# Activity Sets in Multi-Organizational Ecologies:

# A Project-Level Perspective on Sustainable Energy Innovations

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**Abstract**

Complex innovations involve multi-organizational ecologies consisting of a myriad of different actors. This study investigates how innovation activities can be interpreted in the context of multi-organizational ecologies. Taking a project-level perspective, this study proposes a typology of four activity sets that are relevant in this context: strategic predevelopment, engineering, commercialization, and project management. The authors use archival and survey data on government-funded sustainable energy projects in the Netherlands to study the validity and relevance of the typology and show that the typology has discriminant and convergent validity. Results on the prevalence of the activity sets show that all four activity sets occur in sustainable energy projects, but to differing degrees. Furthermore, the typology is relevant because it helps to explain differences in innovation performance for complex innovations. Two activity sets – strategic predevelopment activities and commercialization activities – have significant and positive effects on innovation performance, whereas the two other activity sets – engineering and project management – do not. The data show that for sustainable energy projects, commercialization activities are often insufficient, but important to reach high innovation performance.



**Keywords**: Complex innovations; Multi-organizational ecologies; Innovation activities; Innovation systems; Sustainable energy innovations


**Running title:** Activities in Multi-Organizational Ecologies

**Highlights**

> Sustainable energy innovation projects require many different actors

> Actors in such projects undertake four different types of activities

> Strategic predevelopment activities positively affect performance

> Commercialization activities positively affect performance but are often lacking

## 1. Introduction

Complex innovations are new products (innovations) that consist of multiple components with unknown and unpredictable interactions [1]. Although complex innovations come in various forms, in this paper we focus on complex innovations in which the components are of a technological nature. Such complex innovations can be found in many sectors, including the transport sector (e.g., public transit smart cards), the health care sector (e.g., e-health systems) and the manufacturing sector (e.g., aircraft). In particular, sustainable energy innovations, such as closed-loop greenhouses and sustainable electricity production systems, are often complex. The complexity of an innovation increases with the number of components involved, the degree of customization, the number of design choices, the elaborateness of the system architecture, the range and/or depth of knowledge and required skills, and the variety of information inputs [2]. Developing complex innovations requires the mobilization and management of a wide set of resources, which are rarely found within a single organization [3]. Instead, their development requires active participation by multiple organizations [3, 4], often combining private and public actors [1], that complement each other [5], such as buyers, suppliers, nongovernmental organizations, knowledge institutes, and governments. For example, sustainable housing combines the inputs of architects, builders, suppliers, and local and national governments. Following Dougherty and Dunne [1], we refer to the heterogeneous set of actors involved in the development of a complex innovation as a multi-organizational ecology. In this paper, we focus on the activities undertaken in projects aimed at developing such innovations in multi-organizational ecologies.

Complex innovations have been studied in various literature streams. The first literature stream takes an innovation systems perspective [6-12]. An innovation system is defined as a “network of institutions in the public and private sectors whose activities and interactions initiate, import, modify, and diffuse new technologies” [13]. The innovation systems perspective focuses on innovation at an aggregate level, more specifically, the level of a technology or innovation category (e.g., electric vehicles in general) rather than the level of an individual innovation (e.g., the Tesla Roadster, the Nissan Leaf, or the Opel Ampera, in the context of electric vehicles). In contrast, this paper uses a disaggregated level of analysis by focusing on the development of individual innovation projects. Understanding individual innovation projects is important for understanding innovation systems [8]. Although innovation systems also consist of other elements (e.g., rules, regulations, and unwritten norms), innovation projects are arguably the most important building block of successful innovation systems: innovations systems without successful projects are unlikely to flourish, whereas even a limited number of successful projects may spur an entire innovation system. The project-level perspective complements the innovation systems literature, in particular, the study of activities within innovation systems [e.g., 8, 11]. Therefore, this study takes a project-level perspective on innovation activities in multi-organizational ecologies.

A second literature stream that has studied complex innovations is what we loosely refer to as the interorganizational network literature [e.g., 14, 15, 16]. The literature on interorganizational networks has mainly focused on the relationships among actors when developing (complex) innovations. However, this stream of literature has paid only scant attention to the activities that take place in such endeavors. We argue that a focus on activities is useful for understanding innovation management in multi-organizational ecologies because ultimately actors’ behavior is a major driver of an innovation’s success. Therefore, this paper focuses on the innovation activities that take place in multi-organizational ecologies. In doing so, it responds to repeated claims in the literature that management should be seen as a set of activities aimed at shaping relationships, understandings, and processes and that thus bring about task completion [8, 17-19].

A third stream of literature that is relevant to the study of complex innovations is the new product development (NPD) literature [e.g., 20, 21, 22]. Traditionally, this stream of literature has paid more attention to innovation activities than has the interorganizational network literature, but has predominantly done so within the boundaries of individual organizations, thereby ignoring the multi-organizational ecology context that characterizes complex innovations.

Thus, despite these rich literature streams, we still lack an understanding of the innovation activities undertaken in multi-organizational ecologies. This paper aims to fill that gap in the literature. With its focus on innovation activities, the NPD literature appears to be a good starting point for addressing the gap in the literature. However, findings from the NPD literature might not translate directly to complex innovations because the activities studied in the NPD literature do not take place in a context of multi-organizational ecologies. Therefore, we set out to investigate the following research question: how can innovation activities be interpreted in the context of multi-organizational ecologies? We address this research question in two ways. First, we acknowledge that some activities may need to be adapted to a context of multi-organizational ecologies. Second, we study which underlying generic types of activities exist in the context of multi-organizational ecologies, acknowledging that activities may be categorized into activity sets. Thus, the goal of this paper is to develop a typology of innovation activities that are relevant to the context of multi-organizational ecologies. Typologies are an effective means “to bring order out of chaos”, because they can transform complexity into well-ordered sets [23]. By constructing a typology, we can identify innovation activities and structure them by categorizing them into activity sets. To study the relevance of our typology, we develop and test hypotheses about the effects of the identified activity sets on innovation performance (i.e., the degree to which an innovation is perceived to be a success in terms of business objectives [24-26]).

This paper not only has theoretical relevance, but also offers insights to managers and public policy officers. A better understanding of innovation activities in multi-organizational ecologies constitutes a substantial benefit because coordinating and developing complex innovations, undertaken by multiple parties, remains a constant challenge for managers [27, 28]. Furthermore, this paper may help public policy officers in evaluating innovation projects for funding decisions. Furthermore, insight into specific activities enables actors to manage innovation projects in multi-organizational ecologies.

## 2. Conceptual background

### 2.1 Innovation activities in multi-organizational ecologies

As noted before, the NPD literature provides a good starting point for an investigation of innovation characteristics in multi-organizational ecologies. The NPD literature has a long and rich tradition in detailing the activities undertaken in innovation projects [20-22]. It tends to take a process approach. That is, many studies from this tradition have classified the activities in stages or phases that organizations go through over time when developing new products. For example, Urban and Hauser [29], Cooper [30], Song and Montoya-Weiss [20], Veryzer [31], and Schilling and Hill [32] all have identified innovation activities following this underlying idea of a sequential product development process [see 33 for an overview]. Although it is widely admitted that in reality, innovation processes are not completely sequential (i.e., product development processes may include feedback loops and phases may overlap), such NPD studies do provide a good overview of the innovation activities that are part of an NPD process.

Although they differ in the terminology that they use and the specific aspects that they emphasize, in general these NPD studies are relatively consistent in distinguishing among three broad categories of innovation activities: (1) *strategic predevelopment*, the activities aimed at finding the strategic direction for an innovation project prior to actually developing the new product, (2) the actual *engineering* of the new product, and (3) *commercialization*, the commercial activities aimed at marketing the newly developed product. Therefore, we propose these three broad categories of activities as core activity sets (see Figure 1).

However, as may be clear from the description above, the NPD literature tends to focus on the core activities of the NPD process and pays less attention to supporting activities, let alone the specifics of managing multi-organizational ecologies [34, 35]. Two other streams of literature (literature on innovation systems and literature on interorganizational relationships and networks) may be helpful in complementing the insights from NPD literature in various ways.

First, these two literature streams provide insight into a fourth activity set that reflects the communication and coordination activities that support product development projects. We refer to these activities as *project management* activities and propose that they complement the three core activity sets suggested by the NPD literature (see Figure 1). Accordingly, project management activities refer to the social aspects of innovation management that bind the functional activities together [15, 16, 36]. To reflect the fact that project management activities are not restricted to one specific phase of the NPD process, Figure 1 depicts project management activities as parallel to the three core activity sets. Thus, we distinguish between core and supporting activities.

***---- Figure 1 about here ----***

Second, the literature on interorganizational relationships and networks also suggests a distinction between task-oriented activities and network-oriented activities [36]. Task-oriented activities include articulating the strategic direction of an innovation project (strategic predevelopment) and developing and designing the innovation (engineering). Network-oriented activities include endorsing and launching an innovation (commercialization) and connecting the actors involved in the project (project management). Figure 1 depicts both this alternative categorization and the distinction between core and supporting activities.

Finally, the two literature streams may also help in translating the activity sets into a multi-organizational ecology context. Unlike the NPD literature, both the innovation systems literature and the interorganizational relationships and network literature explicitly account for the network or system in which an organization operates. In combination with the NPD literature, these two streams may reveal the peculiarities of innovation activities in a multi-organizational ecology context.

In the next section, we describe four activity sets in the context of multi-organizational ecologies in more detail and propose hypotheses on their relationship with innovation performance.

### 2.2 Hypotheses

#### *Strategic predevelopment activities*

The first activity set, strategic predevelopment, takes place before an innovation is developed. This strategic effort primarily involves seeking direction for the project. In a multi-organizational ecology, several actors work together on an innovation, each of which brings its specific resources to the table. Therefore, this activity set is of particular importance in this context. To achieve an optimal combination of resources, it is necessary to conduct a strategic analysis of what can be done with the available resources. The result often determines the strategy to follow for the rest of the innovation process. Two activities are part of this activity set: identifying opportunities and integrating innovative technologies.

First, by *identifying opportunities*, the actors define their project by appraising the needs that the innovation might satisfy and making decisions about which markets to enter [29, 37]. In multi-organizational ecology settings, market opportunities must be matched with the resources to be deployed by the various actors [1].

Second, *integrating innovative technologies* means that the actors combine the different technologies that they possess to develop the innovation. Generally, the emergence of a new technology involves a period of confusion; there are many ways to combine product subsystems [38]. In the context of complex innovations undertaken in multi-organizational ecologies, new knowledge may be created by combining separate technologies into new configurations [1]. Therefore, complex innovation projects often start with thinking about how the actors can best combine their different technologies.

Strategic predevelopment activities can be major drivers of innovation performance [39]. They are important to undertake because projects should not move directly from idea generation to large-scale development [40]. Considering the nature of complex innovations, strategic predevelopment is likely to have an even greater impact in this context. We hypothesize:

*H1* *Strategic predevelopment activities have a positive influence on performance in the context of complex innovations.*

***Engineering activities***

Engineering activities focus on actually building an innovation [16]. This activity set therefore lies at the heart of innovation and is important in any innovation project, not just projects for complex innovation. Designing and developing lead to a real innovation that can be launched and promoted. We distinguish between two engineering activities that display some overlap because they often go hand in hand: designing an innovation and developing an innovation.

*Designing the innovation* focuses on a determination of the likely functions and characteristics of a concept product [41]. It thus involves the evaluation and refinement of ideas for producing a product with attributes that indicate a high potential for market success [29]. The design process should lead to a product or service concept that can be developed further in the next step [29]. Some design processes lead to a blueprint rather than a concept. In complex innovations with elaborate systems architecture, designing a blueprint often precedes development.

The second activity, *developing the innovation*, focuses on the actual building of the innovation. If the design or blueprint is satisfactory, innovation construction begins [20] and turns the concept into a functioning product or service by not only constructing the innovation but also confirming its necessary processes [36]. Because engineering activities are necessary to create innovations [42, 43], we hypothesize:

*H2 Engineering activities have a positive influence on performance in the context of complex innovations.*

***Commercialization activities***

Commercialization activities aim to market an innovation and support its introduction. This activity set has particular importance in a multi-organizational ecology setting, where not only must potential customers adopt the new product, but also other parties need to be convinced that the innovation is worth supporting. In other words, multiple stakeholders determine the success or failure of a new product [44]. For example, in the case of sustainable housing, the builder must win over not only customers, but also technology providers, real estate developers, and policy makers. Four activities constitute this activity set: launching, promoting, brokering, and legitimizing the innovation.

First, *launching* reflects the implementation of an innovation on the market. An innovating firm must determine how to enter the market and which marketing strategy to use [8, 22, 29, 45]. In multi-organizational ecologies, launching entails deciding which actors will lead the introduction, which market to enter first, and determining the pivotal stakeholders in that market. Although launching overlaps with promoting the innovation, launching is the strategic precursor of promotion, and is thus more strategic in nature.

Second, *promoting the innovation* refers to making people aware of the innovation and influencing their adoption behavior accordingly [46, 47]. This activity focuses on the marketplace and should encourage new product trials [36], but in a multi-organizational ecology context, it also must spread to the entire network around the innovation. For example, actors may influence wider acceptance of an innovation by stressing its strategic importance [48]. Such actors often are champions, that is, “parties that informally emerge to actively and enthusiastically promote innovations” [49, p. 264].

The third activity, *brokering*, focuses on connecting with new parties that are important for the success of the innovation, such as opinion leaders in the market. In the context of complex innovations developed in a multi-organizational ecology, cooperation with additional partners is often necessary, and brokers can play an essential role by introducing new partners that cooperatively attain better innovation performance [15]. This activity highlights new relationships, such as building new linkages among previously unconnected parties [36, 45, 48, 50, 51]. For example, so-called network champions introduce new relationships when parties at multiple levels must interact to adopt the innovation [52].

Finally, *legitimizing the innovation* involves lobbying for its approval in the eyes of other parties [8, 53, 54]. Actors performing this activity leverage their personal and professional relationships and use their own professional judgment to signal the trustworthiness of the innovation [36]. Actors with the power to drive the project and help overcome obstacles that may arise thus can legitimize the project in the eyes of others [15]. Particularly in emerging or very innovative industries, some parties may hesitate to adopt innovations; a lack of legitimacy leaves them not knowing what to expect [55]. To gain legitimacy, an innovation may rely on association or cooperation with well-reputed, established entities. In our context of complex innovations, legitimizing can be particularly crucial because of the uncertainty that actors have about accepting an innovation created by other actors. Because commercialization activities are important for innovation performance [22, 56], especially considering the nature of complex innovations, we hypothesize:

*H3* *Commercialization activities have a positive influence on performance in the context of complex innovations.*

***Project management activities***

Project management activities are communication activities aimed at harmonizing exchanges among project participants. Project management activities span the other activity sets in that they are needed to execute all other activities satisfactorily. They are very relevant in multi-organizational ecologies where several actors with diverging backgrounds and interests work together to innovate. This activity set also can simplify exchanges and facilitate cooperation in networks with many different actors [14, 16]. Three activities fall within this activity set: task coordinating, communicating with project participants, and communicating with external participants.

*Task coordinating* involves the management of task-related exchanges across multiple participants. This activity is particularly important in multi-organizational ecologies because many participants need to be informed about the tasks that must be completed. Because projects have multiple participants and project-related tasks may be highly interrelated, task coordination is a vital element [57-59].

*Communicating with project participants* refers to nonfunctional communication aimed at creating an atmosphere of solidarity within the network to overcome tension or conflict [57]. It goes beyond communication about the tasks that need to be executed and involves frequent, high-quality contacts. Because innovation processes generally result from communication and information exchanges [34, 35], communication quality is important. In multi-organizational ecologies this activity may be especially relevant to create an “esprit de corps” within the project team.

Finally, in *communicating with external participants,* dyadic communication takes place between a project participant and an external participant. This activity has two goals. First, the two sides should discuss which tasks to complete, so that their communication has a task-related aspect. Second, regular contact with external participants is important for the progress and success of the innovation. Particularly in multi-organizational ecologies, more tasks must be coordinated externally, and external participants need to feel like they are a part of the innovation process.

The multitude of actors in multi-organizational ecologies is likely to make project management activities highly important for innovation performance [1]. Therefore, we hypothesize:

*H4* *Project management activities have a positive influence on performance in the context of complex innovations.*

## 3. Methods

### 3.1 Empirical context and research approach

This study uses the sustainable energy sector as its empirical context because it offers a natural biotope for studying complex innovations [1]. The ongoing transition to sustainable energy involves a broad variety of actors, with widely varying interests, that must participate to address the complexity in this field [60]. We concentrate on projects funded by the Energy Transition and Innovation Programs of the Ministry of Economic Affairs, Agriculture and Innovation in the Netherlands, whose goal is to establish a sustainable long-term energy supply through structural changes. The main focus of the program is to support projects that bring together multiple parties, bundle their resources, and thus induce the structural changes needed to achieve a sustainable energy supply by 2050. Therefore, this context can serve as an example that aids in a better understanding of innovation activities in multi-organizational ecologies.

In this study, we follow a quantitative research approach, which allows us to measure activities over a relatively large cross-section of innovation projects and assess how well the data fit the proposed typology. A quantitative cross-sectional approach fits within a large tradition in NPD research, which tries to use product development activities to explain innovation performance (see [22]). The Energy Transition and Innovation Programs are sufficiently rich to provide a relatively large sample of innovation projects for this purpose.

Examples of the innovation projects within the Energy Transition and Innovation Programs include the development of a new bioplastic, the development of an energy-efficient truck (with a hydrogen fuel cell and a wheel motor) for inner-city transportation, and the construction of a sustainable residential area (involving the replacement of old apartments by new apartments that have closed energy loops and sustainable energy sources). Innovation projects in the current study span seven subsectors: sustainable mobility, green raw materials, chain efficiency, alternative gas, sustainable electricity, built environments, and energy-supplying greenhouses (Table 1).

***---- Table 1 about here ----***

### 3.2 Data

We obtained data from two sources. First, we used archival data to identify and describe projects, according to the project files kept by the government agency administering the Energy Transition and Innovation Programs. These project files contained the grant applications, all interim reports on the project, and various supporting documents. From these files, we identified 189 projects and extracted all of the project leaders' names. The project leaders were grant applicants and were required by the government agency to maintain an overview of the entire project for monitoring purposes. Thus, we judged the project leaders to be competent key informants, which makes the use of a single informant for the activities and performance of each project acceptable [61]. An expert from the government agency helped us to code background information about the innovation projects, such as the subsectors identified in Table 1.

Second, a telephone survey was used to collect data from project leaders about the fulfillment of activities and their projects' perceived innovation performance. Although using a telephone survey limits the number of questions to be included in the study, it did have the advantage over a mail or electronic survey of a high response rate and the opportunity to clarify potentially ambiguous issues in the questionnaire (for example, the definition of a project participant) [62].

The telephone survey respondents were recruited as follows. Prior to the survey, the leaders of the 189 identified projects received a letter from the government agency administering the grants, requesting their participation. Of the 189 project leaders, 122 agreed to participate in the telephone survey, yielding a response rate of 64.6%. Two projects were deleted because of the high number of missing values, yielding a net sample of 120 projects, which ranged in size between 2 and 39 actors, with a mean value of 7 actors.

**3.3 Measures**

The survey's measures included activities and innovation performance. Activities were operationalized using 11 items grouped into the four activity sets that we conceptualized in the theory section (see Table 2). Each activity set was measured by creating a summated scale of the corresponding items. Each item was measured using a Likert-type scale that respondents used to rate the following statement: "In this project, a lot of attention has been paid to [activity]" (1 = "strongly disagree" and 5 = "strongly agree"). In this manner, we measured perceptions about the degree to which an activity was undertaken because a more objective measure of activities (e.g., in terms of hours or deployed resources) would likely have been unreliable and difficult to compare across activities and projects.

The items for measuring activities were developed in cooperation with several experts provided by the government agency that administered the grants. First, specific activities were formulated in a workshop meeting with the experts. Then, using multiple iterations, the items were further developed, constantly checking for understanding and relevance of the items. In this stage, experts from the government agency and two specialists from a data collection institute specializing in business research commented on the set of items, while trying to maintain the parsimony dictated by the use of a telephone survey. These discussions and pretests among experts in the field were aimed at ensuring that respondents would understand the description of the activities. The items were formulated so that respondents could easily relate to and understand them, and were kept as succinct as possible so that they would be suitable for use in a telephone survey. The items used to operationalize the activity sets appear in Table 2.

Some items referred to “project participants” and “external participants”. Telephone interviewers were instructed to explain to the project leaders that “project participants” were the grant co-applicants and that “external participants” were project participants that were not part of the formal grant application. Because the project leaders were responsible for the grant application and monitoring, this explanation was thought to be clear.

***---- Table 2 about here ----***

Innovation performance (the degree to which an innovation is perceived to be a success in terms of business objectives) was measured using items that referred to technical success, market success, financial success, competitive advantage, cost reduction, and sustainability (see Table 2). The first five items were derived from the literature [24-26]. Because the innovations in our sample aimed to stimulate a system change toward sustainability, a sixth item was developed to capture this objective: “This project contributes to a sustainable society.” All six items for measuring innovation performance were weighted equally in a summated scale to compute an overall measure of innovation performance.

Finally, we included several variables in the analyses to control for systematic effects on innovation performance that were unrelated to the activity sets. The control variables were as follows: subsector (using the categories in Table 1), investments in the project (in Euros), project duration (in years), size (in terms of project participants), type of grant (i.e., whether a grant was obtained for the trial development of an innovation versus the implementation of an existing innovation), and whether the project was being led by a small or medium-sized enterprise (SME). We gathered these data from archival project files.

### 3.4 Discriminant validity

To establish the discriminant validity of the measurements for the four conceptualized activity sets, we estimated alternative measurement models using confirmatory factor analysis (CFA). CFA is a method to estimate and subsequently fit a theory-driven model of the relationships among observed measurements and latent variables or factors [63]. As alternative and theoretically plausible operationalizations of activity sets, we specified several measurement models (Table 3). Model 1 does not distinguish activity sets at all and thus includes all eleven activity measures in one dimension. Model 2 divides the activities into two activity sets: core and supporting (as depicted in Figure 1). The eight strategic predevelopment, engineering, and commercialization activities are core activities, whereas the three project management activities are supporting activities. Model 3 divides activities into two different activity sets and distinguishes task-oriented activities from network-oriented activities (as depicted in Figure 1). The four strategic predevelopment and engineering activities are task-oriented, whereas the seven project management and commercialization activities are network-oriented. Models 4 and 5 are three-factorial variants of Model 3. In Model 4, all seven commercialization and project management activities merge into one construct (network-oriented activities), and the remaining two activity sets are as proposed in our theoretical framework. In Model 5, the four engineering and strategic predevelopment activities represent a single construct (task-oriented activities), leaving the remaining two activity sets as proposed in our theoretical framework.

***---- Table 3 about here ----***

None of these alternative models is supported by our CFA. As we show in Table 3, the $\chi^2$ differences between each alternative model and the hypothesized model are all significant at $p < .005$, suggesting that the hypothesized model, which operationalizes activities in four activity sets, is psychometrically superior to all alternative models. Furthermore, the hypothesized model represents the data well, with a $\chi^2$ that does not differ significantly from 0 ($\chi^2 = 49.386$, $p = .102$), a good confirmatory fit index (CFI = .968) [64], and a satisfactory root mean square error of approximation (RMSEA = .050). The CFA results thus indicate that the hypothesized model with four separate activity sets best represents the data.

Another method for assessing discriminant validity is to test whether each of the correlations for all pairs of constructs is significantly different from 1 [65]. All of the correlation estimates across the four activity sets in the hypothesized model differ significantly from 1 ($p < .005$), again demonstrating sufficient discriminant validity across all four activity sets.

### 3.5 Convergent validity and reliability

Convergent validity was assessed by examining the item-to-total correlations and by performing CFAs on the activity and innovation performance measures. In Table 2, we present the item-to-total correlations between the individual items and their respective constructs. All item-to-total correlations for the activity sets are significant ($p < .01$) and range between .740 and .897. Furthermore, the standardized factor loadings from the CFA should be .5 or higher [63], as is the case for all of the items in the activity sets. The convergent validity for the activity sets is thus satisfactory.

For the dependent variable, innovation performance, one performance construct emerges from the CFA ($\chi^2$ = 10.242, df 7, $p$ = .175, CFI = .979, RMSEA = .062). The factor loadings are greater than .5, with the exception of the market acceptance item, which is close to .5. We retained this item, considering that the literature identified it as an important aspect of innovation performance. Furthermore, the item-to-total correlations for all items of innovation performance are significant ($p < .01$) and range between .627 and .765.

We assessed reliability by looking at the internal consistency of the constructs that were measured by summated scales. Cronbach's alphas for the four activity sets and the performance construct (see Table 2) reveal four alpha coefficients greater than .7, which indicate satisfactory reliability [66]. The remaining alpha coefficient, for strategic predevelopment, is close to .7, which is acceptable considering the exploratory nature of this study [63].

### 3.6 Common method variance

In this study, the independent and dependent variables were measured by the same rater using the same method of data collection, which could result in common method variance. Common method variance implies that variance in observed scores can be partially attributed to a methods effect. To examine the potential for our results to be explained by common method variance, we performed Harman's single factor test [67] by entering all of the study's measures into an exploratory factor analysis and restricting the analysis to the emergence of one factor only. The results show that 16.8% of the variance is explained by a single factor, indicating that common method variance is an unlikely explanation for our results.

## 4. Results

First, we explore the prevalence of the activity sets to study their salience by calculating mean scores for each construct representing an activity set. Table 4 shows descriptive statistics along with correlations between the study's constructs. The results show that all activity sets are to some degree executed in the innovation projects. The mean scores for the activity set constructs reveal that project management and commercialization activities are the least prevalent, with means of 3.86 and 3.72, respectively. In contrast, strategic predevelopment and engineering activities are executed to a greater extent (4.27 and 4.34, respectively). The differences in means between strategic predevelopment and engineering on the one hand and commercialization and project management on the other hand are significant (strategic predevelopment – commercialization: t = 6.274, $p = .000$; strategic predevelopment – project management: t = 4.565, $p = .000$; engineering – commercialization: t = 6.470, $p = .000$; engineering – project management: t = 5.010, $p = .000$). Thus, strategic predevelopment and engineering activities are significantly more prevalent than commercialization and project management activities. The relatively low standard deviation for engineering activities ($SD = .786$), combined with the high mean, may indicate that the projects do not differ greatly with respect to engineering activities, and that in almost all projects, a great deal of attention was paid to engineering activities.

A closer look at the correlations among the activity sets reveals that, whereas all correlations differ significantly from zero ($p$ < .05), only project management and commercialization display a strong correlation ($r$ = .565), indicating that these two types of activities often occur together.

***---- Table 4 about here ----***

**4.1 Estimated model**

To test our hypotheses, we estimated a multiple regression model using ordinary least squares with innovation performance as the dependent variable. We included the four proposed activity sets as independent variables, as well as six control variables. We also tested for interaction effects among the activity sets and between the activity sets and the control variables, but we found no significant interaction effects on the dependent variable. Therefore, we do not take interaction effects into consideration in the final model. The R-square value is .261 for the final model. Considering that the model included only activity sets and some control variables, we find the model fit to be acceptable. Table 5 shows the full results of the estimation.

***---- Table 5 about here ----***

Strategic predevelopment activities ($\beta$ = .226, $p$ = .024) and commercialization activities ($\beta$ = .267, $p$ = .019) have positive and significant influences on innovation performance, in support of H1 and H3, respectively. However, engineering and project management activities do not have significant effects on innovation performance, so we must reject both H2 and H4. Closer inspection of the standardized betas in Table 5 shows that strategic predevelopment and commercialization are the strongest predictors of innovation performance in our model.

As shown in Table 5, the control variables have no significant effect on innovation performance. The applicable subsector, financial investments in the project, project size and grant type have no effect all on innovation performance. However, whether the project was led by an SME has a marginally significant ($p < .1$) positive effect on innovation performance, suggesting that projects led by organizations with fewer than 250 employees perform somewhat better than projects led by larger organizations. Perhaps small companies are more eager to do their best on a project because they depend much more on its success. Project duration also has a marginally significant ($p < .1$) positive influence on innovation performance: projects that take more time exhibit greater innovation performance. This could indicate that a certain amount of time is needed to ensure that projects succeed.

## 5. Discussion

The results of the model estimation show that using our proposed typology of innovation activities in the context of multi-organizational ecologies has some relevance because by using our typology of four activity sets and a limited number of control variables, we are able to explain more than one-fourth of the variance in innovation performance. However, not all of the activity sets within the typology significantly influence innovation performance. Therefore, we reflect on the effects on innovation performance for each of the activity sets below.

Our findings show that strategic predevelopment activities have a relatively strong and positive influence on innovation performance in the context of multi-organizational ecologies. This result is in line with findings in the traditional NPD literature [22, 39, 68] suggesting that market studies and preliminary market and technical assessments are activities that are crucial to the success of new products. Our results therefore suggest that strategic predevelopment activities are also important in a multi-organizational ecology context. On average, the projects in our study score high on strategic predevelopment activities, which suggests that project participants are aware that such activities are important.

Our results also show that commercialization has a relatively strong and positive impact on innovation performance in the context of multi-organizational ecologies, corresponding to findings for more traditional NPD projects [39, 56, 69] suggesting that a strong market launch is a distinguishing characteristic of successful innovation projects. The findings also suggest that commercialization activities are generally underrepresented in complex innovation projects, as indicated by a relatively low mean. Apparently, there remains room for improvement with respect to commercialization activities in many projects in multi-organizational ecologies.

Engineering activities do not have a significant influence on innovation performance, which is a result that is different from the results of prior research, which found that technological activities represent the core of value creation and contribute substantially to performance [42, 43, 70]. In our study of multi-organizational ecologies, engineering activities do not explain differences in performance. We do not mean to suggest that engineering activities are unimportant; rather, the insignificant effect of engineering activities may indicate that organizations are well aware of the importance of engineering activities, as implied by the high mean for those activities, which suggests that on average, projects put a great deal of effort into these activities. Engineering activities may be seen as a hygiene factor, which is understood by most projects and which therefore ensures a sufficient activity level. Thus, it is possible that the absence of a significant effect is caused by a “screening bias”: the government agency has screened all of the projects on their technological merits, which has caused our sample to be limited to projects in which a great deal of attention was paid to engineering activities.

Finally, we find no significant influence of project management activities on innovation performance. This result is unexpected; particularly in multi-organizational ecologies, we would expect projects to need strong project management activities. Previous studies have suggested that many organizations struggle with proper project management [27, 28]. We offer two possible explanations for not finding a significant influence of project management activities on innovation performance. First, the projects in our sample were relatively small in terms of the number of participants, so perhaps project management was comparatively easy to undertake. Second, the projects in our study were all funded by a government agency that required significant, detailed information in the grant applications about how each project would be managed. Again, there may be a "screening bias" that explains why in our study, project management has no significant effect. Both explanations suggest that, even given that the mean score for project management is not extremely high, our sample may be characterized by projects that devote sufficient attention to project management activities.

## 6. Conclusions

In this study, we propose that innovation activities in the context of multi-organizational ecologies can be interpreted using a typology of four activity sets. We arrived at this typology by translating activities, mostly taken from the traditional NPD literature, into the context of multi-organizational ecologies. The four activity sets proposed by our typology are demonstrated to be empirically distinct (i.e., to display sufficient discriminant validity). Furthermore, the measurement model that represents our typology is psychometrically superior to the alternative models suggested by the literature. Furthermore, the typology is shown to have relevance, because two of the four activity sets are able to explain differences in innovation performance.

With our typology, we offer a framework for the study of complex innovations in a multi-organizational ecology context by focusing on activities at the innovation project level. In doing so, our study contributes to three literature streams.

First, our study expands the interorganizational network literature by focusing on activities. Previous studies have investigated complex innovation involving multiple actors [71-73], but usually focus on relationships between actors, rather than the activities undertaken by those actors and the impact of their activities on performance. Our study results show that focusing on activities can help to explain differences in innovation performance for complex innovation because some activity sets are shown to have significant effects.

Second, this study complements the traditional NPD literature that has investigated critical activities for successful NPD [20-22, 74]. Although this stream of literature has primarily focused on NPD in single organizations, our study shows that it is possible to translate such activities into a context of complex innovations involving multiple actors. This issue is not trivial: at first sight, three of our proposed activity sets (strategic predevelopment, engineering and commercialization) may seem to resemble findings from prior NPD studies, but the meaning of some of our activity sets differs in the context of complex innovations undertaken in multi-organizational ecologies. In strategic predevelopment, complex innovation projects must integrate techniques from a diverse set of actors, and those actors must critically assess these technologies (and their combination) before embarking on a project. Commercializing complex innovations entails brokering and legitimizing, which demands that more attention be paid to a broader set of stakeholders who must be convinced of the value of the innovation. Only engineering activities appear relatively similar in content to what we already know from the NPD literature. A fourth activity set, project management, is suggested by our literature review and could constitute a worthwhile addition to the NPD literature. Whereas we did not find empirical support for the relevance of this activity set, it could be an interesting topic for further investigation.

Third, this study contributes to the innovation systems literature by offering a project-level perspective on innovation in systems and proposing a typology of activities undertaken in innovation projects. Although prior research has also suggested typologies [e.g., 8], these typologies do not focus on the project level and have remained mostly untested, quantitatively speaking. Whereas the innovation system literature has contributed substantially to our understanding of how technologies evolve at the aggregate level, it has only partially acknowledged the activities that take place at the project level. Therefore, our study provides a first step to complement the innovation system literature by offering an approach to study activities at the project level. This is important because system change (the dependent variable in many innovation system studies) requires some individual projects to succeed [75]. In other words, system change is likely to be at least partially based on grassroots initiatives. Although system change certainly involves more than simply adding up individual projects in the relevant system, our approach provides a basis for understanding complex innovations at the project level and thus presents a new cornerstone for triggering system change.

## 7. Implications for practice and further research

Our study provides useful insights into the determinants of innovation success, which are important for both managers and policy makers. It may help managers understand how to influence innovation performance, i.e., which activities to undertake. Similarly, policy makers can use this study's insights to better understand which projects are the most likely to spur system change, which can be especially helpful for evaluating grant applications. For example, subsidy-granting institutions may wish to require applicants to include detailed activity plans because such plans will help the institutions to derive a better estimate of projects' chances for success.

In addition, our study offers opportunities for further research, some resulting from the status of our study as a first step toward a new perspective on complex innovations and others stemming from our study's limitations. Among the latter, we note that our study involves a relatively small, homogeneous sample from one sector in one country. Further research should investigate the extent to which our findings generalize to other sectors and other countries, preferably using larger sample sizes. Our sample also may be biased toward relatively successful projects, in that it includes only projects that had previously been judged as good enough to be subsidized. Additional research should investigate the effects of this bias. Additionally, this study used a single informant for each project. Given the complex nature of the projects studied, the perspectives of multiple informants could add meaningful information. Although the measures of the activities were carefully constructed, these items for measuring activities relied completely on self-reported, relative perceptions. There is a need to validate such measures by establishing inter-rater reliability using multiple informants. Furthermore, our study relies on a subjective performance measure; therefore, it may be a good idea to include an objective performance measure, such as revenues generated. Finally, our study's quantitative approach inherently lacks the richness of a more qualitative approach. A more qualitative approach could study the social context of the activities that are undertaken in a multi-organizational ecology, including issues such as trust among actors within an ecology, inter- and intra-organizational communication within an ecology and why some organizations or actors are more likely to fulfill certain activities than others, using, for instance, a role-theoretic perspective [76].

The current study may be extended in several interesting ways. For example, we do not consider how the impacts of the various activity sets change over the course of an innovation project, which would require a longitudinal approach. Another interesting avenue for further research would be to focus on combinations or configurations of activity sets, rather than the effect of individual sets. Such an investigation likely would provide more insight into the relative distribution of required activity sets, though it would require a larger sample size than we used. Such a study could investigate the distribution of the activity sets over various actors, that is, who should be doing what? Prior research [77] indicates that an actor's activities should be congruent with its resources (e.g., skills, competences). An extension of our proposed model thus could include resources. Another extension may add moderators (e.g., innovation radicalness) to determine whether the impact of activity sets differs by type of innovation. Thus, we present a preliminary approach to a project-based perspective on complex innovations; we hope it sparks further research in this area.

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**Table 1: Sample profile by subsector**

| *Subsector* | *Frequency* | *Percentage* |
|---|---|---|
| Built environment | 51 | 42.5 |
| Alternative gas | 17 | 14.2 |
| Chain efficiency | 15 | 12.5 |
| Sustainable mobility | 11 | 9.2 |
| Energy-supplying greenhouses | 11 | 9.2 |
| Sustainable electricity | 6 | 5.0 |
| Green raw materials | 9 | 7.5 |
| *Total* | *120* | *100.0* |

**Table 2: Measurement items, loadings, Cronbach's alphas, and item correlations**

| *Construct and items* | *Cronbach's alpha* | *Standardized loading CFA* | *Item-to-total correlation* |
|---|---|---|---|
| *Strategic predevelopment* | .666 | | |
| A lot of attention has been paid to identifying the opportunity. | | .695 | .863** |
| A lot of attention has been paid to integrating the innovative technologies. | | .718 | .868** |
| *Engineering* | .752 | | |
| A lot of attention has been paid to designing the innovation. | | .634 | .894** |
| A lot of attention has been paid to developing the innovation. | | .951 | .897** |
| *Commercialization* | .773 | | |
| A lot of attention has been paid to launching. | | .652 | .789** |
| A lot of attention has been paid to promoting the innovation. | | .797 | .811** |
| A lot of attention has been paid to brokering. | | .671 | .740** |
| *Project management* | .711 | | |
| A lot of attention has been paid to task coordinating. | | .582 | .773** |
| A lot of attention has been paid to communicating with project participants. | | .604 | .789** |
| A lot of attention has been paid to communicating with external participants. | | .809 | .829** |
| A lot of attention has been paid to legitimizing the project. | | .604 | .750** |
| *Innovation performance* | .747 | | |
| The innovation is a technical success. | | .620 | .643** |
| The innovation has high market acceptance. | | .466 | .719** |
| This innovation yields a great competitive advantage. | | .557 | .765** |
| The project results in a profitable innovation. | | .570 | .744** |
| The project leads to cost reductions. | | .603 | .716** |
| The project contributes to a sustainable society. | | .604 | .627** |

** Significant at $p < .01$ (two-tailed).

**Table 3: Alternative measurement models for activity sets (based on CFA)**

| *Model* | | $\chi^2$ | *df* | $p^a$ | *CFI* | *RMSEA* |
|---|---|---|---|---|---|---|
| 1. | One factor (all activities form one activity set) | 135.573[b] | 44 | .000 | .745 | .132 |
| 2. | Two factors (core activities, supporting activities) | 118.691[b] | 43 | .000 | .789 | .122 |
| 3. | Two factors (task-oriented activities, network-oriented activities) | 101.980[b] | 43 | .000 | .836 | .107 |
| 4. | Three factors (network-oriented activities, strategic predevelopment, engineering) | 65.372[b] | 41 | .009 | .932 | .071 |
| 5. | Three factors (task-oriented activities, project management, commercialization) | 87.381[b] | 42 | .000 | .874 | .095 |
| 6. | Hypothesized model (strategic predevelopment, engineering, project management, commercialization) | 49.386 | 38 | .102 | .968 | .050 |

[a] *p*-values refer to a test whether the $\chi^2$ for the model is different from zero (lower $\chi^2$ indicates better fit)

[b] The $\chi^2$ difference with the hypothesized model (model 6) is significant at $p < .005$.

**Table 4: Correlations and descriptive statistics for activity sets and innovation performance**

| *Construct* | *Mean* | *Standard deviation* | *Strategic predevelopment* | *Engineering* | *Commercialization* | *Project management* | *Performance* |
|---|---|---|---|---|---|---|---|
| Strategic predevelopment | 4.27[a] | .820 | 1 | | | | |
| Engineering | 4.34[b] | .786 | .300** | 1 | | | |
| Commercialization | 3.72 | .912 | .394** | .256** | 1 | | |
| Project management | 3.86 | .854 | .310** | .196* | .565** | 1 | |
| Innovation performance | 4.02 | .709 | .353** | .238** | .335** | .193* | 1 |

** Significant at $p < .01$ (two-tailed). *Significant at $p < .05$ (two-tailed).

[a] The mean of strategic predevelopment activities is significantly greater than the means of commercialization and project management activities.

[b] The mean of engineering activities is significantly greater than the means of commercialization and project management activities.

**Table 5: Effects on innovation performance (OLS results)**

| *Variables* | *B* | *Standard error* | *Std. Beta* | *T* | *p* |
|---|---|---|---|---|---|
| *Activity sets* | | | | | |
| Strategic predevelopment | .180* | .078 | .226 | 2.289 | .024 |
| Engineering | .050 | .080 | .060 | .625 | .533 |
| Commercialization | .191* | .080 | .267 | 2.385 | .019 |
| Project management | -.008 | .083 | -.011 | -.099 | .922 |
| *Control variables* | | | | | |
| Subsector[a] | | | | | |
| Alternative gas | -.069 | .189 | -.037 | -.366 | .715 |
| Greenhouse as energy supplier | -.005 | .215 | -.002 | -.021 | .983 |
| Chain efficiency | -.043 | .195 | -.021 | -.222 | .825 |
| Sustainable electricity | -.030 | .260 | -.011 | -.115 | .909 |
| Green raw materials | .205 | .238 | .083 | .859 | .392 |
| Sustainable mobility | .196 | .212 | .087 | .925 | .357 |
| Project investments | .000 | .000 | .088 | .916 | .362 |
| Project duration in years | .087 | .047 | .174 | 1.832 | .070 |
| Project size in participants | -.004 | .015 | -.029 | -.297 | .767 |
| Grant type[b] | -.164 | .147 | -.122 | -1.113 | .268 |
| SME[c] | .264 | .135 | .202 | 1.961 | .053 |

$R^2 = .261$, $n = 120$

* Significant at $p < .05$ (two-tailed).

[a] Dummy variables, with built environment as the reference category.

[b] Dummy variable, 0 indicates trial development of the innovation, 1 is implementation of the innovation.

[c] Dummy variable, 0 indicates ≥ 250 employees, 1 indicates < 250 employees.

**Figure 1: Activity Sets in Multi-Organizational Ecologies**