Innovation-Ecosystem Modeling using Multi-Domain-Matrices

Chloé Aben[1], Tim Wilschut[1], Marco de Baar[2]

[1] Ratio Computer Aided Systems Engineering B.V., the Netherlands
[2]Dutch Institute For Fundamental Energy Research (DIFFER), the Netherlands

Abstract: European countries are increasingly turning to nuclear energy to meet future energy demand. However, the current Dutch nuclear ecosystem is relatively underdeveloped and therefore requires substantial, targeted development and government incentives. Given the multifaceted and interdependent nature of such innovation-based ecosystems, systematic approaches are essential for effective and targeted policymaking. This article proposes a systems engineering methodology that uses Multi-Domain-Matrices (MDM) to represent and organize multiple facets of such ecosystems, and sequencing and clustering algorithms to find technology gaps, advantageous collaborations, and potential control points. The fundamental concepts and methodology are demonstrated via both an illustrative example and an application to the Dutch nuclear ecosystem.

Keywords: MDM, Innovation ecosystem, Graph theory, control points

1 Introduction

The deployment of nuclear energy, specifically Generation III fission, Generation IV fission, and fusion reactors, is being advanced in Europe as a strategic response to the growing demand for sustainable energy and the turbulent geopolitical climate (European Commission, 2026). In the Netherlands, the nuclear ecosystem of reactor developers, reactor operators, technology providers, and service providers is relatively underdeveloped due to a prolonged period of reduced societal and political support. Consequently, substantial scaling efforts are required to develop the nuclear ecosystem in a manner that enables a fully closed and resilient supply chain.

However, given the Netherlands' limited scale, a fully Dutch nuclear supply chain is unrealistic. In general, the Netherlands is knowledge and innovation-centered (Dutch Ministry of Economic Affairs and Climate, 2024) and is therefore more likely to contribute specific knowledge and technology to the (European) nuclear market. Strategizing which innovations and technologies to focus on requires an overview of the technological, fundamental, and social challenges that reactor developers, reactor operators, technology providers, and service providers of specific reactor types face. Additionally, multiple alternative (competing) solutions exist or are under development to resolve the same challenges. The challenges, associated potential solutions, and actors within the ecosystem are interrelated.

For example, selecting materials for new reactor types that withstand harsh environments and meet all regulatory standards is a non-trivial technological challenge faced by reactor developers and their suppliers. Underlying this challenge is the fundamental challenge of obtaining a proper understanding of the material degradation mechanisms within an environment representative of the specific reactor type, which is typically resolved by a knowledge or research institute. Translating the fundamental knowledge into a market-ready product is often realized by technology providers.

The ability of an actor to provide a solution to any of these challenges strengthens their position in the ecosystem. The ability to provide a key solution to a challenge encountered by many, or one that can be applied to many challenges, ensures a particularly strong and influential market position. This is especially true for challenges that arise in the development of several reactor types. This ability is also known as a "control point" (Bohnsack et al., 2024). Even though multiple definitions exist, we define a control point as an entity, such as actors, solutions, and challenges, that other entities rely on to a significant degree.

To develop such a unique solution that cannot be easily reproduced, extensive research and development in collaboration with educational institutions, research institutions, and industry is essential (Mascarenhas et al., 2018). Educational and research institutions possess niche expertise generally unavailable to industry, while industry brings specific use cases and challenges, resulting in rapid market adaptation and valorization. In the Netherlands, collaborations between these actors are often formed with governmental incentives.

From a governmental perspective, formulating a national innovation strategy and, consequently, deciding which collaborations among actors to facilitate is specifically challenging for the nuclear domain. The difficulty of policymaking stems from the inherent complexity of the sector: the technology and fundamental physics are complex, the supply chain is complex, and the regulations are complex. The multiple and overlapping facets of complexity stress the importance of a systematic approach that captures the interrelations among challenges, potential solutions, and actors. To that end, we aim to answer the following research question:

1. How to systematically identify technology gaps, advantageous collaborations between actors, and potential control points for an innovation-centered ecosystem, while remaining visually understandable and scalable?

Accurately representing and respecting the complexity of a (eco)system is a core competence within systems engineering, where methods for structuring dependencies are continuously developed. Building on that, we propose to integrate Multi-Domain-Matrix modelling into ecosystem mapping. By applying systematic methodologies to ecosystems, we can structure and shape their complexity, ensuring automatic, flexible, and correct visualization and mapping to support strategic decision-making.

The outline of the paper is as follows. Section 2 will clarify the concepts of ecosystem mapping and ecosystem orchestration. Additionally, existing methods and tools for ecosystem mapping are briefly discussed. Section 3 elaborates on the developed methodology, exemplified by a running example. In Section 4, the application of the methodology to a real-world usecase is presented. The article concludes in Section 5.

2 Ecosystem Mapping and Orchestration

According to (Autio, 2022), an innovation ecosystem is a community of hierarchically independent, yet interdependent heterogeneous entities that collectively generate a coherent, ecosystem-level output and related value offering targeted at a defined user audience. That is, they create a value chain. Ecosystem mapping refers to the process of representing entities and relations within said ecosystem. These entities may include suppliers, manufacturers, governments, users, and other relevant stakeholders. Relations among the entities, such as ownership, communication, collaboration, or competition, define the structure of the ecosystem. On the other hand, ecosystem orchestration refers to the intentional creation or manipulation of an ecosystem by facilitating connections between its constituent entities, as described by (Paquin and Howard-Grenville, 2013) and (Nambisan and Sawhney, 2011). Both mapping and orchestration are essential activities for actively strengthening an ecosystem.

When interpreting the definition of ecosystem more broadly to include organizations as a particular form of ecosystems, as argued by (Moore, 1993), we find that ecosystem mapping is widely used within businesses and associated innovation management to visualize internal structures and optimize network configurations. Several mapping approaches exist, each suited to different objectives. A commonly used method is the (social) network analysis, as reviewed by (Tabassum et al., 2018), where entities are represented by nodes and relationships are symbolized via edges. The resulting network can be centered around a single entity known as ego-networks, or may represent the relations between and among all entities, referred to as complete networks.

The straightforward way of applying network analysis is via manual mapping, which enables quick visualization and can serve as a useful basis for discussions. However, manual approaches are limited, as it only depicts obvious relations and are therefore susceptible to omissions and inaccuracies. For larger or more complex datasets, software tooling such as the open source Python package NetworkX (https://networkx.org/en/) can aid in the structuring and interpretation of the network. Other ecosystem mapping frameworks, such as the Ecosystem Pie Model, as coined by (Talmar et al., 2020), can be described as visual strategy tools to support decision-making and are therefore not designed to provide an accurate representation of ecosystems.

Another often-used technique for interpreting and shaping organizations is Dependency-Structure-Matrices (DSMs). DSMs are a visualization tool that describes the dependencies between elements from a single domain within a system. Here, nodes are placed on the columns and rows, and edges are symbolized via dots. DSMs have been widely applied in organizational and product development contexts. For example, (Sosa et al., 2007) analyzed the alignment of communication and technical interfaces within design teams. The DSM revealed mismatches and pinpointed where the internal structure of the project should be revisited. (Tian et al., 2022) modeled the knowledge dependence between team members from different departments to identify knowledge activities that could improve the efficacy of knowledge resource management. As described in (Eppinger & Browning, 2012), DSMs can be expanded to include elements from multiple domains, known as Multi-Domain-Matrices. For example, (Chang et al., 2021) visualized and grouped dependencies among multiple aspects of a product development project in an MDM to reduce the organizational complexity. Similarly, (Kabachi et al., 2014) used MDMs to systematically identify an efficient communication process map.

However, these applications focus on intentionally designed and often engineered systems, where the interfaces, whether physical, digital, or procedural, can be explicitly defined. DSMs were originally developed to coordinate such interfaces and ensure components interact correctly. Innovation ecosystem mapping operates in a fundamentally different context. Innovation ecosystems consist of actors whose interactions emerge from social, regulatory, or technological interdependencies rather than from engineered or procedural interfaces. Here, the aim is not to align physical components or communicational procedures, but to identify and strategically leverage the dependencies among actors for targeted policymaking. These dependencies may include shared challenges, knowledge dependencies, and complementary capabilities. Similar to those found in the work of (Winkel et al., 2013), in which the knowledge of a company is translated into a knowledge map to elucidate the structure of teams. It shows the knowledge that is unique to a particular employee or shared amongst the team. Hence, we argue that DSMs offer significant advantages for ecosystem analysis compared to other frameworks. Their format enables scalable visualization and the application of structuring algorithms, which are essential for large, complex (eco)systems. However, to meaningfully apply DSMs, the underlying dataset must be reconceptualized to capture social and technological interdependencies that define how actors relate to one another. In the next section, we will elaborate on the creation of the underlying dataset and the structuring and interpretation of the relations and domains using a running example.

3 Methodology

This article aims to find technology gaps, an optimal order of tackling challenges, potential collaborations, and control points within an ecosystem to support evidence-based policymaking. We define technology gaps as challenges for which no actor has yet developed an adequate solution. Potential collaborations arise when actors face similar challenges or complementary solutions, while control points refer to challenges, solutions, and actors that have a high degree of dependency with other entities. Therefore, we need to map the interdependencies between challenges, solutions, and actors to reconstruct the value chain to identify where collaboration or strategic leverage is most likely to emerge.

To construct this value chain, the approach consists of three main stages:

Ecosystem modeling: We collect a dataset comprising predefined domains, entities, and dependencies.

Dependency derivation and network generation: From the structured dataset, the indirect dependencies are derived, allowing for the generation of a complete network, which is visualized using an MDM.

Network structuring and analysis: Algorithms are applied to the graph to structure the dataset.

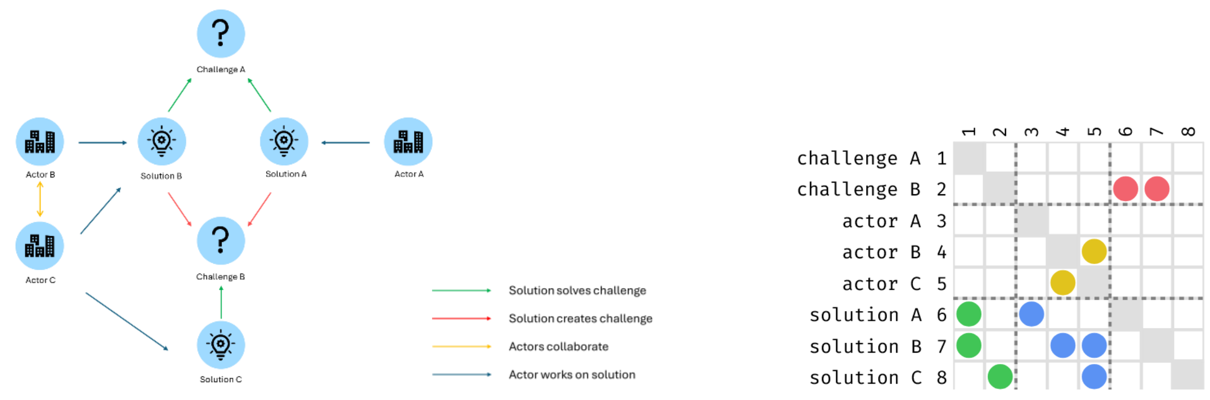
3.1 Ecosystem modeling

To model the ecosystem, we define the domains Challenges, Solutions, and Actors. The challenges include technological, fundamental, and social challenges. The solutions include (sub)solutions to any of the previously defined challenges. The actors include technology developers, service providers, suppliers, regulators, research institutes, and educational institutes. For the nuclear context specifically, we also include reactor types as an additional domain, and reactor developers and reactor operations as additional actors.

Each domain has nodes (entities) that are related to each other via a set of directed relations (i.e. edges), moving from a source → to a target. To be able to determine the dependencies between a predetermined set of challenges, solutions, and actors, we define the following directed relations between domains:

1. solution → challenge: a solution solves a challenge
2. solution → challenge: a new challenge emerges from a solution
3. actor → solution: an actor works on a solution
4. actor → actor: actors collaborate

An example ecosystem can look like the graph in Figure 1A.



A) B)

Figure 1. A) Graph representation of a simple ecosystem on the left. Challenge A has two possible solutions. From both solutions, challenge B emerges. Different actors are working to provide a solution. B) Multi-Domain-Matrix representation of the graph in Figure 1A.

For a full scale ecosystem, a graph-based visualization is visually overwhelming and quickly becomes messy. To structure the plethora of relations, we use Multi-Domain-Matrices (MDMs). Here, nodes are placed on the columns (source) and rows (target), and edges are replaced by dots. Mathematically, the graphs and matrices are equivalent, and no information is lost.

To collect the above relations for the nuclear ecosystem, interviews were conducted with 18 actors active in various roles in the nuclear ecosystem over a period of a few weeks. Information from 3 actors was received from third-party sources. Before the initial interview, a set of possible challenges and solutions was predetermined based on the literature. The main focus was put on technological and fundamental challenges and solutions, as opposed to social challenges. After each interview, the set of challenges and solutions was iterated. The interviews were followed up by email to ensure the correct interpretation of the discussions.

3.2 Dependency derivation and network generation

From the graph, we can use graph theory to derive indirect dependencies. For example, in Figure 1A , actor A works on solution A, which has an underlying challenge B. Therefore, actor A has an indirect challenge B and requires solution C, which is developed by actor C. This indicates that actor C might potentially be a (technology or knowledge) supplier to actor A.

These types of indirect dependencies are crucial to understand the underlying dependencies between entities and are difficult, time-consuming, and error-prone to derive manually. Therefore, the following dependencies are derived from the network based on the following conditions:

1. solution → solution: (sub)solution for
   If solution A has an underlying challenge for which there is a solution B, then solution B is a ` (sub)solution for solution A.
2. actor → challenge: actor has indirect challenge
   If a solution that an actor is working on has an underlying challenge, then the challenge is an indirect challenge of the actor.
3. actor → actor: actor is a potential supplier
   If a solution that actor A is working on has an underlying challenge, for which a solution is being developed by actor B, then actor B is a potential supplier for actor A.
4. challenge → actor: actor works on challenge
   If an actor works on a solution, it also works on the challenge it solves.

solution → actor: solution needed for actor
   If a solution that an actor is working on has an underlying challenge, then the actor needs the solution to that challenge.

challenge → challenge: underlying challenge for
   If challenge A has a solution that has an underlying challenge B, then challenge B is an underlying challenge for challenge A.

Figure 1B shows the MDM based on the direct relations captured by the ecosystem graph in Figure 1A. In Figure 2, the indirect relations are added as well.

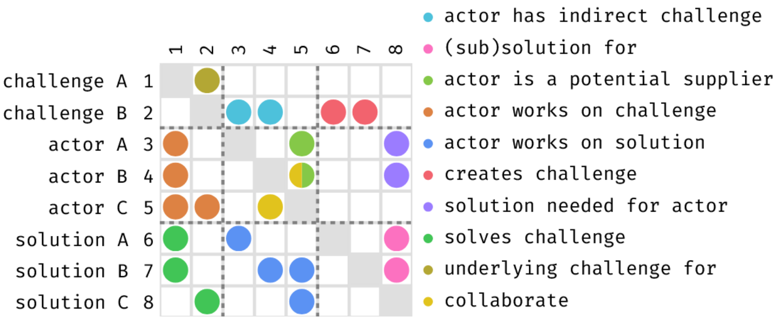


Figure 2. Multi-Domain-Matrix representation of the simple (eco)system, which includes derived relations.

From the MDM, we aim to structure the nodes and relations to find the following:

1. an optimal order of addressing challenges and creating solutions,
2. the likelihood of a node being a control point,
3. advantageous collaborations.

To do so, we will use sequencing, clustering, and traversing algorithms to structure and interpret the data. The open-source Python package RaESL as developed by (Ratio, 2026) is used to generate the network and the visualization.

3.3.1 Optimal order

From the graph representation in Figure 1A, it is evident that challenge B must be addressed first (or at the very least, taken into consideration) before working on challenge A to prevent costly rework and complicated interfaces. The same reasoning applies to the solutions. For targeted interventions, the goal is therefore to find an optimal order of tackling challenges and solutions.

In Figure 1, challenge B is referred to as a root challenge, as it does not have an underlying challenge nor a solution as a source in the graph. The last to-be-solved challenge or solution is referred to as a leaf. The order of tackling challenges and solutions with the least amount of feedback, meaning without repeating nodes, thus starts with root challenges, followed by the corresponding solutions, emerging challenges, and ends with leaf solutions or leaf challenges (if there is currently no envisioned solution). To systematically determine this order, we use sequencing algorithms.

In the MDM in Figure 2, the marks above the diagonal represent feedback marks, meaning that the node on the row (challenge A) is influenced by the node on the column (challenge B). We employ a combined Markov and Tarjans Strongly Connected Component algorithm as developed by (Ratio, 2026), such that the sum of the distances to the diagonal of the feedback marks is minimized, resulting in an optimal order of nodes. In Figure 3, the algorithm is implemented, and the ordering of solutions is such that it is optimal to start with solution C, followed by B and A and challenge B followed by challenge A.

3.3.2 Collaborations

From the data, we aim to find challenges and solutions that are strongly related and should therefore be addressed in conjunction, resulting in opportunities for advantageous collaborations between actors. To that end, we search for groups of nodes, also known as clusters, that have a lot of shared paths using a multi-level Markov clustering algorithm as described by (Wilschut et al., 2017). The clustering is not visualized in the running example, as it requires a larger dataset. However, the clustering algorithm is implemented in Section 3.

3.3.3 Control Points

Nodes that are control points occupy an influential position in the network and thereby contain a substantial number of dependencies. Therefore, to quantify the likelihood that a node is a control point, we employ the metric 'path count', which refers to the number of times a node is used in unique challenge-solution paths. The higher the number, the greater the probability that a node is a control point within the network.

To compute this metric, we aim to find all unique challenge-solution paths that start at root challenges and end at leaf solutions or leaf challenges. Root challenges do not have a solution as a source. However, to distinguish root challenges from challenges that do not yet have any dependencies assigned, the node count of root challenges is set to 1. During the traversing process, the partial paths are stored to detect and prevent cycles. The resulting paths for challenges can be viewed in Table 1. It shows that challenge A is a root challenge, and two paths that travel through challenge B. Similarly, there is a single path that travels through solution A and B, and two unique paths that travel towards solution C. Note: the algorithm assumes that there is at least one root challenge.

Table 3. Challenge-solution paths.

Node	Path
Challenge A	1. challenge A → solution A → challenge B → solution C 2. challenge A → solution B → challenge B → solution C
Challenge B	1. challenge B → solution C

As actors work on solutions, the path count of actors is equal to the sum of the counts of all solutions they are related to. In the example and use case, we do not consider indirect relations in the traversing algorithm. However, if desired, the same method applies.

Figure 3 shows the completed structured Multi-Domain-Matrix, including the optimal order of addressing challenges and solutions, and the path count. Here, challenge B is assigned a count of 2, as two paths are travelling over the node, both originating from challenge A. Actor C is assigned a count 3, because it inherits the counts of solution B and C due to their relation. It also indicates that in this system, challenge B, actor C, and solution C are most likely to be or become control points.

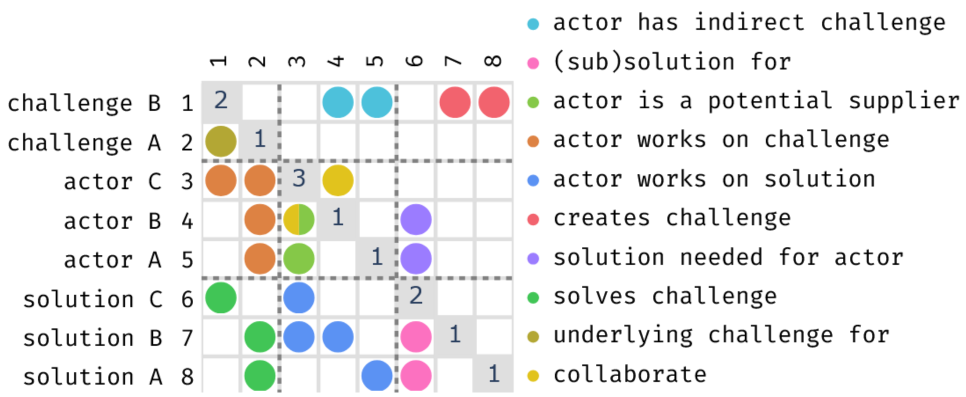


Figure 3. Sequenced Multi-Domain-Matrix with path count on the diagonal.

4 Result

To create an overview of a part of the Dutch nuclear ecosystem, interviews were conducted with various actors operating directly in or supplying to the nuclear sector. From these interviews, a dataset was built from which indirect relations were derived. The resulting dataset was structured using sequencing, clustering and traversing algorithms.

To enhance readability and scalability, the Multi-Domain-Matrix is split into 4 smaller MDMs, containing different combinations of domains and relations to visualize different aspects of the nuclear ecosystem. A summary of the information elucidated from the matrices can be found in Table 2. The underlying database for all matrices is the same, underlining the flexibility associated with the methodology.

Table 2. Summary of the information visualized in the matrices.

	Domains	**Information**
Figure 4	Challenge, actors, solution	Visualizes the challenges actors face, the solutions actors are working on or require, and the degree of control point.
Figure 5	Actors	Visualizes the current collaboration between actors and the possible collaborations based on their challenges and solutions.
Figure 6	Solutions, actors	Visualizes the solutions actors are working on and the critical solutions mentioned by actors.
Figure 7	Challenges, reactors	Visualizes the challenges associated with each reactor type.

4.1 Challenge, solutions and actors

Figure 4 depicts, from top to bottom, the domains challenges, actors, and solutions, and their relations. From this, multiple viewpoints can be retrieved. Firstly, in the top left and bottom right domains, there are no marks above the diagonal, meaning that the ordering of challenge and solution nodes is such that there are no feedback loops. Secondly, the figure shows that several challenge and solution nodes have a lot of similar dependencies. For example, all challenges related to material degradation (22-28) have the underlying challenge of mimicking a nuclear environment (19). Therefore, when developing a solution for mimicking a nuclear environment, the impact can be increased by accounting for other challenges the solution may potentially address. Thirdly, challenges that are currently not linked to a solution or actor, represent a gap and an opportunity within the ecosystem. In this case, challenges such as pollution of the moderator (0), incomplete specifications (2) and digital information exchange (4) are not related to specific solutions or actors and are thus opportunities to pursue. Lastly, the MDM indicates the likelihood of a control point. The nodes incomplete specifications (2), TNO (54), and embedded software (84) are assigned the largest path count. However, for all statements, it should be noted that the included nodes only represent a small part of the ecosystem, and therefore, the dataset should be extended to strengthen the conclusions.

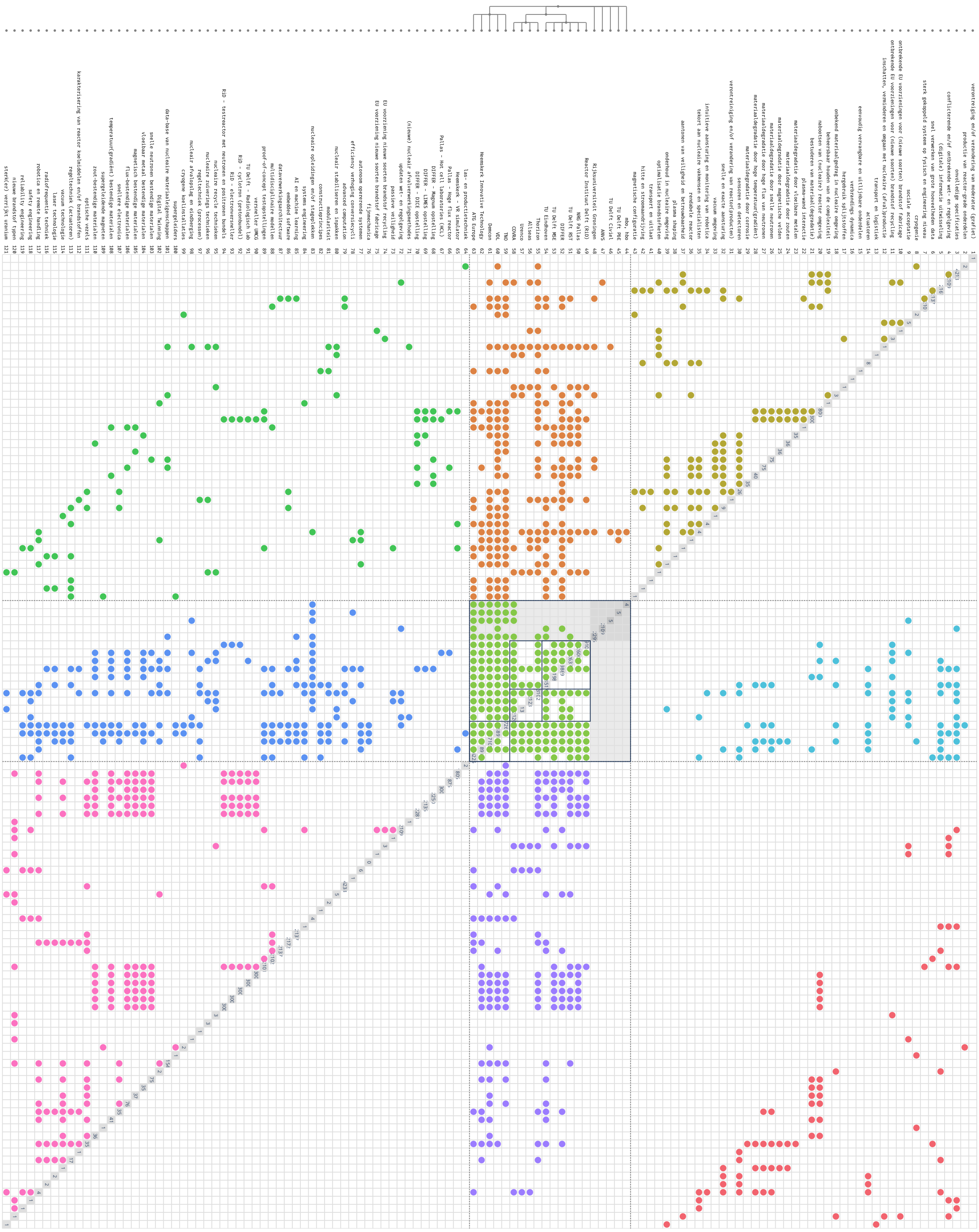


Figure 4. Rotated MDM that includes the domains challenges, actors and solutions. The actors are clustered, and the challenges and solutions are sequenced such that the ordering of the nodes prevents feedback. The number on the diagonal refers to the path count.

4.2 Actors

Figure 5 shows the current collaborations between actors in yellow and the possible collaborations in green, based on the (indirect) challenges the actors face and the solutions they develop or require. The actors are clustered into 6 different clusters. These clusters aid in the assessment of current collaborations and whether they align with the challenges that need to be addressed, or whether more effective projects and partnerships could be developed. For example, the cluster consisting of columns (6-11) and rows (6-11) shows that increased collaboration between research institutes and universities would be beneficial. The cluster at columns (6-11) and rows (12-15) illustrates that the collaboration between universities and the nuclear industry is relatively well-aligned.

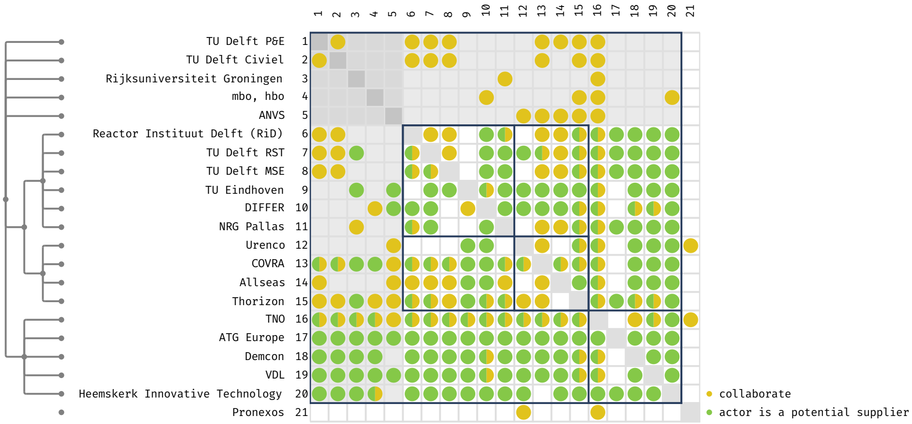


Figure 5. The DSM depicts the current collaborations in yellow, and the possible collaborations in green.

4.3 Actors and critical solutions

Figure 6 shows all the required solutions related to the challenges and the actors who develop them, as well as the critical solutions identified by actors as essential for their businesscase. From the MDM, we can easily recognize solutions that are developed by many, such as column (27). However, columns (18-19) are often mentioned as critical solutions with significantly fewer active actors. Moreover, column (56) is not even related to an active actor. Additional context, such as market potential, required investments, and excluded actors, is required to identify the cause. Still, incentives are crucial if the objective is to close the ecosystem with the current actors.

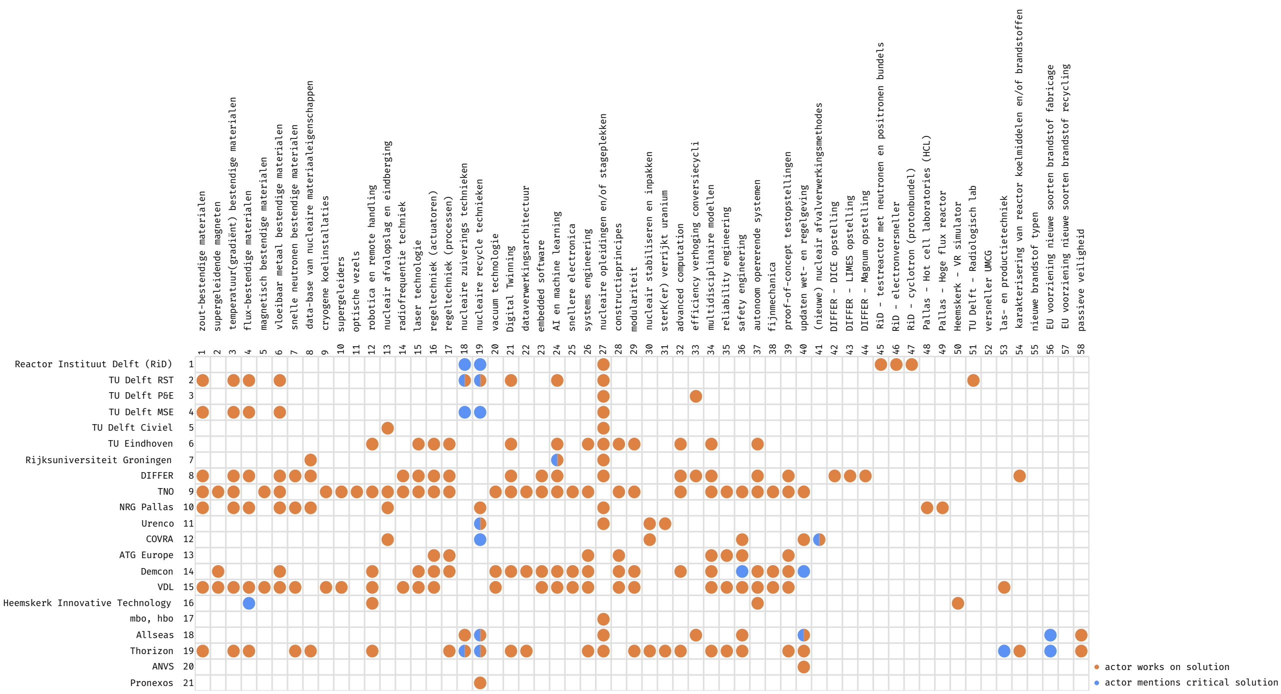


Figure 6. The transposed Mapping-Matrix shows the solutions actors are working on in orange, and the critical solutions actors have mentioned in blue.

4.3 Reactortype and challenge

Figure 7 visualizes the challenges that are associated with each reactor type. The MDM shows the challenges that apply to multiple reactortypes, and are therefore 'general' challenges, and those that are more specific. The strength of the matrix lies in the ability to find challenges that have widespread and long-term strategic benefits when solved, aiding in focused policymaking. The more edges in a column, the broader the application. For example, advancement in corrosion-resistant materials (1) specifically targeted for fusion reactors will inevitably result in improved corrosion-resistant materials for Fission GenIII reactors as well. Similarly, the challenge of estimating, handling, and reducing nuclear waste (28) applies to all nuclear principles. On the contrary, material degradation due to molten salts (6) is specifically related to Fission Gen-IV MoltenSaltReactors (MSRs). It should be noted that the difficulty of the challenge differs per reactortype, which could be visualized by annotating the relations with a weight, but is out of the scope for this project.

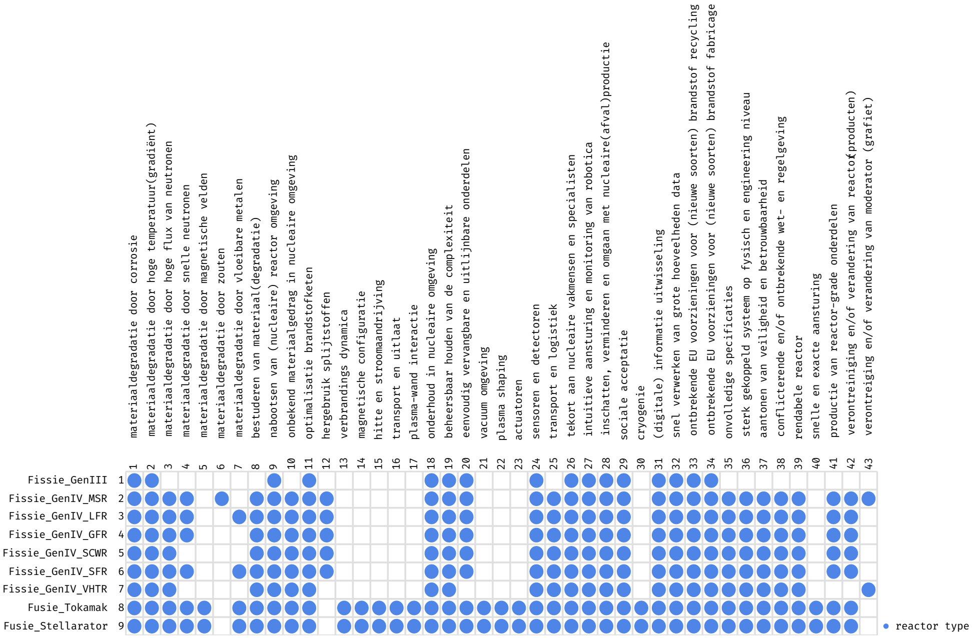


Figure 7. The Mapping-Matrix relates the challenges related to different types of reactors. The more dependencies a challenge has, the more general a challenge is.

5 Discussion and Conclusion

In this article, we presented a graph-based methodology for systematically mapping an innovation-driven ecosystem, aiming to identify control points and opportunities for coordinated ecosystem orchestration. Multi-Domain-Matrices (MDMs) are used to visualize the relations among actors, challenges, and solutions, and algorithms are employed to derive indirect relations and aid in interpreting MDMs. A network-oriented approach across multiple domains has proven advantageous for interpreting and optimizing an innovation ecosystem for two reasons.

Firstly, a graph elucidates the state of an ecosystem. From the graph, it becomes clear which technology solutions are being developed by whom and which challenges remain unaddressed. This understanding provides an opportunity for policymakers to steer regulatory frameworks and financial resources to accelerate the development of critical and disruptive technologies. It also aids the industry in focusing its efforts on developing a solution for an identified technology-gap, intending to acquire a control point within the ecosystem.

Secondly, ecosystems are not static but dynamic and evolving. The flexibility and reproducibility of the methodology support the inherent changing character of ecosystems. New actors may emerge, challenges may be solved, and different types of solutions or domains may be proposed. The approach can be used as a methodology to monitor the envisioned and actual evolution of the ecosystem and steer policy accordingly. The difficulty of the method lies in the generation of high-quality and complete data, as the shape and interpretation of the matrix are highly dependent on the input data. However, this is relevant for all ecosystem mapping approaches.

Given that only a limited set of challenges, solutions, and actors was incorporated into the usecase, the resulting conclusions should be interpreted within that scope. To derive more robust insights, the network should be expanded with additional actors at the national and preferably European level. Nevertheless, the usecase demonstrates that the MDM method can successfully find potential control points and identify promising collaborations that could strengthen the Dutch nuclear ecosystem.

References

Autio, E., 2022. Orchestrating ecosystems: a multi-layered framework. Innovation, 24(1), 96–109. https://doi.org/10.1080/14479338.2021.1919120

Bohnsack, R., Rennings, M., Block, C., Bröring, S., 2024. Profiting from innovation when digital business ecosystems emerge: A control point perspective. Research Policy 53 (3), 104961. https://doi.org/10.1016/j.respol.2024.104961

Chang, M., Yang, Q., Wang, Q., 2021. Multi-domain knowledge integration and organizational clustering in product development project. Proceedings of the 23rd International Dependency and Structure Modeling Conference (DSM 2021). https://doi.org/10.35199/dsm2021.4

Dutch Ministry of Economic Affairs and Climate, 2024. De Nationale Technologiestrategie: bouwstenen voor strategisch technologiebeleid. Government of the Netherlands, The Hague.

European Commission, 2026. Commission unveils strategy to bring Europe's first SMRs online by the early 2030s. European Commission, 10 March 2026. Available at: https://energy.ec.europa.eu/news/commission-unveils-strategy-bring-europes-first-smrs-online-early-2030s-2026-03-10_en

Eppinger, S.D., Browning, T.R., 2012. Design Structure Matrix Methods and Applications. MIT Press, Cambridge, MA. https://doi.org/10.7551/mitpress/8896.001.0001

Mascarenhas, C., Ferreira, J.J., Marques, C., 2018. University–industry cooperation: A systematic literature review and research agenda. Science and Public Policy 45 (5), 708–718. https://doi.org/10.1093/scipol/scy003/4829714

Moore, J. F. 1993. Predators and prey: A new ecology of competition. Harvard Business Review 71 (3): 75–86.

Nambisan, S., Sawhney, M., 2011. Orchestration processes in network-centric innovation: Evidence from the field. Academy of Management Perspectives, 25, 40–57. https://doi.org/10.5465/amp.2011.63886529

NetworkX Developers, n.d. NetworkX: Software for complex networks. NetworkX.org. https://networkx.org/en/

Paquin, R.L., Howard-Grenville, J., 2013. Blind dates and arranged marriages: Longitudinal processes of network orchestration. Organization Studies, 34, 1623–1653. https://doi.org/10.1177/0170840612470230

Ratio Case, 2026. RaESL Python library repository. GitLab. https://gitlab.com/ratio-case-os/python/raesl

Sosa, M.E., Eppinger, S.D., Rowles, C.M., 2007. Component connectivity, team network structure and the attention to technical interfaces in complex product development. SSRN Electronic Journal. https://doi.org/10.2139/ssrn.1032142

Tabassum, S., Pereira, F.S.F., Fernandes, S., Gama, J., 2018. Social network analysis: An overview. WIREs Data Mining and Knowledge Discovery, 8, e1256. https://doi.org/10.1002/widm.1256

Talmar, M., Walrave, B., Podoynitsyna, K.S., Holmström, J., Romme, A.G.L., 2020. Mapping, analyzing and designing innovation ecosystems: The Ecosystem Pie Model. Long Range Planning, 53, 101850. https://doi.org/10.1016/j.lrp.2018.09.002

Tian, S., Zhao, H., Xu, X., Mu, R., Ma, Q., 2022. Knowledge chain integration of design structure matrix-based project team: An integration model. Systems Research and Behavioral Science, 39(3), 462–473. https://doi.org/10.1002/sres.2866

Wickel, M. C., Schenkl, S. A., Schmidt, D. M., Hense, J., Mandl, H., Maurer, M., 2013. Knowledge structure maps based on Multiple Domain Matrices. InImpact: The Journal of Innovation Impact, 5(1), 5–16.

Wilschut, T., Etman, L.F.P., Rooda, J.E., Adan, I.J.B.F., 2017. Multi-level flow-based Markov clustering for design structure matrices. Journal of Mechanical Design: Transactions of the ASME, 139(12), Article 121402. https://doi.org/10.1115/DETC2016-59483

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Contact: C. Aben, Ratio Computer Aided Systems Engineering B.V., Heezerweg 290 5643KL Eindhoven, the Netherlands, c.p.a.aben@ratio-case.nl.