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Developing a Typology for Mission-Oriented Innovation Policies

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Abstract

The goal to address broader societal problems by mission-oriented research and innovation policy has brought new demands for the governance and implementation to the forefront and led to a great diversity of missions. By developing a typology for the classification of different types of missions, this working paper can serve as a first step for studying the impact of the missions of the German High-Tech Strategy 2025 (HTS). Combining existing literature on mission-oriented innovation policy with insights from governance structures, we identify four types of missions - two subtypes of transformer and accelerator missions each - and demonstrate that this typology can be successfully applied to the 12 missions of the German HTS 2025. Thereby, we contribute to a more fine-grained understanding of the different demands and challenges inherent to different missions and thus provide the opportunity for a systematic comparison and a reflection on the varying requirements for assessing the impact of mission-oriented policies.

1 Introduction[1]

The orientation of science and innovation policy has changed considerably in the past decades. Whereas the traditional focus was on fueling economic growth by the commercialization of scientific insights without considerable interference by the state (see Arnold et al. 2018, p. 3), a more active and guiding role of the state has gained importance recently (Schot and Steinmueller 2018). In contrast to the earlier types of mission-oriented policies, current innovation policies are characterized by attempts to closer align policy with tackling grand societal challenges (Robinson and Mazzucato 2019).[2] Considering pressing problems or as stated in the Lund Declaration in 2009 the "grand challenges of our time"[3] such as pollution, climate change or demographic change, there are high hopes that innovative ideas, processes and products will not only address but also solve these problems (directionality). The rising interest of policy makers to foster edu-

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1 This discussion paper originated in the context of a research project (WP 6) commissioned to support the implementation of the German High-Tech Strategy 2025. The project is funded by the Federal Ministry of Research and Education (Förderkennzeichen 16HTF03). The views expressed here are those of the authors and may not be regarded as stating an official position of the Ministry. For more information on the project, please visit: https://www.isi.fraunhofer.de/en/competence-center/politik-gesellschaft/projekte/htf2025.html

2 For changes in the discourse and the shift from a perception of problems towards challenges see Kaldewey 2018; Kallerud et al. 2013.

3 See https://era.gv.at/object/document/130.

cation, research and science that leads to solutions for these pressing problems corresponds with this development and has been labelled as the ‘new mission for science and technology policy’ following the so-called Maastricht Memorandum (Soete and Arundel 1993).

To this end, over the past ten to 15 years, several countries have introduced so-called innovation policy strategies such as the German *High-Tech Strategy* (BMBF 2006) or the British *Innovation and Research Strategy for Growth* (BIS 2011) accentuating a more active role of the state. During the past legislative periods, the focus of these policy strategies has changed from fostering single technological fields or disciplines[4] to supporting adequate solutions for the above-mentioned challenges by formulating comprehensive missions such as "fighting cancer" or "preserving biological diversity" (BMBF 2018). According to Kuittinen et al. (2018a, ii), these new mission-oriented policies are characterized as "ambitious, exploratory and ground-breaking in nature, often cross-disciplinary, targeting a concrete problem/challenge, with a large impact and a well-defined timeframe" (Kuittinen et al. 2018a; similar Mazzucato 2018b; see Larrue 2019, pp. 7–9 for an overview of definitions).

This re-orientation towards societal goals requires conceptualizing innovation policy in a broader and crosscutting way, taking into consideration a significantly wider range of actor groups and stakeholders, understanding the potential impacts of these policies in different sectors and application areas, and introducing new governance arrangements. This becomes clear when Larrue (2019, p. 9) proposes a "concept of mission-orientation constructed as a composite of different elements. It refers to the objective of the policy (societal challenges), its content (a co-ordinated bundle of instruments) and some implementation characteristics (goals and timeframe)". In consequence, mission-oriented policies challenge existing institutional settings for implementing innovation policy and call for a better integration of different policy instruments and actors to achieve the aspired goals. However, without changes to the top-down organized process of implementation, a re-orientation will not necessarily lead to any real transformative innovation, but may also lead to subsuming previous activities under new headlines like putting “old wine into new bottles” (Daimer et al. 2012, p. 223).

At the same time, this new type of missions aiming to address societal challenges instead of merely supporting single technological fields has also multiple implications for the study and evaluation of innovation and research policy. First, the directionality of the

4 The very first version of the German High-Tech Strategy covered 17 different sub-strategies targeting selected technologies and disciplines such as medical devices, information and communication technologies or microsystems technology (BMBF 2006).

policy and the higher coordinative efforts imply an even greater necessity to better understand the role of the state in achieving the desired policy goals. Secondly, new and additional actors need to be taken into account and involved, thereby adding to the complexity of the governance of the missions (Warnke et al. 2016). And thirdly, the far-reaching goals also require new approaches for measurement and evaluation (Amanatidou et al. 2014), as the impact of missions cannot be easily grasped with traditional evaluation techniques, given the lack established approaches (Weber and Polt 2014, p. 9).

In the following, we develop a new typology addressing the diversity of missions with regard to policy goals and inherent challenges. In contrast to most previous literature, this typology specifically emphasizes the importance of governance structures and the role of the state in mission implementation. The purpose of this typology is twofold: First, given the growing number, diversity, and relevance of mission-oriented policies, it aims at providing orientation to analysts and policy-makers on the key distinguishing characteristics of contemporary missions, thereby facilitating systematic comparisons and policy learning. Second, as the typology is developed in the context of a research project in support of the ongoing implementation of the missions of the current German High-Tech Strategy (HTS)[5], by developing – among other aspects – an impact measurement concept, the typology will be used to select four different types from the twelve HTS missions. In the next steps of the project, there will be an in-depth investigation of the selected missions, particularly with regard to the mission goals and the measures and instruments used to reach these goals. The typology therefore serves both as a tool for the selection of relevant missions and provides indications about the different types of challenges associated with different types of missions. The latter is particularly important in order to develop a framework for impact assessment which is sufficiently sensitive with regard to increasing variety among missions.

To arrive at a sound typology that is distinct and – meaningful – from a policy perspective, the paper starts with a summary and a critical assessment of existing mission typologies. Based on this review, requirements for a comprehensive and useful mission typology are outlined (sec. 2). Drawing on the insights of the review and taking into account the requirements identified, a typology is developed and the relationships between different types of missions are discussed (sec. 3). In section 4, we apply this typology to the twelve missions of the HTS, discuss problems encountered during this step and reflect on which missions should be selected based on the typology. The final section 5 summarizes the key insights presented in the paper and proposes areas for further investigation.

5 https://www.hightech-strategie.de/en/index.html.

2 Review and critical assessment of existing mission typologies

2.1 Existing approaches

Given the turn towards a stronger mission orientation, there is a growing diversity of innovation policies and individual missions with regard to their scope, goals, and ambitions (Kuittinen et al. 2018a, p. 32; Larrue 2019). For instance, the German High-Tech Strategy 2025 with its strong focus on the policy areas of research and technology comprises missions ranging from the introduction of a certain technological solution in the health sector, to further investments in research to fight cancer to addressing large societal problems such as carbon dioxide emissions or a transformation of the mobility sector (BMBF 2018). The current British Industrial Strategy (BIS 2011) serves as another example in this respect. Here, the guiding principle is the identification of four Grand Challenges that correspondent with broad, cross-sectoral missions. On the one hand, this approach led to formulating complex and aggregated policy ambitions like tackling the Grand Challenge of an "Ageing society" by the corresponding mission: "Ensure that people can enjoy at least 5 extra healthy, independent years of life by 2035, while narrowing the gap between the experience of the richest and poorest". On the other hand, the UK strategy also contains missions that seem rather straightforward in scope and scale. The challenge of "Clean Growth", for instance, is tackled by two missions: "at least halve the energy use of new buildings by 2030" and "establish the world’s first net-zero carbon industrial cluster by 2040 and at least 1 low-carbon cluster by 2030".[6]

Recent approaches to classify mission-oriented policies are mostly based on a one-dimensional, often dichotomous understanding. Whereas some authors emphasize the scope of underlying problems as the main distinguishing dimension, others primarily focus on the anticipated solutions and goals of missions. Only recently, the role and process of implementation have increasingly attracted the attention of researchers. Therefore, the debate about the classification of mission-oriented policies provides multiple, but related starting points.

Firstly, mission-oriented policies can be understood in terms of the underlying challenges which are the prerequisite for the formulation of a challenge-based approach (Mazzucato 2018b). Georghiou et al. (2018, p. 5) distinguish between two types of challenges: Type A missions with "potentially solvable" challenges that can be translated into specific/ver-

6 https://www.gov.uk/government/publications/industrial-strategy-the-grand-challenges/missions

ifiable goals (e.g. developing a vaccine for Ebola) and Type B mission, the complex character of which makes finding a solution complicated (e.g. Nixon's war on cancer). The understanding of challenges is thereby linked to concepts such as those of "wicked problems" (Rittel and Webber 1973) or the distinction between simple, complex and complicated problems (Glouberman and Zimmerman 2002).

Secondly and closely related to this perspective, there are a number of attempts that categorize policies based on mission characteristics, i.e. the defined goals. Kuittinen et al. (2018a; 2018b) distinguish between accelerator missions, which have a narrowly defined scientific/technological focus, and broader transformer missions aiming at a transformation of existing systems and often addressing societal problems (see also Hekkert n.d.). A similar understanding can also be found in Robinson and Mazzucato (2019), who distinguish between traditional (Type 1) and challenge-driven (Type 2) mission-oriented policies, where the latter is characterized by a greater diffusion of responsibilities and the expectations for changes affecting also societal behavior. The main characteristics of mission-oriented policies comprise the call for missions being oriented towards problems of wider societal relevance and have a cross-disciplinary and cross-sectoral/-actoral approach.[7]

Building on an inductive approach and the insights of over a hundred case studies, Polt et al. (2019) extend this typology further. Observing differences with regard to the motivation (aspirational vs. problem-driven), the intention (understanding vs. solution), the definition of a target/the scope (well- vs. ill defined), and the means (technological vs. socio-institutional), they empirically identify four types of missions:

i. science missions (e.g. US Cancer Moonshot - fundamental/basic research with high uncertainty)
ii. technological missions (e.g. Concorde, Apollo mission - specific goal with a strong focus on technological/scientific solutions)
iii. transformative missions (e.g. German Energiewende - aiming at systemic change)
iv. umbrella missions (e.g. German High Tech Strategy - comprehensive long-term policy frame)

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7 However, differences between policies might also have a gradual character and meeting the requirements to varying degree (Mazzucato 2018b; Kuittinen et al. 2018b). Taking these requirements as a baseline, one could argue that higher degrees of mission-orientation should be more prevalent for transformer missions, as described by Polt et al. (2019), compared to more narrowly defined accelerator or science missions.

While these concepts rest on the assumption that types of challenges and corresponding missions are closely linked with each other, Wanzenböck et al. (2019) seek to disentangle these dimensions and highlight the different modes of interaction between them. Similar to Patton (2011), they argue that both problems and solutions can exhibit varying degrees of complexity, creating different ideal types of constellations in a 2x2 problem-solution matrix. The more views on both the problem and the possible solution diverge, the harder it will be to achieve the desired outcomes. What sets Wanzenböck et al. (2019) apart from the so far discussed typologies is that unlike the others, it does not follow a static, but a dynamic perspective. Accordingly, constellations can change over time, e.g. through public debate or new technological developments, shifting the situation more towards an alignment of views on the problem/solution.[8] Therefore, they outline several policy pathways that can lead to the desirable state of alignment: a (1) problem-led, experimental, (2) an open, fundamental research knowledge creation, and (3) hybrid, co-evolutionary pathway. However, while pinpointing to the potential dynamics of the process, the time horizon – depending on the perspective – might reach beyond the goal of a mission and rather capture challenges at different states of alignment.

Finally, some authors have broadened the perspective by highlighting that besides complexity as an inherent characteristic of problems and/or solutions, mission-oriented policies can vary with regard to their implementation requirements. Larrue (2019) develops a framework that serves a twofold goal: Firstly, classifying policies on a meta-level with regard to the main purpose of a policy (characteristics of different initiatives, not missions) and its integration into the overall policy framework. In consequence, he distinguishes between a focus of the policy on outlining a general conception, (e.g., German High-Tech Strategy), the priority of policy-coordination (e.g., German Energiewende) or the active link to the implementation level (e.g., DARPA in the US). Secondly, in order to systematically analyze mission-oriented policies, he provides a comprehensive check list of potential factors which can be grouped into three main categories: strategic orientation, policy co-ordination and policy implementation. This perspective implies that the diversity of missions might not only be captured by the underlying challenges and missions, but also by the resulting requirements how to coordinate and manage the realization of missions and thus pay more attention to governance and implementation. In particular, this focus can contribute to overcoming the inherent challenges in the evaluation of mission-oriented policies (see above), by better understanding the dynamics and processes within a mission.

8 At the same time, Wanzenböck et al. (2019) do not discuss the hypothetical case of disalignment and an increasing contestation of a solution, assuming that seemingly problems only can converge towards alignment or remain locked-in at the status quo.

In contrast, the strand of research in science, technology and innovation (STI) studies analyzing fundamental shifts in technological areas or disciplinary fields appears less suited for enhancing an understanding of missions. While research on transition pathways can yield insights into the dynamics of innovation processes (see, for example, Geels 2002; Geels and Schot 2007; Geels et al. 2016), it does not allow a more pronounced understanding of mission characteristics and in particular the role of governance structures (Arnold et al. 2018, p. 37). Relying on an ex-post perspective, it exhibits an implicit preference for "successful" cases, being primarily interested in explaining changes instead of a reproduction of systems (cf. Geels and Schot 2007, p. 406). While Geels and co-authors reject the criticism of pursuing an overall structuralist approach and offer refined pathways incorporating a stronger role of agency (2007; 2016), their focus is primarily on the innovation process of single technologies rather than the implementation of policies.

The perspective of Geels and Schot is in so far broader, as they assume that policy coordination is the result of the convergence of opinions during transition processes, while they downplay the role of specific policies for achieving this goal. This perspective becomes particularly clear when Geels and Schot (2007, p. 402) argue that "[i]n our view, no transition is planned and coordinated "from the outset" (p. 1502 [Smith et al. 2005])". And every transition becomes coordinated at some point through the alignment of visions and activities of different groups". From this perspective, mission-oriented policies are located at a different conceptual level, as they constitute a part of a transition process and should only gain relevance once there is consensus on a given goal. Whereas missions in our understanding are clearly embedded in a deliberate political strategy aimed at achieving a certain outcome and require an active coordination, transition pathways describe the overall process.[9]

2.2 Demands for a new typology of missions

To provide a useful starting point for a better understanding of mission-oriented innovation policy, there is further need for capturing the diversity of missions in a typology with regard to the inherent challenges, goals and governance requirements. This ties in with the observation of Cherp et al. (2018, p.187), who contend that there is a lacking consensus on how to integrate different perspectives in transformative policies into a uniform framework. Aiming to strive towards an uniform framework, we therefore argue that a typology should address the following two main challenges: (1) overcome the vagueness with regard to the level of analysis and outline a typology based on individual missions,

9 For a call for a stronger integration of politics in the understanding of innovation processes see also Meadowcroft (2009).

and (2) bridge the gap in current research by bringing together the understanding of challenges (problems/solutions) with the role of actors and the governance of missions.

2.2.1 Conceptualizing the level of analysis

Firstly, many of the conceptions are rather ambivalent with regard to the level of analysis and are seemingly more closely related to the strategic policy level than to specific missions. This becomes most visible with regard to the "umbrella missions" as understood by Polt et al. (2019), which refer to policies comprising of a number of individual missions (like the German High-Tech Strategy) and therefore might be on a different conceptual level than the remaining types of missions. In consequence, several science missions, for instance, could be part of an "umbrella mission". The diversity of goals makes it not only harder to assess the impact of mission-oriented policy, but also creates conceptual obstacles, as typologies might not necessarily “travel” across different analytical levels.

For a more systematic perspective on mission-oriented policies, it is therefore necessary to clarify the level of analysis before proceeding with the development of a typology. Keeping in mind the goal of performing an impact assessment in later steps, the mission level appears to be the natural level of analysis, as it can open the “black box” of larger strategic programs and prepare the ground for unpacking the diversity within larger policies in a more systematic way. While missions can be considered as the groundwork for mission-oriented innovation policies, their connection to challenges and overall policies is not straightforward. Missions, as the intermediary level between overarching strategies and single policy instruments, are supposed to be translations of challenges into solvable problems (Mazzucato 2018a, pp. 811–812; Robinson and Mazzucato 2019, p. 936), thus can address only a subset of a challenge or can be linked to other missions and overall policy strategies in different ways.[10] Firstly, a single challenge can be addressed by multiple missions, so that missions and the main goal related to a challenge are not necessarily identical (see European Commission - Directorate-General for Research and Innovation 2017, p. 15). Secondly, missions can address challenges at different levels of granularity, thus putting emphasis on different aspects of a challenge (Larrue 2019, pp. 20–21). Finally, several missions can be subsumed in one - more or less coherent - policy strategy, addressing multiple challenges (like in the German HTS). Moreover, different types of missions may differ systematically in their orientation. Griniece and Sorokins (2018), for instance, report from a survey among stakeholders in R&I policy that

10 A single strategy might be driven by the interplay of different goals of different missions, creating additional obstacles for understanding the impact of policies due to the complementary character of missions. In consequence, it can be difficult to disentangle individual contributions at an aggregate level.

not all criteria for mission-oriented policy suggested by Mazzucato (2018b) can be equally applied to all missions.

2.2.2 The role of governance and actors for the implementation of mission-oriented policies

The focus on the scope of necessary transformations (Kuittinen et al. 2018b; Polt et al. 2019) or the complexity of solutions (Wanzenböck et al. 2019) only indirectly links to the actor constellations and challenges arising from the implementation of mission-oriented policies that have been emphasized recently (e.g. Grillitsch et al. 2019; Larrue 2019). The directionality coming along with mission-orientation imposes a more active role of the state in coordinating and formulating goals, bringing together different groups of actors at different levels and creating the need for new means of cooperation (Weber and Rohracher 2012; Arnold et al. 2018, p. 56; Boon and Edler 2018; Mazzucato 2018b).[11] At the same time, it is likely that directionality will fuel the emergence of conflicts between different actors with their distinct own preferences which do not necessarily coincide with the goals formulated in the outline of the policy, thereby entailing higher degrees of politicization of innovation policy. In consequence, mission-oriented policies require a systemic policy-making approach that i) allows for coordination of different parts of the internal policy system, ii) engages them in discursive processes (reflexive and transformative governance), and iii) leads to the development and implementation of policy mixes (Smits and Kuhlmann 2004) cutting across and reaching beyond the confines of established policy areas and policy communities. This has been also reflected in frameworks trying to conceptualize the types of transformations by highlighting the role of coordination as one core dimension (Berkhout et al. 2004; Grin et al. 2010)

Against this background, it is obvious that the role of governance is of key importance in order to achieve the changes aspired by mission-oriented policies. In general terms, we understand governance activities as "purposeful efforts to guide, steer, control, or manage (sectors or facets of) societies" (Kooiman 1993, p. 2). In relation to the policy areas of science, technology and innovation, we draw on Borrás and Edler who define governance as the

"*[...] way in which societal and state actors intentionally interact in order to transform ST&I systems, by regulating issues of societal concern, defining processes and direction*

[11] The example presented by USAID (2018, p 3-4) demonstrates well that complexity might not be necessarily limited to the technological solution. For instance, the science part in a vaccination program might be of limited complexity, while the logistic of distributing the vaccination can be the larger challenge and for instance requires the cooperation of multiple actors in a difficult environment.

of how technological artefacts and innovations are produced, and shaping how these are introduced, absorbed, diffused and used within society and economy." (Borrás and Edler 2014, p. 14)

Compared to other suggestions, this definition is particularly useful in our context as it refers specifically to innovation and the transformation of systems. In addition, the definition explicitly emphasises actors' purposeful attempts to influence decisions, decision-making processes and framework conditions to achieve certain ends (Lindner et al. 2016)

Given the importance of *governance of change* for mission-oriented innovation policies, a meaningful typology has to account for the distinct goals and specific governance-modi. The complexity for governance can arise along two lines, requiring a critical reflection on the role and performance of public and private actors, who should bring about the desired change connected to the missions (Edler et al. 2003; Braun 2008; Lindner 2012; Matthews 2011; Flanagan et al. 2011). The first perspective ought to take the view of internal governance arrangements since missions, according to their crosscutting nature, more often than not fall into the shared responsibility of several ministries as well as several units in the involved ministries. In consequence, mission implementation imposes higher demands for the internal coordination and cooperation among public actors.

Secondly, the realization of policies depends on the interplay and cooperation of multiple public and external stakeholders from industry, science and society. The main challenge in this context is to ensure an efficient coordination among all these actors and use the available policy instruments in a way that they serve the desired outcomes. Again, a greater number of involved actor groups and a great variety of policy instruments increase the level of complexity for policy coordination and should hence be reflected in a useful typology of mission-oriented innovation policies.

3 Towards a new typology of missions

This section outlines a novel approach for understanding the variation of mission-oriented policies by suggesting a typology at the mission-level that addresses the aforementioned problems. While explicitly building on previous literature highlighting the problem structure of missions as a crucial feature (complexity of problem/solution), we extend this understanding by accounting for the requirements arising from the governance of missions - both the interplay of public and private actors, the way they are affected by different types of instruments, and the governance of responsibilities and activities within public administration. This adds a better understanding of the obstacles within the implementation of such missions and allows differentiating more precisely between varying levels of complexity.

We propose to distinguish a total of four (ideal) types of missions, which are nested into the two main categories of transformer and accelerator missions (see also Figure 1 for an overview). The differences between the main categories of transformer and accelerator missions, which are well established in the literature, can be found in the structure of the underlying problem and the way the problem is supposed to be addressed. At the same time, within these overarching categories, the demands for coordination and governance can vary considerably, so that we distinguish between two sub-types for both cases. The following section outlines the main characteristics of each of the types in greater depth and discusses the existing differences.

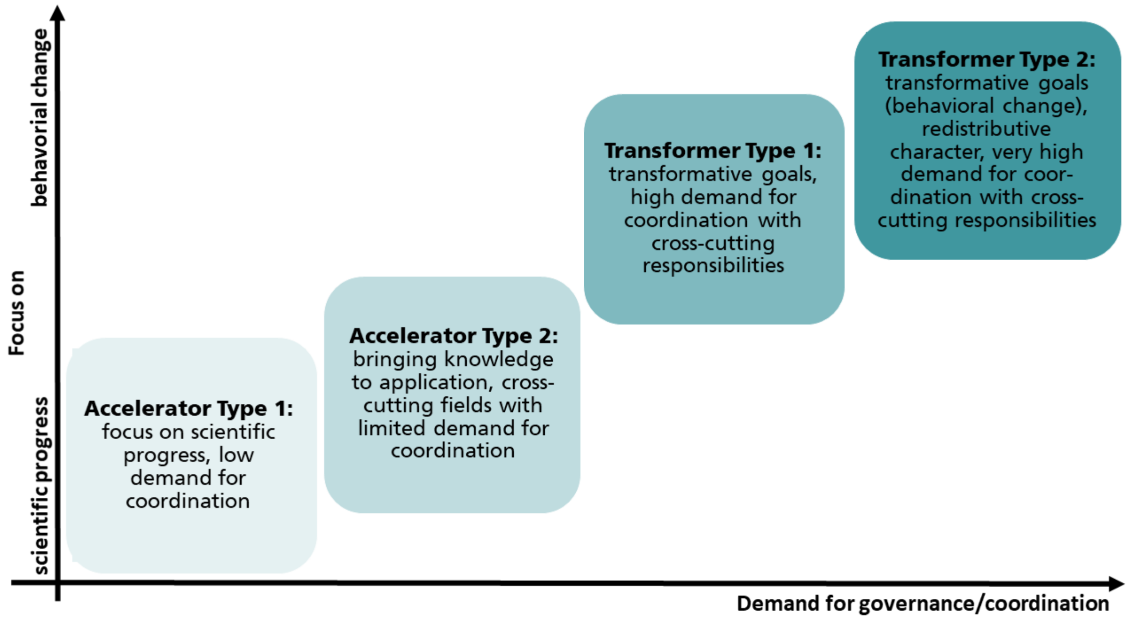

Figure 1: Types of missions (own elaboration)

3.1 Accelerator vs. transformer missions

The first difference between missions relates to their purpose. Inspired by the notion of Wanzenböck et al. (2019), who argue that the extent of complexity of a mission arises from both the type of challenge addressed and the possible solutions, we follow the well-established differentiation between accelerator and transformer missions.

First of all, missions vary with regard to the kind of failure they address. Following Weber and Rohracher (2012) innovation policies can aim to fix different kinds of failures: market failures (e.g. information asymmetries, externalities of expenditures), structural system failures (e.g. lack of infrastructure, capacity, formal rules), and transformational system failures (e.g. lack of vision on project, difficulty to learn about public demand, need for policy coordination).[12] With increasing complexity of the challenge, additional types of failures gain importance, layered on top of lower level failures such as market failure and therefore impose additional requirements for state interventions (Weber and Rohracher 2012, p. 1042). This understanding of failure closely links to the scope of the underlying challenges. In the case of accelerator missions, the main target of interventions is to overcome market or structural institutional failures, while in the case of transformer missions, the failures tend to be much more complex and multi-faceted. These missions are directed towards overcoming more substantial problems such as the difficulty to determine public demand and attempt to steer the direction of the innovation process.

Secondly and closely related to the kind of challenge, also the solution of the problem might vary in its complexity. While generally more complex problems also make more complex interventions necessary (see also Walton 2016, p. 414), missions might attach varying importance to the role of scientific progress vis-a-vis the other dimensions. Whereas in accelerator missions, changes primarily affect the area of science and/or technology and can involve changes in the institutional setting (laws, regulations, etc.), the level of change is more comprehensive for transformer missions. Goals of transformer missions cannot be achieved only by technological/scientific progress, but imply a substantial transformation of the overall system and its structure, including the societal sphere, institutions and behavior of actors. Accordingly, they complement the neo-classical canon of input and output additionality to remedy market failure by aiming at behavioral change and additionality. Following an exploratory definition of Gök and Edler (2012, p. 307), "a policy [addressing behavioral change] is only successful if it increases the capacities of agents that are crucial for innovation activity and performance (cognitive, networking, etc.) and by doing so leads to persistent effects". Transformer missions are hence substantially broader in their goals and take a broader variety of stakeholders into consideration. Therefore, they require the application of a more diverse set of policy-instruments to reach these goals.

This distinction between transformer and accelerator missions closely ties in with the well-established perspective of missions as a dichotomy which can frequently be found in the literature (Kuittinen et al. 2018a; Kuittinen et al. 2018b; Robinson and Mazzucato

12 Daimer et al. (2012) use the term orientation failure.

2019; Hekkert n.d.). Instead of breaking with this perspective, we argue that it is necessary to differentiate missions beyond this dichotomy and take into consideration the role of governance and anticipated pathways of reaching mission goals including the role of the applied policy instruments and their mix.

3.2 Accelerator Type 1 and Type 2

Accelerator missions can be understood as missions that seek to find an answer to a challenge with a relatively confined scope (e.g. Moonshot, research in one particular field), but do not aim for a comprehensive system change. Despite this uniformity at the aggregate level, one can delineate two different sub-types of accelerator missions.

While being rather clearly delineated from transformer missions, accelerator missions internally differ with regard to the type of failure they address as well as the anticipated complexity of the solution. Accelerator Type 1 (A1) missions primarily seek to overcome a market failure and rely on scientific and/or technological innovation in order to address the challenge. In contrast, the constellation in Type 2 (A2) is often more complex, as the failure is not only rooted in information asymmetries or the lacking externalities of costs/benefits, but also requires structural adjustments, e.g. in the regulatory dimension. In consequence, accelerator Type 2 mission goals typically cannot be accomplished by technological or scientific solutions alone, but need to be accompanied by a broader set of measures and a more complex policy-mix in order to make these insights applicable to a wider range of areas.

Whereas these two criteria already allow for a distinction of subtypes of accelerator missions, the additional dimensions reveal further insights into the implementation structures. Type 1 missions (A1) tend to be aligned with fundamental research, having two implications. Firstly, the final product has a higher level of uncertainty, so that the mission is rather defined by the problem (dealing with a certain illness, etc.) than by the solution how to achieve it. Secondly, the focus on research activities limits the demands for governing a change process, as both the number of involved groups and the diversity of policy instruments (financing research activities) is rather low.

In contrast, A2 missions have a different focus as there exists an already defined solution, the main challenge therefore is the pathway to achieve the goal. In consequence, the process is less open with regard to the type of solution and the choice of technology.[13] At the same time, it emphasizes the spill-over/application of scientific/technologi-

13 This deviates from the idea that mission-orientation implies an openness to different solutions and technology (Dachs et al. 2015, p. 11).

cal insights to a broader range of actors, which in turn increases the importance of governing the process. On the one hand, state actors need to be actively involved in the implementation process of the mission beyond financing, e.g. by coordinating different groups or actors or adjusting legislation in line with the desired outcomes.

3.3 Transformer Type 1 and Type 2

Transformer missions aim to achieve a comprehensive change affecting a socio-technical system as a whole and are therefore not limited to scientific progress and regulatory changes. In contrast to the previously discussed accelerator types A1 and A2, which exhibit multiple clear-cut differences, the two sub-types of transformer missions rather differ in degree than by kind. Therefore, they can be considered as ideal types on a continuum, placing missions at different levels of complexity with regard to the goal and the role of governance.

Transformer type 1 missions (T1) are comparatively narrow in their scope in two ways. Firstly, T1 missions emphasize the solution over the goal to address the problem, thus possess a clearly defined agenda what part of a challenge to address by which means. Secondly, despite high levels of complexity for coordination and governance, the changes might be smaller compared to transformer type 2 missions. While the crosscutting character of the mission affects a wider group of actors, these are rather located at a low level of the innovation chain, thus do not directly affect end users. In consequence, they can be managed more easily, as both the range of public and private actors is less comprehensive and they are less likely to be exposed to interaction effects with other fields. Moreover, the achievement of mission goals is also (partly) linked to improvements in efficiency, thus does not strive for a full overhaul of the existing system. An example could be missions that aim for systemic change in production systems, but neither directly affect end users, nor are likely to substantially disadvantage certain actors as the solutions are primarily improving efficiency.

In contrast, type 2 missions (T2) have the highest level of complexity of all mission types. Given the considerable scope of the challenge and the absence of a promising solution, they are primarily problem-driven and rather present a framework of possible goals. However, they do not offer a specific solution yet, so that there might be multiple avenues for addressing the problem. They require an active state intervention and are particularly prone to interaction effects as they are embedded in a multi-actor setting providing solutions closer to the end users and thus require also considerable behavioral changes. Moreover, they have stronger redistributive effects compared to T1 missions, as changes may affect actors unevenly and impose costs only on some of them. For instance, altering the existing practices of mobility may shift power and resources between different sectors and means of transportation. Given the existence of potential interaction effects with other policies, the crosscutting character results in a larger number of actors involved. This subsequently increases the risk of conflicts, deadlocks in negotiation and imposes a higher need for coordination and cooperation among involved actors.

3.4 Discussion of typology

This typology suggests a framework that distinguishes between transformer and accelerator missions and at a second level differentiates between subtypes in each of the categories. Table 1 summarizes the key characteristics of the four mission types that were discussed in greater detail in the previous sub-sections. While this typology shares some commonalities with the findings of Polt et al. (2019), it extends it in several important ways. Firstly, it suggests a more fine-grained distinction between different types of transformer missions. Instead of considering transformer missions as a uniform category of missions with rather broad goals reaching beyond technological solutions alone, it seeks to understand the differences with regard to structure and its distinct challenges within this category. As discussed beforehand, the main difference can be found in the increasing complexity of governance structures, tying in with the recent trend in the analysis of mission-oriented policies to pay more attention to the implementation and role of governance (Grillitsch et al. 2019; Larrue 2019). This step might be particularly relevant against the background of attempts to better understand the impact of mission-oriented innovation policies as it can help to better map relevant missions, open up the way for a more systematic comparison, and link the evaluation of missions closer to their key characteristics.

Moreover, the relationship between different types deserves additional attention. Generally, the framework can be understood as a continuum of increasing complexity ranging from accelerator missions to more comprehensive and complex transformer missions with a wider variety of obstacles in implementation (Kuittinen et al. 2018a, p. 32; Arnold et al. 2019).[14] At the same time, the framework is not perfectly symmetric. Whereas in the case of accelerator missions there seems to be a consistent picture with regard to the different dimensions pointing to a systematic cut-off point, the differences in case of transformers are of a more gradual character. In consequence, T1 and T2 appear even more strongly as ideal types within a continuum, suggesting that T2 might be more vague and ambiguous by comprising more complex and far-reaching challenges. This is also an alternative understanding to the term "umbrella missions" used by Polt et al. (2019).

14 This perspective gains additional support from attempts to employ factor analysis for eliminating irrelevant dimensions. The analysis found that most factors were loading on one dimension only.

Instead of subsuming multiple missions under the auspices of one policy, umbrella missions might be understood as widely defined goals with a low level of specification of means to achieve the formulated goal.

Table 1: Characteristics of different types of missions

	Accelerator Mission		Transformer Mission	
	Type 1 (A1)	Type 2 (A2)	Type 1 (T1)	Type 2 (T2)
Type of problem	Market failure	Market and structural failure	Transformational system failure	Transformational system failure
Type of solution	Scientific innovation	Technological/ regulat. change	Transformation of system	Transformation of system (behavior)
Problem vs. goal oriented	Problem-oriented	Goal-oriented	Goal-oriented	Problem-oriented
Demand for governance	Low	Medium	High	Very high

4 Empirical application of the typology to the German High-Tech Strategy (HTS 2025)

4.1 Operationalization

Building on the typology developed in the previous sections, the following paragraphs provide a step towards the application of the typology to the twelve HTS missions. In particular, we outline an operationalization for the relevant dimensions and discuss subcomponents for the governance dimensions. In most cases, given the lack of quantifiable data, the subsequent analysis will rely on qualitative assessments, providing a usually dichotomous distinction between different options. Table 2 provides an overview of the relevant sub-dimensions to be included, the character of the variable (binary, index) and the relation to other literature.

Given the absence of a natural threshold, a qualitative assessment can distinguish between high and low levels for individual dimensions. The first two dimensions primarily describe the structure of the challenge and possible solutions to it. Firstly, the type of failure and thus the underlying scope of the problem shapes the need for intervention and gives insights into the complexity of the problem. Following Weber and Rohracher (2012), we assume that a transformational system failure implies a higher level of complexity compared to market or structural system failures alone. Therefore, only those missions that are motivated by a failure that is deeply rooted in the existing system structure will be classified as a transformational system failure. The second dimension refers to the anticipated solution of the problem and is more closely linked to the mission as such. The main question to delineate the type of the solution is whether the anticipated change is driven by scientific/technological progress, or whether the mission requires a deeper transformation reaching further and leading to a reconfiguration of the institutional setting and potentially even altering the behavior of actors in the field.

Beyond this distinction between accelerator and transformation missions, the previous sections have outlined additional characteristics. First of all, there is the question whether the mission is primarily developed based on the perception of a problem, or whether it already provides the solution to a problem, shifting the focus on the steps towards achieving this goal. A problem-orientation implies that the type of challenge is acknowledged and one aims for the improvement of the situation, however, without yet being able to provide a solution how to achieve this.

Secondly, the demand for coordination can be characterized by an internal and external perspective on governance. Given the multi-faceted character of these aspects, we rely on multiple items in an additive index to capture the demands for coordination. External coordination can be understood as the interplay of public and private actors and the means used to achieve the desired outcomes, thus the question about actors (agency) and policy instruments. A wider range of involved actors increases the need for coordination. To capture the range of potential actors, we use an additive index of key players (state, research/science, economy, society understood as citizens and formal organizations representing relevant non-economic groups). As key players we define those actors that can be considered as necessary for achieving the mission goal. We consider the following dimensions of state activity as relevant to understand the interplay of actors and the dynamics in the field:

i. Informing: supporting the acceptance of technological advancements that address missions or/and facilitate behavioral change among citizen by providing information and persuasive efforts.
ii. Financing: providing a substantial share of financing in order to ensure the realization of the mission.
iii. Regulating: adjusting existing regulations to new developments and set a legal frame for its implementation.
iv. Coordinating: coordination of the interplay of different actors and actively creating new (institutional) structures for the realization of the mission.
v. Redistributing: the potential importance for the state to overcome redistributive consequences in order to ensure the realization of the mission.

Table 2: Dimension of typology and operationalization

Dimension	Operationalization	Type of variable	Related Literature
Type of problem	Type of failure (transformative vs. non-transformative)	Binary	Daimer et al. 2012; Weber and Rohracher 2012
Type of solution	Scientific/technolog. innovation as the main driver vs. systemic change (behavioral additionality)	Binary	Gök and Edler 2012; Polt et al. 2019; Wanzenböck et al. 2019; Hekkert n.d., p. 13
Problem- vs. goal-oriented	Mission defined by goals vs. problem description	Binary	Polt et al. 2019
External co-ordination (equally weighted)	Cross-sectoral diversity (state, science, economy, society)	Additive index	
	Dimensions of state activity (financing, regulating, coordination, redistribution, information)	Additive index	Lowi 1972; Hufnagl 2010; Larrue et al. 2019, p. 13; Borrás and Edler 2020
Internal co-ordination	Dimensions of internal interaction (number/type of actors involved, governance architecture/leadership)	Additive index	Larrue et al. 2019

While governance on the one hand implies that public and private actors need to collaborate, the turn towards mission-oriented policies also requires a rethinking of traditional forms of administration, cross-cutting ministerial and territorial responsibilities. This internal dimension of governance can act as a constraining or limiting factor to the governance of change. The more complex the governance of mission-oriented policies within state actors, the harder it will be to effectively get involved in the realization of the mission goals and successfully fulfill its role in the interaction with other actors. Again, the complexity of internal coordination is measured by an additive index, capturing different sources increasing the efforts for internal coordination:

i. Horizontal coordination: number of ministries involved in coordination of policy (low: <3 ministries, medium: 3-4 ministries; high: >4 ministries).
ii. Vertical coordination: multi-level structure (national, regional, local, subordinated agencies, supranational) in implementation of policy required.

4.2 Empirical classification of HTS missions

Having outlined a general concept for the classification of individual missions in mission-oriented policies, this section applies the typology to the twelve missions of the German High-Tech Strategy 2025. According to the official information about the HTS 2025, the missions are grouped into three main categories (societal challenge; future competencies; open innovation and venture culture), ranging from the challenge of health over regional development to sustainability. Relying on a qualitative assessment by multiple members of the project team, each mission was coded for the aforementioned dimensions based on information provided in official program documents of the HTS 2025 (BMBF 2018, 2019; a detailed description justifying the coding of individual missions can be found in the appendix). Table 3 summarizes the coding and provides an overview of the classification into the four categories.

Empirically, the HTS seemingly contains missions corresponding to each of the four ideal types formulated in the mission typology. Among accelerator missions, especially the research-oriented mission on Cancer appears as a Type 1, as its focus on science and research activity limits the challenges with regard to internal and external governance. In contrast, the more applied missions on intelligent medicine (2), battery cells (8), artificial intelligence (11), and carbon dioxide reduction in the industry (4) are classified as accelerator Type 2 missions. The remaining transformer missions usually address more substantial types of failures and therefore require a more complex intervention, both with regard to the solution and the governance of involved public and private actors. However, even in these complex settings, some variation exists.

As can be seen from Table 3, especially the missions on circular economy (5) and open knowledge (10) appear to exhibit a lower degree of complexity with regard to the coordination of private and public actors and the use of policy instruments. As discussed in the following section, however, not all missions neatly fit into a certain category, but exhibit sometimes hybrid characteristics or ambiguities due to the description of the mission.

The results of this classification are illustrated by the use of cluster analysis techniques. Figure 2 displays the dendrogram for a cluster analysis for the selected categories (average linkage, Gower dissimilarity measure for mixed binary/continuous data).[15] Whereas the upper branch of the dendrogram indicates the existence of two subtypes of transformer missions with quite some difference to each other, especially the cancer mission (1) stands out among the accelerator missions. In all subtypes there is evidence for minor diversity, however, the overall differences are rather small in comparison to differences between subtypes, as indicated by the length of the vertical lines in the dendrogram.

15 The emerging cluster structure is highly similar when using a single/weighted linkage or different dissimilarity measures. Also aggregating requirements for coordination into one variable does not alter the emerging picture.

Table 3: Assessments for relevant dimensions (Index variables only display aggregated values of individual dimensions).

	Combating cancer (1)	Intelligent medicine (2)	Battery cells (8)	Artificial intelligence (11)	CO2 emission industry (4)	Circular Economy (5)	Open knowledge (12)	Plastic waste (3)	Biodiversity (6)	Mobility (7)	Good life (9)	Technology for humans (10)
Type of failure (transformational system failure)	No	No	No	No	No	Yes	Yes	Yes	Yes	Yes	Yes	Yes
Type of solution (technological change as main factor)	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No	No	No
Orientation of mission (solution-oriented)	No	Yes	Yes	Yes	Yes	Yes	Yes	No	No	No	No	No
Complexity external governance (0-1)	0.55	0.65	0.58	0.68	0.68	0.78	0.8	0.9	1	1	1	1
Sectoral depth (Number of key actor groups involved) (0-1)	0.5	0.5	0.75	0.75	0.75	0.75	1	1	1	1	1	1
Range of policy instruments (0-1)	0.6	0.8	0.4	0.6	0.6	0.8	0.6	0.8	1	1	1	1
Complexity internal governance (0-1)	0	0,75	0	0.25	0.25	0.25	0.75	1	0.75	0.75	1	1
Depth of governance/Involved ministries (0-1)	0	0.5	0	0.5	0.5	0.5	0,5	1	0.5	0.5	1	1
Vertical depth/Multi-level structure (0-1)	0	1	0	0	0	0	1	1	1	1	1	1
Type of Mission	**A1**	**A2**	**A2**	**A2**	**A2**	**T1**	**T1**	**T2**	**T2**	**T2**	**T2**	**T2**

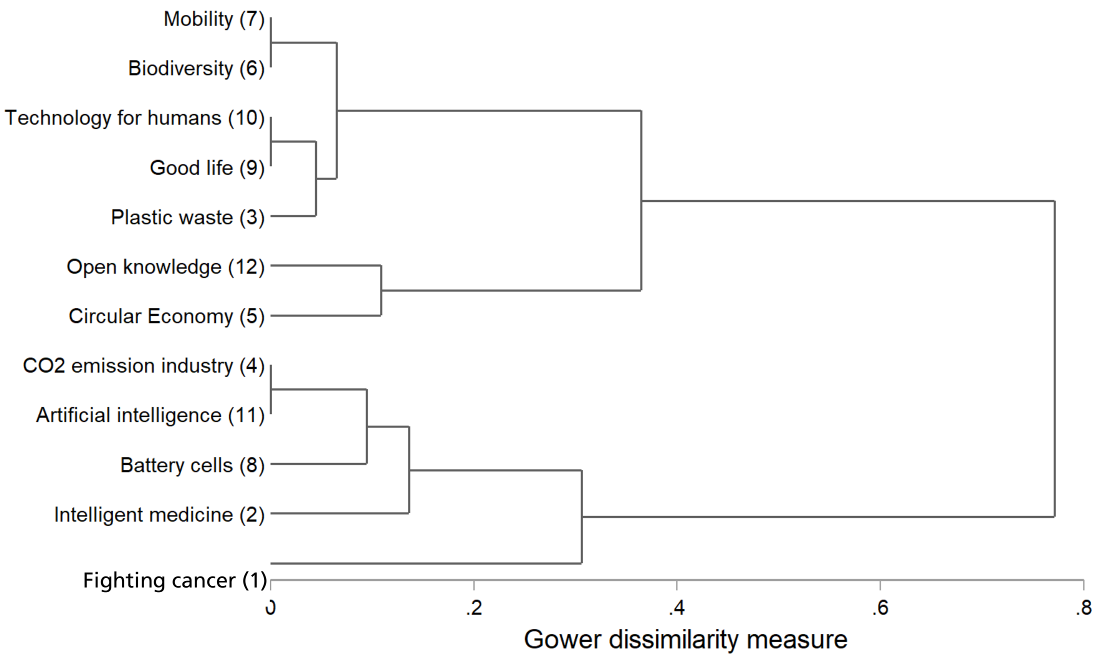

Figure 2: Dendrogram for the twelve German HTS missions

4.3 Discussion of empirical findings

The application of this new typology to the twelve missions of the German High-Tech strategy demonstrates its usability to systematically classify real-world missions. What sets this new typology apart from previous research are mainly three points: the conceptual delineation between policies and missions, the emphasis on the actor constellations and governance as a factor for shaping the realization of mission goals, and the attempt to provide a more fine-grained differentiation between different types of transformer missions. The latter, so far, have usually been subsumed in a single category, ignoring the existing variation between them. Instead, we argue that there might exist important differences between different types of transformer missions that require further attention.

While we believe that this new typology offers a practical and theoretical value for conceptualizing and evaluating mission-oriented policies, we acknowledge several theoretical and methodological limitations. First of all, our classification is closely linked to the formulation of the missions.[16] On the one hand, missions may only address a subset of a challenge or adopt a narrow approach to it. This is most obvious in the case of mission four (reduction of carbon dioxide in industry). The mission description puts its focus on

16 Not all missions might necessarily fulfill the commonly agreed criteria for mission-orientation (see also Mazzucato 2018b; Kuittinen et al. 2018b) and instead might rather reflect old paradigms for research and innovation policy.

technological solutions, without aiming for broader systemic changes. On the other hand, the assessment depends on the quality of the mission definition, i.e. how specific goals and means to achieve these goals are defined, what was a challenge in case of some rather vaguely and ambiguously defined missions (6, 9, 12). From this perspective, the incorporation of governance structures constitutes a major asset of this typology, as it brings in additional dimensions that can be observed using quantifiable data. At the same time, the attributed values across dimensions appear to be highly correlated, thus increasing the reliance of the previously obtained values. In order to overcome the potential problems arising from a bias of mission descriptions, the empirical classification of missions and its dimensions underwent extensive discussion in the project team and were cross-checked wherever possible with external data. Also, in view of the rather early stage of enacting the HTS 2025 missions, further empirical investigations might reveal the need to revise some of the assessed criteria, allowing for the possibility that missions change over time.

Secondly, in many instances there is an empirical overlap of several of the key dimensions, a problem already described in the practical implementation of research in this area (Walz et al. 2017, p. 15). While complex problems in most instances result in missions with complex interventions, there are good reasons to rely on a broader conceptual framework. On the one hand, as argued beforehand, missions may address only subparts of a challenge, making it necessary to take a closer look at the overall setting. Especially from a comparative perspective, this can be a crucial step to identify variation even among seemingly similar missions. On the other hand, the rather comprehensive approach is rooted in the foreseen impact assessment. As different types of missions might have different foci for evaluation due to different types of problems and outcomes, it is necessary to capture potential variation from the very beginning, in order to provide an adequate framework for impact assessment.

Finally, the typology as such does not directly conceptualize the relationship between different missions within a strategy (like the HTS 2025). Aiming to study several missions from a comparative perspective might therefore imply the need to broaden the horizon in order to understand how different missions are related to each other. This raises the question to what extent other missions affect the implementation of a mission. Such interdependencies and couplings may impose an additional layer of complexity for evaluation, as the success of a mission might be affected by outcomes of other missions (Amanatidou et al. 2014, p. 425).

4.4 Thoughts on the selection of missions for in-depth investigation

The mission typology developed in this paper is a first step towards the measurement of impacts of mission-oriented research and innovation policy. By providing a fine-grained typology, it is possible to select individual missions for an in-depths study that can build on a framework that takes into consideration the specific challenges and pitfalls of each type. This section outlines some thoughts that might provide a starting point for the refinement of the case selection process.

For selecting cases, we propose to take the following two main criteria into consideration: Firstly, selected missions should be typical/representative cases (see, e.g., Seawright and Gerring 2008) that exhibit a high degree of similarity to the ideal types described in section 3. From a comparative perspective, typical cases are particularly beneficial as they allow maximizing the variation between cases under study and make the selection less vulnerable to ambiguities in the project description (see discussion above). While missions can be located in a continuum between these ideal types, hybrid cases make it more difficult to investigate the with-in case dynamics and may limit the ability for generalized conclusions. Secondly, the complexity for evaluation may increase with the level of interdependency/interaction with other missions, making it difficult to control for all dynamics (Amanatidou et al. 2014, p. 425). From this perspective, particularly the following missions might be promising:

- Accelerator Type 1: **Fighting cancer (1)** → Being the only example for an accelerator Type 1, fighting cancer is a paradigmatic example for a “classical” science mission, having a broadly defined goal and being exposed to high uncertainty about the outcomes. Moreover, the challenges for coordination are limited due to the prevalent focus on research activities.
- Accelerator Type 2: **Intelligent medicine (2), CO2 emissions in industry (4)** and **battery cells (8)** → The aforementioned missions come closest to the principle of bringing knowledge into application and have a clearly defined final product. While these translation efforts might be also observed in case of **artificial intelligence (11)**, in the latter case there might exist a number of interactions with other missions, making it difficult to clearly delineate effects.
- Transformer Type 1: **Circular economy (5)** - A relatively strong focus on technological/scientific solutions and the supply side (producers) places mission 5 at the low end of transformer missions, as consumers only play an indirect role for the realization of the mission. In contrast, the more fuzzy mission of open knowledge (12) appears to exhibit stronger tendencies towards Type 2, as behavioral changes play a more pronounced role.

- Transformer Type 2: The missions on **mobility (7) and good life (9)** can be considered as a representative cases for the fourth category. Both missions have highly transformative goals, a complex constellation of actors both from an internal and external perspective, and potential redistributive conflicts. The mobility mission can be considered to be located at the high end of the innovation chain, with mobility being affected by innovations in many related fields and even other missions of the HTS 2025 (like battery cells).

5 Conclusions

The paper has presented a novel analytical framework for the study of mission-oriented innovation and research policies. The key argument is that the turn towards a stronger directionality of these policies has substantial implications for the role of the state. Accordingly, the study of mission-oriented policies needs to adjust its perspective and pay more attention to governance, implementation processes, and actor constellations. We thereby seek to go beyond the dichotomy of the state correcting vs. creating markets by taking a closer look at the role of state actors - a blind spot in innovation research recently addressed by Borrás and Edler (2020). Building on previous research and the distinction between transformer and accelerator missions, we have outlined a framework at the mission-level that distinguishes between four types of missions. Thereby, we aim to reflect the varying degrees of complexity within mission implementation and account for the different logics and goals of mission-oriented policies.

Based on these insights, the typology can contribute to develop appropriate approaches to evaluate and measure the impact of mission-oriented innovation and research policies by accounting for mission-specific problems and characteristics. Arnold et al. (2018, 16-54) argue that the complexity of evaluation depends on the complexity of the problem. In a similar vein, Kuittinen et al. (2018b, p. 35) argue that "mission-oriented R&I initiatives should be evaluated against criteria adapted to their objectives and the problems they target", rejecting a one-size-fits-all approach. In other words, different mission types face different challenges at different levels (see Table 4) and thus require different approaches for evaluation. Therefore, the focus on the effects of missions in case of accelerator type 1 might be more closely linked to the generation of new knowledge and thus can be addressed by conventional science, technology and innovation indicators, whereas a stronger transformation component like in transformer missions requires a broader approach that draws on additional measures and indicators.

We apply this typology to the twelve missions of the German *High-Tech Strategy 2025* and find that most missions can be clearly classified along the mission types. Based on this typology, we outline suggestions for the selection of adequate missions for an in-depth study, focusing on representative cases for each mission type while making an informed choice about the role of interaction effects between missions. It should be noted, however, that missions might evolve over time and could theoretically travel from one type to another. Such potential dynamic changes need to be taken into account in any typology-driven analysis of mission-oriented innovation policies.

Table 4: Mission-types and types of challenges

	Goals	Obstacles/potential issues
A1	• Increasing research output and scientific knowledge production in defined area	• Coordination of instruments and research actors • Ensuring efficiency of means and resources used • Setting up and implementing instruments, selection beneficiaries • Creation of appropriate infrastructure and context conditions
A2	• Creation of new infrastructure • Adjustment of regulatory framework • Bringing products to market	• Coordination of support schemes, regulation, interplay of different actors • Transfer of knowledge (science -> economic actors) • Management of insecurity about outcomes
T1	• Substitution/Reconfiguration of existing systems •	• Coordination of transformation process and policy mix • Long-term orientation and strategic planning • Translation efforts between different areas and from science to application
T2	• Substitution/Reconfiguration of existing systems • Change in behavior and attitudes	• Coordination of transformation process and policy mix • Long-term orientation and strategic planning • Translation efforts between different areas and from science to application • Moderating transformation processes and changes in societal behavior • Compensation of potential losers of transformation

Identifying variation across missions points to several implications for future research. Firstly, research should empirically test this mission typology by applying it to additional cases, like the British *Innovation and Research Strategy for Growth*. Secondly, the comparison of different mission types can help to explore to what extent different challenges and governance structures shape the dynamics and outcomes of missions and their implementation processes (see Table 4).

Thirdly, it seems of utmost importance to analyze the connection between the formulated missions and the ways and means on how these missions should be accomplished or tackled, namely the policy instruments. Fostering innovation by applying policy instruments has always been a difficult task. However, given the complex setting of mission-oriented policies, it even becomes more challenging to correctly observe and examine the cause and effect relationship of policy actions and the desired outcomes. Shifting the perspective towards the role of governance may help to map the field more clearly. Especially the study of failed missions might be particularly revealing, in order to understand whether complex missions indeed fail due to their overall complexity and too high ambitions or because of problems at the implementation level. Thus, this typology also can contribute to a better understanding on the context-specific role of policy-mixes (Rogge and Reichardt 2016) and the effectiveness of different policy instruments (Edler et al. 2016).

Finally, the typology allows shedding light on the interplay between different missions and exploring interactions in larger policy frameworks. While multiple missions may address one challenge at the same time, their relation with each other may vary considerably (complementary, reenforcing, conflicting). Mapping the different types of missions may be one step ahead to grasp the interplay of different missions theoretically and study their impacts from a broader perspective, by moving from the mission-level to the overall policy-level.

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Appendix: Detailed discussion of the 12 HTS missions

Mission 1 (Fighting cancer)

Fighting cancer (Mission 1) can be considered as a clear case of an **accelerator type 1** mission. Being heavily reliant on further progress in science in order to develop new approaches to cure cancer, the main failure in the past is the limitation of financing, classifying it as an archetypical case of market failure. The mission is defined from the perspective of the problem (fighting cancer) and does not provide a clear pathway how to achieve this goal. While the most current report also highlights the goal to bring the insights to application, the focus is mainly on research, whereas insights from application are supposed to feedback into research activities. At the same time, the governance structure both internally and externally is of limited complexity. Neither does the role of the state go considerably beyond financing research, nor does the coordination appear to be crosscutting a wide range of public and private actors.

Mission 2 (Intelligent medicine)

The introduction of the electronic patient file can be classified as a case for an **accelerator type 2** mission. The main challenge connected to this mission is less based on finding new technological solutions, but rather implementing an already defined solution (electronic patient record) and thereby overcoming the prevailing transformational system failure. The role of the state is not limited to financing, but also includes regulatory and coordinative tasks, making both efforts for internal and external coordination necessary.

Mission 3 (Plastic waste)

The mission on plastic waste can be considered as a **transformer mission type 2**. Addressing a part of the grand challenge on sustainability, it seeks to engage in a large variety of areas (research, information, regulation, etc.) and strives for a change of societal behavior. Thus it does not limit the mission to finding technical solutions, but aims for a systemic change. The complexity of the endeavor is also reflected in the variety of national (and international) stakeholder resulting in highly diverse projects and the coordination of the mission across six ministries (BMBF, BMU, BMEL, BMJV, BMWi, BMZ).

Mission 4 (Zero emission CO2)

The mission aims at reducing carbon-dioxide emissions in the industry and is classified as an **accelerator type 2**. While addressing a complex problem, the emphasis in the mission is clearly on providing new technological solutions and their application at industrial level (BMBF 2019). Thus, the scope of the mission is much more narrow than the overall challenge, as can be seen from the lacking reference to regulatory means in current documents. The rather narrow understanding of the mission goal and focus on technological progress suggests also comparatively limited levels of internal and external complexity (though the collaboration of BMU and BMWi might imply competing interests). Depending on the reading of the mission and weight attached to the underlying challenge, a different classification might be possible.

Mission 5 (Circular economy)

Mission 5 with its focus on circular economy leans towards **transformer mission type 1.** While the underlying problem is complex and involves a wide variety of actors and cannot be understood by a market/structural failure only, it appears as rather narrowly defined for a transformer mission. Having outlined a clear, quantifiable goal (increase resource productivity by 30% until 2030), the mission strongly emphasizes the role of technological innovation and structural changes compared to a broader transformation. At the same time, this focus on innovation and increasing productivity/efficiency implies a lower level of contestation (redistributive questions) and a more limited scope of (public and state) actors, as the mission is primarily focused on the production/recycling process. At the same time, it can be considered at the low end of the innovation chain and thus being less exposed to interdependencies with efforts in related fields.

Mission 6 (Biodiversity)

Mission 6 falls into the category of a **transformer mission**, **leaning towards type 2**. The decline of biodiversity can be considered as a multi-faceted complex problem that is affected from a transitional failure requiring a comprehensive state intervention, addressing not only technological but also regulatory and behavioral dimensions. While the initial programming document emphasized the role of research, the current report includes regulatory activities. The constellation can be also considered as more problem-oriented and complex when thinking about its implications for anticipated activities like regulatory changes in the agricultural or housing/planning sector, making coordination more conflicting and complex both between public and private and within state actors (BMBF, BMEL, BMU).

Mission 7 (Mobility)

Much alike the mission related to carbon dioxide, mission 7 (mobility) can be considered as a **transformer mission type 2**. It addresses a fundamental challenge with transitional failure which cannot be solved by regulatory and technological means only. Presenting a bundle of measures it does not provide yet a solution to the problem, but departs from the observation that mobility is at the edge of a transformational process. It comprises a wide variety of stakeholders and has potential redistributive effects turning the issue into a highly contested debate. At the same time, the crosscutting character of this challenge also necessitates the cooperation of multiple state-actors imposing a high coordinative burden on the state in order to fulfil its role in steering the development process.

Mission 8 (Production of battery cells)

The production of battery cells can be considered as an **accelerator mission type 2.** Being placed at the intersection of scientific innovation and the application into the industrial domain it has a rather clearly defined final product. While the mission description highlights the role of research, the anticipated role of state behavior is not limited to financing of research, but requires a more active involvement in shaping a favorable environment for fueling the production of battery cells.

Mission 9 (Good life)

Like climate change and the related topic of mobility, mission 9 targets one of the big challenges, arising from demographic change and the widening gap between rural and urban communities. Therefore, it also qualifies as a **transformer mission type 2**, given the wicked structure of the challenge and the transformative character of a possible solution that requires a broad variety of instruments. Enlisting a number of problematic dimensions, the mission does not yet provide a solution and thus is more problem oriented. Furthermore, the multi-faceted character of this problem makes the coordination between public and state actors necessary and is likely to lead to contestation about the prioritization of measures (for instance about the geographical prioritization of support). A similar structure can be also found with regard to the internal governance of the mission, which crosscut several policy fields and therefore creates high demands for a successful coordination of different actors.

Mission 10 (Technology for humans)

Mission 10 targets a broad field of problems, making current technological developments available for social purposes. While resting on a notion of technological innovation, the scope of this mission is considerably broader aiming to reach into domains like the work environment. Instead of focusing on a single technology, it suggests a general approach, suggesting that it is best classified as a **transformer mission type 2**. Addressing a topic with broad societal implications, it pursues a problem-oriented approach, which rests on the insights of emerging challenges based on technological innovation. Following the rather vague mission description, the focus is more towards exploring the impacts of new technologies on the social sphere including behavioral change of citizens and the adjustment of existing regulations as a reaction to a changing environment.

Mission 11 (Artificial intelligence)

Similar to mission 8, also mission 11 which aims to promote the development of artificial intelligence can be classified as an **accelerator mission type 2.** While highlighting the importance of research, the mission clearly links the goal to the application of insights and strengthening the German position in the emerging field. Again, governance is more complex compared to Type 1 missions, as it involves a wider range of potential actors (universities, enterprises, etc.) and cannot be achieved by a support of research activities only. Facilitating the emergence of new applications requires both the creation of favorable environments as well as higher regulatory and coordinative efforts and the dispersion of information to address emerging issues.

Mission 12 (Open knowledge)

The mission aims at creating new avenues for open knowledge and has the characteristic traits of a **transformer mission, leaning towards type 1**. It deals with a problem that is not a mere market- or structural failure, but has deeper roots that require an overall transformation of existent processes of knowledge exchange and innovation. Having already defined a focus on open access/science/data/innovation the mission has moved from a mere problem description towards a solution-oriented approach with a feasible technical solution. What limits its complexity with regard to the governance is mainly the fact that the level of contestation might be rather limited, as it complements existing strands (what can be also seen by the combination of existing instruments used) without replacing them completely. The outreach might be also limited in so far, as the coordination is supposed to be carried out by two ministries only, suggesting that the topic is not treated as crosscutting a wide variety of policy fields and ministerial responsibilities.