. However, also the conceptual integration itself needs further work, in order to address some of the more complex obstacles we are facing when pursuing sustainability and resilience in manufacturing ecosystems.

One of the most important research challenges is the strategic management of possible rebound effects. Rebound effects are one of the most underestimated barriers when moving towards sustainable production. They can firstly counteract resilience strategies, e.g., digitizing energy supply networks for resilience against local breakdowns may create new hazards for attacks on the digital twin. Similar, less environmental impact by higher efficiency and resource productivity is frequently offset by an increased usage. Digitization promotes dematerialization and thus reduces resource consumption. However, building and maintaining its technical infrastructure (e.g., data centers, cloud storage, distributed ledger technologies) must not outweigh the possible savings. Digital photos are more environmentally friendly than traditional prints. But as they incur little cost to the user, many more are created and stored. In the end, the resources saved by digitalization are counterbalanced. In the worst case, consumption even rises above the previous level. Car sharing platforms can lead to fewer people owning a car but may increase car usage instead of public transportation.

Innovative digital business models, supported by visibility and transparency through shared data, must avoid this rebound effect by not aiming to consume resources but promoting their saving. Transferring approaches from consumer products (nudging consumer behavior, virtual scarcity) to the world of industry and production is an open challenge.

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References

Adner, R. (2017). Ecosystem as Structure. Journal of Management, 43(1), 39–58. https://doi.org/10.1177/0149206316678451

Bader, S., Pullmann, J., Mader, et al. (2020). The International Data Spaces Information Model. Proc. ISWC 2020, 176–192.. https://doi.org/10.1007/978-3-030-62466-8_12

Baier, K., Mtaré, V., Liebenberg, M. Lakemeyer, G. 2015). Towards integrated intentional agent simulation and semantic geodata management in complex urban systems modeling. Computers, Environment, and Urban Systems, 51(5), 47-58.

Baldwin, C. Y., & Woodard, C. J. (2007). Competition in Modular Clusters. Harvard Bus. School WP 08–042. https://ink.library.smu.edu.sg/sis_research/797/

Bauernhansl, T., Hartleif, S., & Felix, T. (2018). The Digital Shadow of production – A concept for the effective and efficient information supply in dynamic industrial environments. Procedia CIRP, 72, 69–74. https://doi.org/10.1016/j.procir.2018.03.188

Becker, F., Bibow, P., Dalibor, M., et al. (2021). A Conceptual Model for Digital Shadows in Industry and its Application. Proc. ER 2021, 271–281. Springer. https://doi.org/10.1007/978-3-030-89022-3_22

Boucharas, V., Jansen, S., & Brinkkemper, S. (2009). Formalizing Software Ecosystem Modeling. In R. Di Cosmo & P. Inverardi (Eds.), Proc. IWOCE '09, 41. ACM Press. https://doi.org/10.1145/1595800.1595807

Brettel, M., Friederichsen, N., Keller, M., & Rosenberg, M. (2014). How virtualization, decentralization and network building change the manufacturing landscape: An Industry 4.0 Perspective. Mechanical, Industrial Science and Engineering, 8(1), 37–44.

Camarinha-Matos, L. M., Boucher, X., & Afsarmanesh, H. (Eds.) (2021). Smart and Sustainable Collaborative Networks 4.0: 22nd IFIP WG 5.5 Working Conference on Virtual Enterprises, PRO-VE 2021, Springer. https://doi.org/10.1007/978-3-030-85969-5

Capiello, C., Gal, A., Jarke, M., & Rehof, J. (2020). Data Ecosystems: Sovereign Data Exchange among Organizations. Dagstuhl Seminar 19391. https://doi.org/10.4230/DAGREP.9.9.66

Claas of America (2022). DataConnect: A new era in precision agriculture. https://www.claasofamerica.com/product/precision-farming/data-connect-2

Cusumano, M. A., & Gawer, A. (2002). The Elements of Platform Leadership. MIT Sloan Management Review, 43(3), 51. https://doi.org/10.1109/EMR.2003.1201437

Dalpiaz, F., Franch, X., & Horkoff, J. (2016). IStar 2.0 language guide.

Dalpiaz, F., Paja, E., & Giorgini, P. (2011). Security Requirements Engineering via Commitments. Proc. IEEE STAST 2011, 1–8. https://doi.org/10.1109/STAST.2011.6059249

Dattée, B., Alexy, O., & Autio, E. (2018). Maneuvering in Poor Visibility: How Firms Play the Ecosystem Game when Uncertainty is High. Academy of Management J., 61(2), 466–498. https://doi.org/10.5465/amj.2015.0869

Eisenmann, T., Parker, G., & van Alstyne, M. W. (2011). Platform envelopment. Strategic Management Journal, 32(12), 1270–1285. https://doi.org/10.1002/smj.935

ElMaraghy, H.A., Youssef, A., Marzouk, A., & ElMaraghy, W. (2017). Energy use analysis and local benchmarking of manufacturing lines. Cleaner Production, 163, 36–48. https://doi.org/10.1016/j.jclepro.2015.12.026

ElMaraghy, W., ElMaraghy, H., Tomiyama, T. and Monostori, L. (2012). Complexity in Engineering Design and Manufacturing, CIRP Annals Manufacturing Technology, 61(2), 793 – 814. https://doi.org/10.1016/J.CIRP.2012.05.001

ElMaraghy, H., ElMaraghy, W. (2022). Adaptive Cognitive Manufacturing System (ACMS). Int. J. of Production Research (IJPR), https://doi.org/10.1080/00207543.2022.2078248

ElMaraghy, H., Monostori, L., Schuh, G., ElMaraghy, W., 2021). Evolution and Future of Manufacturing Systems. CIRP Annals Manufacturing Technology 70(2), 635-658.

Gans, G., Jarke, M., Kethers, S., & Lakemeyer, G. (2003). Continuous requirements management for organisation networks: A (dis)trust-based approach.

Requirements Engineering, 8(1), 4–22. https://doi.org/10.1007/s00766-002-0163-8
Hauschild, M.Z., Kara, S., Røpkec, I. (2020). Absolute sustainability: challenges to life cycle engineering, CIRP Annals, 69(2), 533-553.
Jansen, S., Brinkkemper, S., & Finkelstein, A. (2007). Providing Transparency in the Business of Software: A Modeling Technique for Software Supply Networks. In L. M. Camarinha-Matos et al. (Eds.), Establishing the Foundation of Collaborative Networks, 677–686. Springer. https://doi.org/10.1007/978-0-387-73798-0_73
Jarke, M. (2020). Data Sovereignty and the Internet of Production. Proc. CAiSE 2020, Springer LNCS 12127, 549-558..
Jureta, I. J., Borgida, A., Ernst, N. A., & Mylopoulos, J. (2014). The Requirements Problem for Adaptive Systems. ACM Trans. Management Information Systems, 5(3), 1–33. https://doi.org/10.1145/2629376
Koren, I., Braun, S., Van Dyck, M., & Jarke, M. (2021). Dynamic Strategic Modeling for Alliance-Driven Data Platforms: The Case of Smart Farming. In Proc. CAiSE 21 Workshops, Springer LNBIP 424, 92-99.. https://doi.org/10.1007/978-3-030-79108-7_11
Liebenberg, M., & Jarke, M. (2020). Information Systems Engineering with Digital Shadows: Concept and Case Studies. Proc. CAiSE 2020. Springer LNCS 12127, 70–84. https://doi.org/10.1007/978-3-030-49435-3_5
Lucassen, G., Brinkkemper, S., Jansen, S., & Handoyo, E. (2012). Comparison of Visual Business Modeling Techniques for Software Companies. In van der Aalst, et al. (Eds.), Software Business, 79–93. Springer. https://doi.org/10.1007/978-3-642-30746-1_7
Mouratidis, H., & Giorgini, P. (2007). Secure Tropos: A Security-Oriented Extension of the Tropos Methodology. Software Engineering and Knowledge Engineering, 17(02), 285–309. https://doi.org/10.1142/S0218194007003240
Stark, R., Kind, S., Neumeyer, S. (2017). Innovations in digital modelling for next generation manufacturing system design, CIRP Annals, 66(1), 169-172.
Otto, B., & Jarke, M. (2019). Designing a multi-sided data platform—Findings from the International Data Spaces case. Electronic Markets, 29(4), 561–580. https://doi.org/10.1007/s12525-019-00362-x
Otto, B., Lohmann, S., Auer, S., et al. (2017). Reference Architecture Model for the Industrial Data Space. International Data Space Association.
Otto, B., ten Hompel, M. & Wrobel, S. (2022). Designing Data Spaces: The Ecosystem Approach to Competitive Advantage. Springer.
Pant, V., & Yu, E. (2018a). Generating Win-Win Strategies for Software Businesses under Coopetition. Proc. 9th ICSOB, 90–107. Springer. https://doi.org/10.1007/978-3-030-04840-2_7
Pant, V., & Yu, E. (2018b). Modeling Simultaneous Cooperation and Competition Among Enterprises. Business & Information Systems Engineering, 60(1), 39–54. https://doi.org/10.1007/s12599-017-0514-0
Pfeiffer, A., Krempels, K.-H., & Jarke, M. (2017). Service-oriented Business Model Framework. Proc. 19th ICEIS. 361–372. https://doi.org/10.5220/0006255103610372
Piller, F, Falk, S, Gitzel, R, Klement, P, Madeja, N, Rüchardt, D, Schiller, C, Schmidt, F, Wegener, D. (2021) Industry 4.0 and sustainability: Ten propositions how digital business models foster sustainability in Industry 4.0. Policy paper of the German National Platform Industrie 4.0, Berlin, http://dx.doi.org/10.2139/ssrn.3996223
Piller, F., Nitsch, V., Lüttgens, D., Mertens, A., Pütz, S., Van Dyck, M. (2022). Forecasting Next Generation Manufacturing: Digital Shadows, Human-Machine Collaboration, and Data-driven Business Models. Springer, Cham.
Schermuly, L., Schreieck, M., Wiesche, M., & Krcmar, H. (2019). Developing an industrial IoT platform—Trade-off between horizontal and vertical approaches. Proc. WI 2019, 32–46.
Sisinni, E., Saifullah, A., Han, S., Jennehag, U., & Gidlund, M. (2018). Industrial Internet of Things: Challenges, Opportunities, and Directions. IEEE Trans. Industrial Informatics, 14(11), 4724–4734. https://doi.org/10.1109/TII.2018.2852491
Thomas, L.D.W., Autio, E., & Gann, D. M. (2014). Architectural Leverage: Putting Platforms in Context. Academy of Management Perspectives, 28(2), 198–219. https://doi.org/10.5465/amp.2011.0105
Tilson, D., Lyytinen, K., & Sørensen, C. (2010). Research Commentary—Digital Infrastructures: The Missing IS Research Agenda. Information Systems Research, 21(4), 748–759. https://doi.org/10.1287/isre.1100.0318
van Alstyne, M. W., Parker, G. G., & Choudary, S. P. (2016). Pipelines, Platforms, and the New Rules of Strategy. Harvard Business Review, 94(4), 5462.
Van Dyck, M., & Lüttgens, D. (2019). Design Faktoren und Strategien für digitale Plattformgeschäftsmodelle im B2B-Kontext am Beispiel der Agrarindustrie. In J. Gausemeier et al. (Eds.), Vorausschau und Technologieplanung , 215–232.
Van Dyck, M., Lüttgens, D., Piller, F., Diener, K., & Pollok, P. (2021). Positioning strategies in emerging industrial ecosystems for Industry 4.0. Proc. 54th HICSS.
Vitali, M. (2022). Towards Greener Applications: Enabling Sustainable-aware Cloud Native Applications Design. Proc. CAiSE 2022 (Leuven). Springer LNCS 13295, 93-108. https://doi.org/10.1007/978-3-031-07472-1_6
Woodard, C. J. (2008). Architectural control points. Proc. 3rd Intl. Conf. DESRIST 2008, 359–363.
Yin, R. K. (2018). Case Study Research and Applications: Design and Methods (Sixth edition).
Yu, E., & Deng, S. (2011). Understanding Software Ecosystems: A Strategic Modeling Approach. Proc. IWSECO@ICSOB.
Yu, E. S.-K. (1996). Modeling Strategic Relationships for Process Reengineering. Ph.D. Dissertation, University of Toronto, Ca.