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From sustainability transitions to security: Mapping the new terrain for innovation policy

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Abstract

Increasing rise of military and non-military security issues, globally, influences innovation policies and interacts with policy aspirations to address societal challenges, notably around sustainability transitions. Drawing from research on security, geopolitics, and transformative and mission-oriented innovation policy, we map out what an increased focus on security means for challenge-led innovation policymaking. The analysis is structured around five policy imperatives: directionality, experimentation, inclusivity, regime destabilisation, and policy mix adaptation. Some clear synergies exist between sustainability and security, e.g., directing innovation support towards technologies that reduce supply chain dependencies, or dual-use technologies that improve resource efficiency and defence capability. Tensions also exist, e.g. security-risks of smart 'clean' technologies, or making innovation processes more closed for security reasons. Three broad policy strategies to govern the interrelations between security and sustainability objectives in innovation policy are proposed. The contribution raises awareness and provides nuance regarding ways the rising security concerns influence challenge-led innovation policy.

1 Introduction

Recently, we have seen the increasing rise of security and geopolitics issues in the context of science, technology and innovation (STI) policies. This is not a new topic for STI policies (McLeish and Nightingale, 2007; Zervos and Siegel, 2008), but one that was on the backburner for most of 2010s when STI policies increasingly embraced the challenge of climate change and other societal grand challenges (Schot and Steinmueller, 2018a). Due to the increasing geopolitical turbulence of the 2020s, especially since Russia invaded parts of Ukraine in 2022, security as a topic has made a strong comeback to the innovation policy agenda. This focus inevitably interacts with the ongoing aspiration of innovation policies to be challenge-led and address societal problems, especially towards sustainability transitions. Moreover, it also interacts with the increasingly strong demands on STI policy to enhance competitiveness and lead to value added. Just how the securitisation of policy concerns interacts with competitiveness and environmental sustainability in the context of STI (innovation) policy is a major concern of policymakers and analysts alike.

This paper aims to explore synergies and tensions between the sustainability transition and security objectives in the context of innovation policymaking, the former framed via the lens of challenge-led innovation policy. In discussing the analysis, we also reflect upon the traditional and underlying objective: competitiveness.

Security as a concept is multi-dimensional, having undergone broadening from purely military and state-oriented threats to, for example, environmental and human security (Peoples and Vaughan-Williams, 2015) and deepening by elaborations of positive and negative security (Hoogensen Gjørv, 2012; Roe, 2008). In line with the broadening of security discourse, we also understand security here in a broader sense, encompassing both military and non-military issues, extending to societal resilience. In policymaking, security has recently and occasionally been linked to other concepts, such as autonomy or sovereignty, and sectors such as energy, health and provision of many commodities (i.e. security of supply).

Although specific discussions on security in innovation policy have in many places resulted from the events in 2022, there were signs of more protectionist developments triggered by system competition and growing distrust between different global regions already in the 2010s. Besides increasing efforts to secure critical infrastructure and raise dual-use technologies into discussion, examples include policies on strategic autonomy in the EU (Miró, 2023) and the rise of new industrial policy and protectionist policies in the United States (US) (Juhász et al., 2024; Steinberg and Tan, 2023). Our focus of interest in this paper is the EU, while developments elsewhere have also shaped how the EU considers security in innovation policymaking. The debate on security and strategic autonomy has been intense on the EU level compared to the member state level (in many places). In the EU, open strategic autonomy (OSA) as a political concept, was initiated in the defence and foreign policy context but has since spread, for example, to concern energy and industrial policies, with an objective to safeguard the EU's independence from other countries (Edler, 2024; Kivimaa and Rogge, 2024).[1]

The financial crisis of 2008 dramatically reduced foreign direct investment and gave rise to populist politics in Europe and the US, questioning the long-term trend of internationalisation that had lasted

[1] OSA has been defined as 'the capacity of a country or region to pursue strategically important activities free of foreign interference' where adding 'open' to the term emphasises global interdependencies and the importance of international partnerships (Kroll, 2024, p. 4).

several decades (Leijten, 2019). Russian gas disruptions to Ukraine in 2006 and 2009, and invasion of Crimea in 2014, were signs of military and energy-related security threats. The early 2020s disruptive events, the Covid-19 pandemic and Russia's invasion of parts of Ukraine leading to a renewed sense of vulnerability and an energy price crisis in Europe, led to new 'emergency' policies such as the Recovery and Resilience Framework (RRF) (European Commission, 2020) and RePower EU (EC, 2022). The RRF was initially used as a tool to promote the economic recovery of the EU from the pandemic. It was subsequently expanded to support energy transition and energy security as part of the RePower EU policy.[2] During the 2020s, the EU has tried to increasingly address supply disruption risks related to critical raw materials (EC, 2020) and semi-conductors (Trippl et al., 2024), and sabotage of critical energy and data infrastructure interconnections between EU member states.

Since around 2020, academic attention began to slowly turn towards the links of innovation policy to security, sovereignty and autonomy. Most often, those contributions focused on how countries and, more explicitly even, the EU, can safeguard their sovereign development and use of critical technologies in the wake of systems competition (Bauer and Erixon, 2020; Caravella et al., 2021; Crespi et al., 2021; da Ponte et al., 2023; March and Schieferdecker, 2023), emphasising the importance of cross-border collaboration in innovation processes and the continued attention to global sustainability challenges (Edler et al., 2023; Leijten, 2019).

Against this background, we argue that security-related and geopolitical considerations have complemented the rationales for innovation policymaking: This new focus has severe implications for innovation policy as it has been developing in the last decade. Thus, security, as a rationale, needs to be balanced with addressing environmental and social problems (from here on referred to shortly as "sustainability") as well as competitiveness.

Currently, when security and geopolitics have seeped into the domain of innovation policy, governments around Europe and the EU itself are still grappling with new forms of challenge-led innovation policies – or have even incurred a backlash to previous progress with sustainability transitions. Challenge-led policies are such that go beyond mere R&D investments and economic growth, and also support the development and diffusion of innovations to tackle urgent but persistent sustainability challenges, often expressed in terms of UN Sustainable Development Goals (Kuhlmann and Rip, 2018; Laatsit et al., 2025). This kind of policy shift is, or was, manifested in the widespread attention for transformative and mission-oriented innovation policies, which provide new frameworks for engaging public and private innovation actors to pursue shared societal goals (Janssen et al., 2021; Schot and Steinmueller, 2018a).

So far, little is known about how the simultaneous developments towards sustainability-led and security-aware innovation policies interconnect (Kivimaa, 2022). For instance, innovation-driven sustainability transitions can both respond to and create shifts in material dependencies (for businesses and countries) with geopolitical and security implications. Geopolitical conflicts also change the short-term landscape for many industries and systems in transition (Wiertz et al., 2023), calling for both anticipatory and reflexive policies (Wiarda et al., 2024). Such 'landscape shocks' can create new windows of opportunity for transformative innovation. Alternatively, they may halt ongoing transitions and bring stronger support for established socio-technical systems. Sometimes both happen in parallel.

[2] While some member states have used the RRF to support challenge-led innovation policy (Kivimaa et al., 2023), overall, there have been strong disparities between EU member states in the content, process and transformative value of emergency policies (Schwaag Serger et al., 2023).

Drawing from security studies, research on geopolitics and innovation policy studies, especially literatures on transformative and mission-oriented innovation policy, we will map out and discuss what increased focus on military and non-military security, and negative and positive security, mean for challenge-led innovation policy.

Our research questions are:

- What does a broad take on security mean for challenge-led innovation policy?
- What kind of synergies and tensions does security have with the features of challenge-led innovation policy?

This paper is a conceptual exploration of a novel topic, based on a review of different sets of literatures at the cross-section of innovation policy studies and of security studies and international relations. We conducted an integrative review[3] on this emerging topic which "benefit[s] from holistic conceptualisation and synthesis of the literature to date" (Torraco, 2005, p. 357). Empirical references are made explicitly to the EU context.

First, the paper starts, in Section 2, with a brief overview of the history of innovation policy in Europe. In this context, challenge-led innovation policy is described via the evolution of three frames of innovation policy towards the transformative lens, and five 'imperatives' drawing from mission-oriented and transformative innovation policies are presented. Subsequently, in Section 3, security is defined and the history of security and geopolitics in innovation policy is reviewed, ending with the recently emerging debate in the European Union (EU) on strategic autonomy and technology sovereignty to provide an important context for our analysis. What then follows in Section 4 is an analysis of synergies and tensions with challenge-led innovation policy, when security is introduced as a new policy rationale. The discussion, in Section 5, summarises the analysis, and presents three broad strategies and avenues for further research. Section 6 concludes.

[3] The initial literature review, described in Section 3, used the research databases Scopus and Google Scholar for academic literature. The search terms for Scopus were: (TITLE-ABS-KEY ("innovation polic*") AND TITLE-ABS-KEY (security) OR TITLE-ABS-KEY (geopolitic*) OR TITLE-ABS-KEY (geoeconomic*) OR TITLE-ABS-KEY ("strategic autonomy") OR TITLE-ABS-KEY ("technology sovereignty") OR TITLE-ABS-KEY ("technological sovereignty") OR TITLE-ABS-KEY ("international relations") OR TITLE-ABS-KEY ("defence") OR TITLE-ABS-KEY ("defense")). This was conducted 7 January 2025, resulting in 227 hits. Google Scholar was searched for publications on relevant sub-topics, e.g. "geopolitics of science" and "geopolitics of innovation". We also searched for relevant reports published, e.g., by the European Commission and the OECD. This method matches with the emerging character of the topic of security in the context of (challenge-led) innovation policy, where much information continues to be published in the form of 'grey' reports and scientific studies.

2 Rise and characteristics of challenge-led innovation policy

2.1 Evolving context and objectives of innovation policy

To put current security-related innovation policy pressures in perspective, we briefly recount the developments of the STI policy field towards challenge-led perspectives (e.g. Boon and Edler, 2018; Fagerberg, 2018; Kuhlmann and Rip, 2018). The historical overview of innovation policy by Schot and Steinmueller (2018a) shows that evolutions in the legitimacy, scope and nature of innovation policy result from at least three interrelated factors: advances in research on innovation processes and policy support (our knowledge about innovation policy); major changes in the geography and impacts of technologies and economic activities (the reality in which innovation policy is situated); and shifts in societal priorities and concerns (expectations towards innovation policy outcomes).

Innovation policy originated after the second World War, although then framed differently as science and technology policy. Schot and Steinmueller (2018a) call it the first frame of innovation policy, oriented to growth, mass production and consumption, to help economic recovery during the post-war period. Science was hoped to help maintain peace and generate industrial profits (Schot and Steinmueller, 2018a). In the US, national security was one objective for post-war innovation policy (Lundvall and Borrás, 2005).

A period of tension between the US and Soviet Union until 1990, known as the "Cold War", contributed to defence R&D and formation of national innovation systems (Mowery, 2012), such systems called as second frame of innovation policy (Schot and Steinmueller, 2018a). The innovation systems approach gained prominence during the 1980s-1990s as a response to the perceived limitations of frame 1 policies. It highlights interactions and network formation between different actors and institutions (firms, universities, government organisations, end-users) and technology transfer to stimulate innovation development and diffusion (Schot and Steinmueller, 2018a).

After the Cold War, economic growth and competitiveness became the main agenda for innovation policy in many countries, although military R&D also took place. In the 1990s, while growth-orientation took the front stage of innovation policy, the European Commission coordinated telecoms and IT research programmes that funded dual-use developments, alongside pursuits towards defence industrial policy (Edler and James, 2015; Martins and Mawdsley, 2021). From 2000 onwards, defence sector R&D was officially kept separate from more general innovation policy. However, terrorist actions increased focus on internal security, enabling R&D spending contributing to the defence sector. For example, the security research programme, forming part of the EU's 7th Framework Programme during 2007-2013, was framed in terms of civilian purposes and internal security; it prevented defence and military technology funding, but allowed funding for dual-use developments and had close interests with defence companies (Martins and Mawdsley, 2021).

Broadly, there has been a gradual development that has at least unofficially increased security orientation in EU innovation developments. However, since 2022, military security has made a stronger comeback to the policy agenda. Because "contemporary defence decisions increasingly depend on technological advancements and R&D they become enmeshed with industrial and innovation policies"; for instance, the European Defence Fund established in 2017 is a part of EU industrial policy (Martins and Mawdsley, 2021, p. 1458).

The economic growth agenda of innovation policy has led to major environmental problems, such as climate change, pollution and biodiversity loss, being the reason for the challenge-led innovation policy agenda (Kivimaa, 2022), named as the third frame of innovation policy (Schot and Steinmueller, 2018a). Although frames 1 and 2 can be agnostic about the direction of innovation (Lundvall, 2024) and are insufficient to stimulate system innovation (Geels, 2005), for the third generation of innovation policy addressing persistent or grand societal challenges is an explicit objective (Kuhlmann and Rip, 2018). Academic propositions for frame 3 innovation policy emphasise transformative change of entire socio-economic and socio-technical systems. As a rationale for innovation policy, it builds directly on Weber and Rohracher's (2012) notions of transformative system failures (expanding the market and system failures legitimising frame 1 and 2, respectively), highlighting several factors that keep innovation systems from driving system change. Examples are directionality and policy coordination failures that prevent synergetic innovation efforts needed to enable systemic change. While many would likely subscribe to the objective of targeting innovation policy at societal challenges, difficulties exist around actual policy development, implementation and evaluation (Haddad et al., 2022; Laatsit et al., 2025).

During the ongoing attempts to shape challenge-led innovation policies, societies concerned with geopolitical tensions are currently witnessing a come-back of the competitiveness objective (Cincera et al., 2025; Mariotti, 2024), contributing to the revival of industrial policy (Barbieri Góes and Viesti, 2025; Juhász et al., 2024). Among the most notable developments is the Draghi report (Draghi, 2024), commissioned by the European Commission, on the future of European competitiveness. The proposed competitiveness strategy seeks to simultaneously address technological, environmental and geopolitical challenges through coordinated policies and substantial investments. This involves coupling innovation and technological advancements, and industrial policy and investment, with strategic autonomy and economic security. In response to these recommendations, the European Commission proposed its Competitiveness Compass framework in January 2025. Its three pillars comprise closing the innovation gap, reducing excessive dependencies and increasing security, and decarbonisation and competitiveness (EC, 2025).

2.2 Imperatives for challenge-led innovation policy

We propose a set of main imperatives for challenge-led innovation policy that have been identified as essential for the governance of transformative innovation policy (TIP) and mission-oriented innovation policy (MIP), and that we later use to reflect on synergies and tensions between security and sustainability in this context. Elaborated views on relevant features can be found in the two prominent literatures of TIP and MIP.

TIP is closely aligned with Schot and Steinmueller's (2018a) third frame of innovation policy and Weber and Rohracher's (2012) concept of transformative system failures. Its central perspectives on driving system transformation are grounded in science-technology-society studies, socio-technical systems theory and sustainability transitions literature, particularly the multi-level perspective. While the debate on TIP harbours variety (Diercks et al., 2019), studies operationalising TIP underscore the significance of participatory approaches and involving diverse stakeholders and communities in innovation processes (Boni et al., 2025; Clement et al., 2025; Molas-Gallart et al., 2021). Innovation, within this context, is understood technologically and socially (Edler et al., 2024), and to encompass institutional innovations aimed at eliminating harmful practices that obstruct sustainable alternatives (Haddad et al., 2022).

MIP, in contrast, emerged from fields of innovation economics, innovation studies, political economy, and public policy and governance research. Its revival was heralded with a special issue in Research

Policy (Foray et al., 2012), and Mazzucato's ideas of the (entrepreneurial) role of the state in advancing innovation (e.g. Mazzucato, 2015). In 2018, this culminated into a proposal for the European Commission's next R&D framework programme (Mazzucato, 2018a), which also sparked MIP at (sub)national levels (Larrue, 2021; Uyarra et al., 2025). The governance modes and policy instruments deemed suitable for MIP depend on how MIP is understood, alternative interpretations leaning towards science policy, industrial and entrepreneurship policy or transformative policy (Janssen et al., 2023; Larrue, 2021; Wittmann et al., 2021). Over time, the debate on MIP has increasingly incorporated views from adjacent fields such as transition studies (Hekkert et al., 2020; Wittmann et al., 2021) and responsible research and innovation (Wiarda et al., 2024).

Although TIP and MIP are sometimes equalled to each other, they do not necessarily overlap (Schot and Steinmueller, 2018b): TIP can exist without missions and MIPs are not always transformative (Janssen et al., 2025, 2021). Accordingly, the related but distinct literatures emphasise slightly different policy imperatives and practices. The available frameworks share some commonalities (e.g., directionality is always covered), but not all (e.g., phasing-out generally receives less attention). With the aim to be comprehensive but parsimonious, we have combined the key features of TIP and MIP into challenge-led innovation policy imperatives, using Nordling's (2024) typology of goals, knowledge dynamics, actors, strategies and institutions as a broad frame, as shown in Table 1. The imperatives reflect those principles that the vast academic literature on TIP and MIP has identified as being both essential for effective governance of TIP and MIP and as posing the highest challenges for governments to modify their traditional modes of innovation policymaking. Further elaboration of the imperatives follows in Section 4, as part of the analysis of synergies and tensions between security and sustainability as objectives for innovation policy.

Table 1: Imperatives of challenge-led innovation policy

Imperative	Description	Example references TIP	Example references MIP
Goals: *Directionality*	The intentional and pro-active guidance or steering of innovation processes, and trajectories, toward specific societal goals. This includes, e.g., (facilitating) vision creation, pathways and/or missions.	Weber & Rohracher 2012; Grillitsch et al. 2019; Haddad et al. 2022; Parks 2022; Bergek et al. 2023	Mazzucato 2018b; Larrue 2021; Wanzenböck et al. 2020; Wittmann et al. 2021; Janssen et al. 2023
Knowledge dynamics: *Experimentation and deep learning*	The deliberate and often iterative real-world testing of new ideas, innovations, policies, and governance approaches, with the aim to acquire, integrate and share insights into system factors (incl. institutional) affecting development and diffusion possibilities. This includes processes of second-order learning and unlearning.	Weber & Rohracher 2012; Grillitsch et al. 2019; Ghosh et al. 2021; Haddad et al. 2022; Borrás & Schwaag Serger 2023	Mazzucato 2018b; Kattel & Mazzucato 2018; Wanzenböck et al. 2020; Larrue 2021; Janssen et al. 2023; Elzinga et al. 2023
Actors: *Inclusivity and diversity*	The integration of diverse actors, perspectives, and interests into innovation and policy processes to build trust and engagement, and to ensure that the benefits of innovations are distributed equitably across society.	Kuhlmann & Rip 2018; Ghosh et al. 2021; Haddad et al. 2022; Borrás & Schwaag Serger 2023; Grillitsch et al. 2019	Mazzucato 2018b; Wanzenböck et al. 2020; Wittmann et al. 2021; Janssen et al. 2023; Nylén et al. 2023; Wiarda et al. 2023, 2024

Imperative	Description	Example references TIP	Example references MIP
Strategies: *Regime destabilisation and phase-out*	The resistance-removing processes by which existing socio-technical systems are disrupted (e.g. challenging and taxing undesirable practices, compensating losers), thereby improving opportunities for new innovations to emerge and diffuse.	Grillitsch et al. 2019; Ghosh et al. 2021; Molas-Gallart et al. 2021	Hekkert et al. 2020; Klerkx & Begemann 2020; Elzinga et al. 2023
Institutions: *Comprehensive and adaptive policy mix*	The coordinated and flexible use of a diverse set of policy objectives, instruments and processes (including supply and demand side policies) to drive systemic change across multiple sectors or domains. This includes the coordination across governmental departments and responsibilities.	Weber & Rohracher 2012; Haddad et al. 2022; Borrás & Schwaag Serger 2023; Santos & Coad 2023	Kattel & Mazzucato 2018; Larrue 2021; Wittmann et al. 2021; Janssen et al. 2023

Source: Based on own research.

3 Security and geopolitics in the context of innovation policy

Security and geopolitics in relation to challenge-led innovation policy is an emerging topic. Hence, little published academic literature existed on it at the time of writing of this paper. Empirically, most discussion around innovation policy and security has focused on the energy and digital sectors, while discussions using alternative or related terms of technology policy and industrial policy reveal also discussions around defence.

This section introduces the concept of security in the context of innovation and innovation policy (sub-section 3.1), alongside other related concepts, including geopolitics (sub-section 3.2), strategic autonomy and technology sovereignty (sub-section 3.3). A thorough understanding of these concepts is essential for analysing the synergies and tensions between security and sustainability.

3.1 Security and securitisation

Reacting to the geopolitical turmoil and other security developments during this decade, the renewed focus on security and securitisation intensifies societal concerns like resource availability and security of supply chains; security of operation of technical systems; climate and environmental security; and internal stability within states. To respond meaningfully to those demands, it is important to comprehend the nature of the security risks and the meaning of securitisation in the policy debate. Security risks can be of different scope and scale. International, cross-border risks include: resource flow disruptions, trade conflicts, military interventions/wars and data colonialism. Risks that often occur more locally or nationally relate to system failures, societal tensions and frictions, violence, terrorism and even collapsing state administrations. In addition, there are security risks which can be of local or cross-border character, such as infrastructure damage, environmental disasters, health epidemics, economic or financial crashes, cyber-attacks, and spread of disinformation.

Traditional security studies originated from discussions of military security and states as unit of analysis (or referent objects as security studies frames it) (Buzan et al., 1998). Over time the field expanded to other sectors and referent objects, considering, for instance, human and environmental security (Peoples and Vaughan-Williams, 2015). With increasing digitalisation of societies and the rapid development of artificial intelligence, cyber and data security have become of heightening concern for states and business actors alike. Besides the state-oriented 'hard' security perspectives coiled under the term 'negative security' (Hoogensen Gjørv, 2012), several scholars have talked about positive security as a complementary framing. Positive security is about how people experience security or 'freedom from insecurity', emancipation, and empowering people and communities (Booth, 2007; Hoogensen Gjørv, 2012; Hoogensen Gjørv and Bilgic, 2022; Roe, 2008).

The current debate further intensifies a tension emanating from an increased concern with security expressed in the political discourse, which has been conceptualised as securitisation. The Copenhagen School of International Relations has referred to the concept of securitisation in relation to the implications of using the security-term on nonmilitary issues (Peoples and Vaughan-Williams, 2015). More specifically, securitisation is described as a political act (Buzan et al., 1998) or a speech act with political consequences (Hansen, 2012). In practice, this can mean moving an issue from normal politics to the realm of security politics, which according to Floyd (2019) implies a reduction of democracy. Securitisation has also been described in terms of adopting extraordinary measures which break normal political practices, move decision-making power from ministries to agencies, and limit information from

the public (Heinrich and Szulecki, 2018). While securitisation has generally a negative undertone, it may also result in positive implications, such as raising the importance of climate change on the political agenda (see Dupont, 2019) and the comparison of the severity of climate change to other security issues (see Berling et al., 2021). Desecuritisation, instead, means shifting issues out of the emergency mode (Hansen, 2012). This can result in either the issue becoming politicised or depoliticised, the latter involving risks of "marginalisation of urgent and serious issues" (Trombetta, 2009, p. 589).

3.2 Geopolitics of science and innovation

Geopolitics concern the interaction between geographical factors, politics and international relations. The literature on geopolitics is divided into classical realist geopolitics which is focused on the effect of geographical factors between states and states' needs to secure territorial access and resources (Blondeel et al., 2021), and critical geopolitics that investigates how geographical assumptions influence global politics (Kuus, 2017). It is intertwined with questions of international trade and security via both concrete changes in relations between states and experts' perceptions about ongoing and future events. International dynamics, such as changes to global value chains, material constraints, and global competition, impose challenges for innovation policies (Kivimaa et al., 2022). For instance, related to geopolitical and technological changes taking place, trade relations will be increasingly influenced by many critical factors, such as technology and intellectual property rights, manufacturing and innovation capabilities of states, labour and skills, and capital costs of decarbonisation and electrification (IRENA, 2024).

Until the 2010s-2020s, the world experienced an increasing trend in international academic collaboration, mostly viewed positively (Schwaag Serger and Shih, 2024). The shift in the economic and political environment towards geopolitisation of science and innovation has led to techno-geopolitical uncertainty. Luo and Van Assche (2023) describe this kind of uncertainty as "the propensity of disruptions caused by significant policy changes taken by powerful nation states who seek interlocked techno-nationalist and geopolitical gains vis-à-vis rival states". This has put a system that by nature is oriented to expanding knowledge and creating opportunities and where "everybody would be a winner" (Leijten, 2019) under pressure. Currently, international scientific and technological collaboration connected to the post-World War II liberal international order – based on openness, rules and multilateral cooperation – is being replaced by an increasingly nationalist and inward-looking approach by states (Luo and Van Assche, 2023; see also Schwaag Serger and Shih, 2024).

Consequently, more protectionist policies that have emerged in several countries around the globe (linking to OSA and TS as described in Section 3.3), may continue to have large implications on the openness of science and innovation. For instance, the US CHIPS and Science Act, approved in 2022 "prohibits American nationals (citizens and permanent residents) from supporting the development and production of advanced chips in Chinese firms" (Luo and Van Assche, 2023). In essence, this shift means that managing and sustaining global innovation networks, as we have known to date, becomes much more challenging (Luo and Van Assche, 2023). Such "geopolitisation of science and innovation" does not only concern globally powerful states. Schwaag Serger and Shih (2024, p.14) note that "[g]eopolitical competition is forcing researchers, institutions and countries to re-examine and reconsider the premises, purposes and potential pitfalls of cross-border scientific collaboration".

Signs of securitisation of science are visible in an increasing number of countries, including the group of G7 countries and the EU. In the EU, the term "research security" has appeared alongside strategic autonomy. Research security implies that there is a need to protect research from foreign actors and

interests, linking to the pursuit of technological leadership in many areas (Schwaag Serger and Shih, 2024; see also Draghi, 2024). In certain dual-use contexts, such stipulations existed already two decades ago (McLeish and Nightingale, 2007), although the EU avoided incorporating dual-use in its STI programmes.[4]

The geopolitisation of science and innovation is linked to cross-sectoral processes towards strategic autonomy and technology sovereignty. These concepts can be seen to exist in the interface of competitiveness and security pursuits in the EU, and possibly elsewhere too. The next section explains these concepts and their connection to security in more detail.

3.3 Emerging debate on open strategic autonomy and technology sovereignty

In the OECD world, the need to develop and master innovation-driving technologies (e.g. nanotechnology, biotechnology, AI; also described as key enabling technologies) has been a major feature in innovation and technology policy since the 2010s (Foray, 2019). The main concern for states and the EU has been to ensure that national economies are able to compete with other nations for the leadership in producing those technologies, and, more recently, increase industrial innovation to address societal challenges and creating advanced sustainable economies (European Commission, 2018).[5]

However, since around 2020, the meaning of key (enabling) technologies has shifted, and with it the rationale for supporting them. Triggered through the increasing competition between China, Europe and recently the US and the experiences in Europe during COVID-19, policymakers at national and EU levels recognised the need to identify those technologies that are indispensable, not only for competitiveness, but also for the functioning of the economy and the provision of public goods through the state itself. This is referred to as *technology sovereignty*, which has been defined as "the ability of a state or a federation of states to provide the technologies it deems critical for its welfare, competitiveness, and ability to act, and to be able to develop these or source them from other economic areas without one-sided structural dependency" (Edler et al., 2020).[6]

A related term is that of *open strategic autonomy* that has originated in EU defence and foreign policy (Damen, 2022) and has expanded to energy and industrial policy domains (Schmitz and Seidl, 2023; Kivimaa and Entsalo, 2026). OSA aims to reduce the EU's dependencies from third countries in critical sectors (Miró, 2023) and to pursue openness while being resilient and assertive (Schmitz and Seidl, 2023). Openness in this regard has been argued to create internal policy contradictions (Huang and Soete, 2025), while the EU's research and innovation system has remained 'notably open' (Cerra et al., 2025). Although the concept is vague and broad, it pushes policymaking towards similar trajectories as technology sovereignty. Similar policies are also instigated by major states, such as the US and China aiming to bolster industrial policy and safeguard domestic capabilities.

[4] "Dual-use military applications of civilian technologies remained explicitly outside of the European scope of action; they were eliminated from any of the framework research support programmes of the EC when they were first developed in the 1980s and subsequently renewed and enlarged to the current Horizon Europe R&D support programme." (Kattel and Soete, 2024, p. 19)

[5] Accessed 25.4.2025: https://knowledge4policy.ec.europa.eu/foresight/topic/accelerating-technological-change-hyperconnectivity/key-enabling-technologies-kets_en

[6] The major elements of this definition are shared widely in the literature and in policy documents, see e.g. Di Girolamo et al., 2023; Kroll et al., 2024; Da Ponte et al., 2023; March and Schieferdecker, 2023.

There are two main consequences for this paper's debate. First, there is a need to provide the ability to use and, if needed, to produce, the technologies required for three major purposes: economic welfare, politically defined directions (e.g., energy transition, mobility transition, digitalisation of administrations) and critical public goods (e.g., security in a broad sense, defence, health provision). Second, just when the provision and use of key enabling technologies is recognised as being of broader and more basic importance, the very provision and use of them is less secured, because trust in the global division of labour and global cooperation in R&D and innovation diminished considerably.

The concept of technology sovereignty is now firmly embedded in debates around national industrial or innovation policies (Edler, 2024; Lee et al., 2024). It has been argued that this push for sovereignty in innovation policy is largely based on the military notion of security (Huang and Soete, 2025) as opposed to other notions, such as positive security (see, e.g., Hoogensen Gjørv and Bilgic, 2022). Technological sovereignty means, primarily, that strategic decisions are to be taken as to what kinds of technologies are critical against the three purposes mentioned above. This is important for our discussion, because the concept as now developed and implemented, does not per se favour security concerns over other concerns (e.g. competitiveness). Rather, it recognises the importance of sovereignty for the ability to act more broadly. Furthermore, both academic contributions and policy applications recognise that sovereignty is not to be confused with autarky (Edler et al., 2023; March and Schieferdecker, 2023). Contrarily, sovereignty, or OSA, implies to mobilise synergies and cooperation with trusted partners. It is a means to increase international technology cooperation in a more restricted international space, while it cuts ties in critical areas with less trusted partners. Hence, it risks contributing to further decline in understanding and trust between, and increasing integration within, blocs. Thus, the concept, while being applied to economic, security and broader transformational rationales domestically, may increase the sense of resilience domestically and within international spaces of sufficient trust, while increasing tensions globally, beyond and between those areas of trust. In extension, technology sovereignty may be a catalyst for synergies between like-minded countries (if such still exist) and within integrated economic spaces such as the EU. The increased division of labour between the like-minded may increase the overall effectiveness of innovation policy, while it reduces those synergies on a global scale. Therefore, synergies and tensions between different innovation policy objectives (e.g. sustainability and security), which is at the heart of this article, may play out differently within the area of trusted partnerships versus relationships between different areas of trust.

4 Synergies and tensions brought by security as a new objective for challenge-led innovation policy

This section explores synergies and tensions between security becoming a new objective for and the sustainability-orientation of challenge-led innovation policy. Although economic goals, competitiveness and growth, have characterised STI policies since their post-World War origin (Lindner et al., 2024), our analysis focuses on how security influences the third frame of innovation policy. The section is organised based on the five imperatives that are of particular importance for TIP and MIP as identified and described in Section 2. The ways in which the increased focus on security will interact with those imperatives will shape the relationship with TIP/MIP.

4.1 Directionality

Directionality "indicates that innovation processes can take different directions, with more or less favorable consequences" (Pel, 2024, p. 2). The imperative of providing direction, to enable synergies in transformation processes, implies a process of exploring and pursuing desirable and feasible directions for innovation processes (Weber and Rohracher, 2012). Visions, missions and targets can be seen as some of the ways to guide directionality (Geels et al., 2019). Directionality is described as a political process that poses questions, such as who gives direction, which direction is given, where and how is direction given, when and why does a direction change (or not) (de Graaff et al., 2025). Introducing security and geopolitics as an objective for innovation policy means that new security-oriented actors emerge to give direction, influence what directions are taken, and potential changes in directions. For example, dual-use technologies have recently strongly re-emerged as an area of increasing interest for innovation policy, following a risen security rhetoric (Blais-Savoie, 2025; Caviggioli et al., 2023; Grinbaum and Adomaitis, 2024).

There can be obvious synergies when the environmental or social challenges addressed by challenge-led innovation policy also bring security benefits. Examples include innovating in, for instance, energy efficiency, resource efficiency, demand response or energy storage technologies which reduce the need for imported fossil fuels (EASAC, 2025). These kinds of innovations can reduce concerns for security of supply and geopolitical power of fossil fuel producers (Scholten et al., 2020; Vakulchuk et al., 2020).

However, as technological development is fast, also pertaining to sustainability-oriented innovations, the governance of transitions is challenged by possible security threats and vulnerabilities created by technologies which are essential for those transitions but for which technology sovereignty is hard to realise (March and Schieferdecker, 2023). An example is when the 'smart parts' of zero-carbon technologies, such as of solar panels or electric vehicles, are produced non-domestically and could potentially be controlled by a third-party state or a private actor with malicious intentions. Other risks include the creation of new dependencies on concentrated supply chains. For example, the EU has strategic dependencies on China in mid- and downstream parts of solar PV production (Caravella et al., 2024). It has been argued that pursuits towards increased security and strategic autonomy as part of innovation and industrial policies should focus on critical sectors, materials and components. There are also broader cyber-security risks associated with increasingly digitalised innovations (Cavelty and Egloff, 2019; EASAC, 2025).

Finding synergies and alignment between security and sustainability is a crucial part of providing direction but such pursuit also comes with some risks. As particular visions around innovation may reject other directions of change (Stirling, 2009), vision building seeking synergies between sustainability challenges and security, may overrule innovation trajectories that are not applicable for such synergies. This could, for instance, mean that innovation processes aiming for dual-use technologies[7] will be funded more easily or with proportionally greater budgets than single use solutions. Yet, dual-use has been noted to complicate the design of innovation policy that simultaneously needs to address diffusion of socially beneficial technologies, often managed by non-state actors who are external to the remit of national security policy (McLeish and Nightingale, 2007). Moreover, innovation processes entail substantial uncertainty about future outcomes, and hence, overruling certain innovation paths based on second guessing can be harmful from the perspective of sustainability transitions. Missions often aim for a more concrete direction than broader sustainability visions, but they do so at the expense of openness and diversity associated with innovation in transitions (Bulah et al., 2024).

The temporal dimension of directionality is important too from the perspective of synergies and tensions. If too a short-term perspective is adopted in innovation policy, immediate security and defence needs may override more gradually developing global challenges around nature loss, health or poverty. The proposal to redirect EU cohesion policy funding for defence and dual-use already shows some movement in this regard.[8] Cohesion policy has been argued to be under pressure from shifting EU priorities, where obscuring regional priorities with current geopolitical agendas may risk the previous beneficial features of cohesion policy, i.e., responsiveness to local conditions and inclusion, and lead to increasing economic polarisation (Rodríguez-Pose, 2025). Contrarily, orientation into long-term security and peace-building processes (Huda, 2024) can find synergies with long-term sustainability transitions.

Synergies and tensions between sustainability and security also depend on what kind of terminology is used, and how key concepts are defined. Section 3 introduced the concepts of negative and positive security that imply differences in terms of key actors (states and militaries vs. citizens and communities) and orientations (protection against threats vs. increasing feelings of wellbeing and being empowered). Other concepts linking to security, such as open strategic autonomy and technology sovereignty also have different interpretations. In effect, Lee et al. (2024) argue that technology sovereignty can be interpreted via more protectionist techno-nationalism or more open collaborative sovereignty. They argue that the former actually fails to promote sovereignty, because, first, technologies are not owned by specific countries but developed in global innovation networks, second, the development pace of advanced technologies is so fast that global knowledge networks are needed to keep up, and, third, national innovation systems tend to be path-dependent and hence exclude certain capabilities (Lee et al., 2024). From the perspective of directionality, a path-dependent and techno-nationalist approach is more likely to miss important directions that, in the future, can provide synergies between sustainability and security.

[7] Dual-use can be understood in terms of technological convergence, where different downstream technologies (some military, others peaceful) share some of their upstream technological inputs, where dangerous military applications may be overestimated by policymakers (McLeish and Nightingale, 2007).

[8] Accessed 25.02.2026: https://ec.europa.eu/commission/presscorner/detail/en/qanda_25_930

4.2 Experimentation and deep learning

Experimentation has a substantial role in challenge-led innovation policy, as means of policy (i.e. experimental culture, policy experimentation) and as interim outputs (e.g. different types of technical, social and market experiments) (Kivimaa and Rogge, 2022; Mazzucato, 2018b; Sengers et al., 2020). A key feature of experimentation is the kind of learning it generates, in particular deep learning and unlearning established practices (Brown et al., 2003; van Oers et al., 2023) and the spread of such learning across innovation actors and the society. An example is the interface between electric vehicles and the energy system, where experimentation is needed to configure how the charging infrastructure can help rapidly respond to disruptions in electricity production and what kind of institutional or practice-based conditions this requires.

Integrating security into challenge-led innovation policy places perhaps even more emphasis on the need for different types of experimentation, to find the ways in which the dual objectives of innovation policy can be pursued and achieved. Types of learning in sustainability transitions can be described in terms of technical, market, policy and cultural learning. Integrating security into challenge-led innovation implies, for example, technical learning about the opportunities of dual-use technologies, market learning about how security will shape sustainability innovation markets, policy learning in terms of what kind of policies can best address combined challenges, and cultural learning about the changing context we are living in. The present geopolitical-security shift may be a very influential driver, because wars have been noted to substantially alter the cultural and symbolic landscape (see Johnstone and McLeish, 2022). Such shifts were also observed following the invasion of Russia into Ukraine in 2022 (Kivimaa and Sivonen, 2024).

A potential tension is related to diffusion of knowledge and learning, as security aspects tend to bring in more confidentiality in innovation processes. For instance, there is empirical evidence in how biosecurity[9] concerns have reduced scientists' freedom to publish results (McLeish and Nightingale, 2007). Although in the STI efforts following World War II, defence actors drove the use of their research in peacetime applications (Schot and Steinmueller, 2018a), subsequently the defence industry has become a "closed knowledge system" aiming to prevent information exchange, raising questions on how to integrate such a system into policies designed for openness (Kattel and Soete, 2024). Tensions may also result from psychological barriers for collaboration between two distinct communities, or from the redirection of resources from transition experimentation to defence.

4.3 Inclusivity and diversity

Challenge-led innovation policy emphasises the inclusion of more marginal actors in innovation (policy) processes and inclusive growth, thereby, widening the traditional scope of actors in innovation policy (Akon-Yamga et al., 2021; Grillitsch et al., 2020; Mazzucato, 2016). Both TIP and MIP also emphasise the importance of bottom-up processes (Mazzucato, 2018b; Schot and Steinmueller, 2018a). This may be in contradiction to an orientation into negative (i.e. hard) security approach, where sensitive information can require exclusion on a need-to-know basis. In the context of dual-use biological technologies, non-state actors have been viewed both as sources of threat and of technological capabilities (McLeish and Nightingale, 2007). A shift of power to private actors has also been argued to pose a more general security risk related to technology sovereignty (March and Schieferdecker, 2023).

[9] Biosecurity refers to the prevention of the spread of harmful organisms, such as pathogens, pests, and invasive species that can harm human, animal or plant health or the environment.

Yet, private sector actors have often been found to be more innovative than the more stagnant and path dependent public sector. However, if more generally (although not necessarily in the context of dual-use) focus can be directed also to positive security in innovation policy, synergies can be found between challenge-led and security approaches via empowerment of communities and citizens in innovation (policy) efforts leading to improved feelings of safety. Instead, if innovation policy is only linked to hard security, democratic processes may face risks due to increased securitisation of innovation policymaking.

Vision setting processes, which should be at the core of challenge led policies, have been argued to be influenced by power and agency, where incumbent and powerful positions tend to dominate, overriding diverse representation (Bulah et al., 2024; Weber and Rohracher, 2012). Attention to security, and especially to negative security, may re-strengthen incumbent power positions based on defence and hard security in innovation policy (see Johnstone and Newell, 2018).[10] Here an important determinant is the degree of incumbency and their orientation into transition versus change (Apajalahti et al., 2018; Stirling, 2019; Turnheim and Sovacool, 2020).

Bulah et al. (2024) argue that diversity associated with transitions needs to also include the heterogeneous nature of places, such as regions or cities, because working solutions are influenced by their geographical fit, culture and regional capabilities. This means that there is variation in how and what kind of synergies can be found between security and sustainability challenges across regions. One clear example is that states and regions traditionally dependent on imported fossil fuels, can find synergies between innovations that aim to reduce CO2 emissions and reduce such dependencies (Kivimaa and Sivonen, 2023). The same logic applies to products and processes using critical raw materials and especially rare earths, that has already resulted in cross-domain strategies addressing both circular innovation and strategic dependencies (e.g. the EU's Critical Raw Materials Act and the Clean Industrial Deal).

4.4 Regime destabilisation and phase-out

Previous empirical research has pointed out that often traditional security concerns have slowed down sustainability transitions in the energy sector (Johnstone et al., 2017; Kivimaa, 2024). Some of the key issues here have been tightly interconnected structures of militaries and energy, in terms of using fossil fuels in army operations dating back to World Wars I and II, as well as STI activities across civic and military nuclear power development. The larger states' militaries also play a role in safeguarding fossil fuel trade routes. Hence, this incumbent historical interconnection between militaries and fossil energy has created a tension between security and sustainability.

However, the globally turbulent situation, alongside climate change already affecting military operations, have created rapid needs for technological advancement in the military sector. For example, in India, the military is increasingly addressing climate security risks in its strategies and operations (Jayaram, 2024). NATO has noted the impacts of climate change on its military bases and operations, affected via permafrost thaw, flooding, storms and forest fires (NATO, 2024). Innovation is needed for military near-zero and zero-carbon solutions to decouple military infrastructure and equipment from carbon-intensive fuel sources, which can be facilitated by NATO's Environmental Protection Working

[10] Defence companies function as policy advisers, while simultaneously benefit from decisions made; e.g. the European Defence Fund has been argued to be 'captured' by the defence industry lobby (Martins and Mawdsley, 2021).

Group that delivers expertise to alliance-wide innovation, ongoing innovation on alternative fuels, and sharing of procurements standards (Farham et al., 2023).

Some synergies and tensions are sector- or region-specific, as noted above. Efforts towards regime decline goals in challenge-led innovation policy create security benefits, when import of materials, components or supplies are presently delivered from concentrated supplier countries. This is often coupled with replacement technologies that may create new dependencies, for which assessments are needed as part of the innovation policy mix (see sub-section 4.5).

From the perspective of positive security, socio-technical regime destabilisation also creates tensions. As feelings of 'freedom from insecurity' (Booth, 2007) are based on rather stable conditions, sustainability transitions may create uncertainty and resistance especially in those regions where incumbent industries have been large employers (see Lempinen, 2019; MacNeil and Beauman, 2022).

4.5 Comprehensive and adaptive policy mix

Providing a balanced and adaptive innovation policy mix has become of central importance in challenge-led policymaking (Haddad et al., 2022; Rogge and Reichardt, 2016). A policy mix, in this context, refers to the combination of policy goals, instruments and processes that influence the advancement of socio-technical transitions towards sustainability (Rogge and Reichardt, 2016). While perspectives considering more comprehensive and real-word attuned policy mixes have been argued for (Flanagan et al., 2011), considering security as part of the innovation policy mix may be challenging if the policy mix is considered too broadly in horizontal terms.

A challenge-led innovation policy mix, attuned to security, would consider besides the promotion of dual-use technologies, the reduction of environmental impacts of security-oriented innovations and the reduction of security risks from sustainability-oriented innovations. This would be akin to 'environmental policy integration' into security innovation and 'security policy integration' into sustainability innovation (see Cejudo and Michel, 2017; Lafferty and Hovden, 2003) improving policy coherence between the objectives of sustainability and security.

The negative environmental effects of military and defence activities are well noted, while militaries have also become actors in responding to climate change effects (Depledge, 2023; Jayaram, 2023), see previous section. Innovation policy mixes could seek to promote innovations that minimise the environmental impacts of military technology development. Some proposed examples include environmental requirements for steel and other components used for security and defence technology development and developing near-zero alternative fuels for the military (Farham et al., 2023).

Both TIP and MIP approaches indicate that policy mixes driving systemic change require balancing supply and demand side measures (Haddad et al., 2022). A typical example of the latter involves strategic use of public procurement, for instance, for policy goals related to competitiveness and sustainability (Kundu et al., 2025). Rising security concerns could lead to restrictions in terms of who to procure from, or what to procure. This could imply limited access to innovative or sustainable solutions from suppliers located in risky countries, corresponding to Lee's (2024) warnings regarding the perils of techno-nationalism. Alternatively, more stringent procurement criteria could also improve the playing field for nearby suppliers providing sustainable and/or innovative solutions (Meershoek, 2023). A recent survey of EU-wide public procurement suggests that conducting national security assessments in public procurement does not harm or benefit competition or sustainability and stimulates innovation at the national level (ref to be added after publication).

5 Discussion

This section provides a summary of insights on the above exploratory analysis of synergies and tensions caused by security as a new objective for challenge-led innovation policy, discussing the implications for policymaking. This leads to a proposition of three broad policy approaches to tackle this issue, followed by outlining future research needs.

Table 2 offers a summary of the dimensions along which challenge-led innovation policy imperatives and heightened security concerns may exhibit synergies or generate tensions.

Table 2: Summary of synergies and tensions between challenge-led innovation policy and security.

Challenge-led innovation policy imperative	Synergies with security as a new policy objective	Tensions with security as a new policy objective
Directionality	• Innovating in resource/energy efficiency or other solutions that reduce dependence on foreign suppliers. • Identification of critical sectors and technologies, in terms of security and competitiveness, that also have sustainability benefits. • Development of dual-use solutions with applications in both sustainability and security domains. • Long-term directional processes to address global environmental/social change and peace-building. • Orientation to security and defence that is framed in terms of openness, collaboration and wellbeing/justice is more likely to reap synergies via challenge-led innovation policy.	• Security risks and vulnerabilities of increasingly smart technologies used in sustainability-oriented innovations. • Overruling innovation trajectories that are not simultaneously applicable to both sustainability and security goals (possibly based on limited information). • Dual-use complicating the design of innovation policy, e.g. in case of conflicts to involve both state and non-state actors in security-sensitive processes. • Short-term urgency and orientation to security and defence may override the severity and urgency of addressing sustainability challenges. • Techno-nationalist and path-dependent interpretations of security likely to miss out on future synergies, water down the commitment to international commitments (Paris) and suffer from lack of capabilities.
Experimentation and deep learning	• An experimental policymaking approach, typical to challenge-led innovation policy, is likely to support the synergy finding process to address security, competitiveness and sustainability together.	• Spread of experimental learning limited by confidentiality issues and publication bans related to security (and competitiveness). • The general psychological barriers to experimentation are heightened through the need to bring together hitherto distinct communities for joint experimentation

Challenge-led innovation policy imperative	Synergies with security as a new policy objective	Tensions with security as a new policy objective
Inclusivity	• Orientation into positive security, i.e. empowerment of citizens and communities, can also be beneficial to tackling sustainability challenge via innovation policy. • Synergies between sustainability and security are placed-based, where in best cases the security of supply and security of infrastructure risks are reduced via the advancing transitions.	• Tension between broadening the scope of innovation actors in challenge-led policy versus more closed processes oriented to (hard) security and confidential information. • Shift of power to private, non-state actors, considered as a security risk. • Security-orientation may restrengthen incumbent power positions, potentially countering sustainability efforts and limiting learning. • Risk to democratic decision-making processes via securitisation of innovation policy, and thus delegitimization of potential solutions and alienation of parts of science community.
Regime destabilisation and phase-out	• Synergies between near-zero military innovation and preventing worsening impacts on climate change on military operations. • Creating synergies by means of just transitions and empowerment that offer new opportunities for citizens and regions.	• Path-dependent interconnections between military and fossil fuel sectors have hindered sustainability transitions. • Regime destabilisation creating uncertainty and resistance in some communities and regions.
Comprehensive and adaptive policy mix	• Possibilities for alignment via policy mixes supporting dual-use technologies, and an approach for advancing policy integration and coherence. • More public procurement from strategic partners implies a better playing field for sustainable and/or innovative solutions from EU/domestic suppliers	• Negative sustainability impacts of increasing promotion of defence and security technologies. • Governance coordination failure between administrative units with different rationales and practices.

Source: Based on own research.

Regarding synergies and tensions, our analysis highlights the complicatedness of combining the latest two objectives of innovation policy, i.e. sustainability and security, as each objective brings its own rationales, strategies, knowledge dynamics and actor-networks. This has implications for how to safeguard the imperatives of challenge-led innovation policy, while ideally also contributing to enhanced security. For instance, tensions around the directionality imperative suggests that ways in which security is defined and seen as part of innovation policy needs to be broad and open (enabling capability development and combination), rather than narrow and exclusionary. Experimentation and deep learning need to be encouraged by setting up living labs and regulatory sandboxes that enable exploring how to reap synergies between sustainability and security in innovation (policy) processes. Regarding the inclusivity and diversity imperative, innovation policy processes should account for the role of incumbency in exploring and pursuing innovation directions. Pertaining to regime destabilisation and phaseout, to create more synergies between positive security and sustainability transitions, challenge-led innovation policy needs to create opportunities via new employment prospects and by empowering citizens and communities. The imperative of a comprehensive and adaptive policy mix emphasises

the needs for improved policy integration between security and sustainability objectives (for instance, in technology assessment and public procurement).

The above are required generic policy responses to the dilemma presented in this paper. Their empirical manifestation is likely to differ across sectors, regions and time. That is, besides uncertainties associated with innovation itself, there are also uncertainties stemming from ongoing real-world developments around security, geopolitics and sustainability transitions (including the actions major states take). These uncertainties are in turn subject to different interpretations by actors, depending on their cultural, political and economic settings (Kivimaa and Sivonen, 2024; Laatsit et al., 2025). New expectations can be created via technological progress, but large cultural imprints change slowly and are shaped by wars and other security crises (McLeish et al., 2022).

Acknowledging the variabilities in how security synergies and tensions manifest themselves, or are perceived and framed, reflexive policymaking should be at the heart of challenge-led innovation policy. So far, however, reflexivity has been found to be poorly addressed by the current innovation policy toolbox (Laatsit et al., 2025). The EU policy community has proposed approaches that somehow couple competitiveness and security (i.e. open strategic autonomy and technology sovereignty). Meanwhile, the academic community has derived concepts of TIP and MIP with some applications in the EU (e.g. in the five EU missions), which occasionally address competitiveness alongside sustainability (e.g. the EU Green Deal). The interface of sustainability and security, however, has been largely ignored, while new thinking on energy security finds synergies between the two objectives (see EASAC, 2025). Likewise, specific policy concepts and approaches are still lacking at the intersection of all three objectives, although the new European Commission policies, such as the Competitiveness Compass and the Clean Industrial Deal in some ways mention the three objectives of competitiveness, sustainability (in terms of decarbonisation mostly), and security (primarily in terms of economic resilience). More comprehensive approaches are needed to address this intersection.

5.1 Three broad policy strategies

Our discussion of possible synergies and tensions pointed at various ways to reconcile security and sustainability objectives in innovation policy. To offer a conceptual basis for comprehensive policy approaches, addressing multiple possible innovation policy objectives at once, we abstract from the more detailed findings and distinguish

three broad policy strategies: 1) aligning objectives and seeking synergies; 2) minimising counter-effects of security-oriented policies on sustainability transitions; and 3) minimising new security risks and vulnerabilities of challenge-led innovation policies.

The preferred strategy, alignment, means supporting innovation paths and technologies that create either double (sustainability and security) or even triple potential (sustainability, security, and competitiveness). Examples here include energy efficiency; resource efficiency and circular economy-oriented innovations; electrification of military vehicles in certain conditions; and dual-use technologies. Policies should encourage for governing actors and others to identify the existence of such win-win(-win) scenarios, and what it would take to realise them in practice. However, as the various objectives are often not fully or even partially compatible (as indicated by many intrinsic tensions), the other two strategies are important too.

When innovation paths pursued for security cannot simultaneously serve sustainability, it is essential to at least minimise the counter-effects on sustainability. Here, an example is to guide security-related

innovations to better consider material needs and environmental risks. Pertaining to strategic autonomy, for instance, advancing 'cleantech' to pursue new industries must not only think about their greenhouse gas emissions, but the effects of mining and industrial facilities on biodiversity, water quality or air emissions – which not only fail to address sustainability but may also exacerbate environmental security risks. It is also important to be aware of the nature of 'securitisation' (see Section 3.2) taking place and avoid cases where the wider public is kept uninformed of the potentially detrimental environmental and social effects of innovations justified on security grounds. Policymaking should also become desecuritised when a potential emergency phase is over.

In line with the logic of the second strategy, the pursuit of challenge-led policies must attempt to be aware and minimise adverse effects on security. This is not an easy endeavour, as so far, for instance, the advancement of sustainability transitions has shifted the EU's fossil fuel import dependencies to increased dependencies on critical raw materials (largely controlled by China), affecting security of supply and strategic autonomy. Hence, future innovation policies and activities must try to better anticipate them before the possible dependencies and independencies that sustainability innovations create in terms of resource, trade and value chains, data-related risks or critical infrastructure.

For seeking synergies and minimising counter-effects, policymakers can and should consider a wide range of policy and governance measures. Following distinctions used in innovation policy (Flanagan et al., 2011) and environmental governance literatures (Oberthür, 2019), this could include hard policy measures (financial incentives or coercive tools) and soft (non-coercive) policy measures. For instance, one might seek synergies by implementing innovation support instruments or procurement guidelines targeted at leadership in security-sensitive critical technologies or materials, or merely by creating new governance structures that formulate and coordinate mission-like ambitions on security and sustainability. Counter-effects can be minimised by, for example, strictly obliging sustainable innovation subsidies to prioritise sovereignty, or through softer discouragement of reliance on actors or components from risky countries.

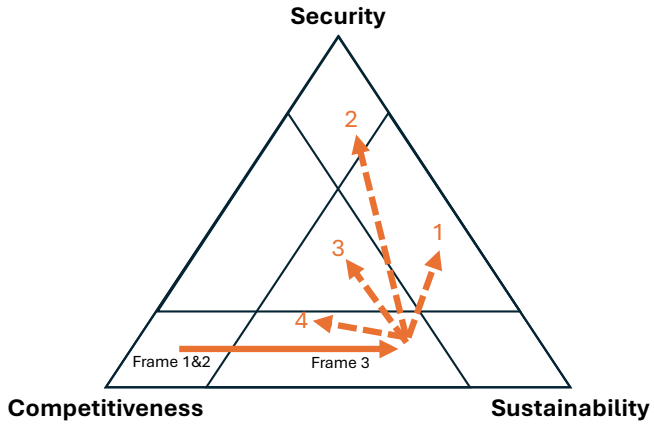
Given the potential misalignment among innovation policy objectives, and the fact that synergies or tensions between them are often indirect and therefore not immediately apparent, it is reasonable to expect that policymakers may not rely solely on measures with an explicit security orientation. Instead, they may adopt more implicit strategies that promote security objectives *de facto* rather than *de jure*. Regarding the example of setting policy targets that aim to have a positive security and sustainability impact, this could take the shape of articulating missions centred on themes like 'green AI' (Schwartz et al., 2020). While not overtly related to security, such initiatives may nevertheless contribute to broader goals such as digital sovereignty. Similarly, directing public investment toward the civil development of dual-use technologies may provide an indirect route for pursuing security-related aims. Ultimately, the extent to which policymakers choose either explicit or implicit approaches—and the implications of these choices for policy effectiveness—remains to be seen.

Our key suggestion for policymakers is that they should seek synergies between different innovation policy objectives (competitiveness, sustainability, security), but recognise what directions may be closed in the process – and carefully evaluate the cascading impacts of such closed directions. Moreover, we advise to include defence, foreign policy and other security actors in innovation (policy) processes. Preferably such processes remain as inclusive as possible, while ensuring that taking on board different actors does not limit other actors – except in exceptional circumstances (e.g. particular dual-use technologies).

5.2 Avenues for further research

Our paper is intended as a new opening for the research communities around (challenge-led) innovation policy, international relations and security. It illustrates how the real-world policy context is becoming increasingly challenging, with unknown implications for how the innovation policy field will continue evolving. Figure 1 sketches possible directions, ranging from a scenario in which security considerations enhance the integration of sustainability goals (based on the identified synergies), to a scenario in which the pendulum swings back to competitiveness-focused innovation policy. There are also in-between scenarios in which security is positioned alongside sustainability challenges (e.g. as another societal challenge), or where all goals are considered simultaneously. To what extent such all-encompassing innovation policy is feasible is yet to be determined, as genuinely addressing sustainability challenges might involve difficult trade-offs for all the situations in which a win-win-win scenario remains out of scope. We thus call for empirical research examining how the triple objectives presented (competitiveness, sustainability, security) have been or could be addressed in different regional, national and sectoral contexts and in EU innovation policymaking. What kind of tensions are caused by security as a new objective for innovation policy? What practical tools or policy instruments are available or could be used to find synergies and minimise contradictions in practice? What kind of needs does security present for the further evolution of TIP and MIP research? Future research should also explore synergies/tensions associated with potential further horizontal 'objectives' for innovation policy. These include, for example, the increasing digitalisation-data-AI development, or the calls for improving justice and fairness of policies.

Figure 1: Four possible scenarios for further evolution of the innovation policy field



1. Security-sustainability synergies could reinforce challenge-led innovation policy
2. Security might bend the challenge-led debate, away from sustainability challenges
3. Security (and sustainability) issues become an integral part of innovation policy
4. Security concerns mark a return to competitiveness-oriented innovation policy

Source: Own illustration.

The overall contribution of our study consists of raising awareness and providing nuance regarding the many different ways rising security concerns influence challenge-led innovation policy. These influences can have the form of synergies or tensions, even for individual properties of challenge-led innovation policy. That having said, it remains important to acknowledge that challenge-led innovation policy as such might become sidelined now that attention and budgets are shifting so rapidly. Or, stated differently, now that security is becoming the challenge perceived as more pressing than any other societal challenge. For the increasingly overshadowed innovation policies concerned with for instance sustainability per se, there is a risk that a losing momentum undermines their continuation

and fruition. We recommend future research to follow these developments closely and explore possibilities to sustain the much-needed long-term perspective and stability transformative and mission-oriented innovation policies demand.

6 Conclusions

In this paper, we argued that increasing security concerns influence also innovation policy. From this basis, we analysed potential synergies and tensions that the introduction of security as a policy objective creates for challenge-led innovation policy – focusing on one of the main current societal challenges, i.e. the transformation towards sustainability.

We combined literatures on transformative innovation policy (TIP) and mission-oriented innovation policy (MIP) to derive five imperatives required for successful challenge-led innovation policymaking. We conclude that there are several important potential synergies, supporting a positive connection between security and innovation-policy-driven sustainability. However, rising security concerns are also likely and put pressure on the imperatives and thus the promise of challenge-led innovation policy. The identified tensions within those imperatives need to be understood and addressed to better align the two policy objectives with each other, and with the traditional objective of innovation policy – economic competitiveness.

The key output of this paper was to generate attention as to the range of synergies and tensions that security as a policy objective brings for challenge-led innovation policy. This initial conceptual analysis is intended to guide further (empirically oriented) assessments on synergies and tensions, their prevalence and importance in different sectoral, national and regional innovation policy contexts. Such analyses would also help in emphasising the reflexivity of innovation policymaking, where new and revised assessments are needed with changing geopolitical developments and technological progress.

We also showed that defining security broadly – both as military and non-military security and as negative and positive security – is useful in the identification and elaboration of synergies and tensions. On this basis, we argue that the ways in which security is defined and seen as part of innovation policy needs to be broad and open, rather than closed and narrow. Such an open approach also recognises that security is very much a place-based phenomena, influenced by pre-existing technologies, resources, institutions, cultural settings and capabilities in different regions and states. Yet, simultaneously, we can see changes in the global context and the World order that affect innovation practices across borders. Therefore, there are probably also common synergies and tensions for different innovation policy settings.

Finally, mobilising the literatures on TIP and MIP can be useful in a practical sense when it comes to developing innovation policy and security policy agendas. First, the developed framework and the identified imperatives might give guidance as to how to advance security as a new innovation policy objective. While originally proposed in the context of challenge-led innovation policy, imperatives regarding directionality and inclusivity can also serve security goals. Second, empirical experiences on advancing "security as a challenge" within innovation policy can also help us derive general lessons on how challenge-led policies can be advanced in different and more politically amenable contexts. Further, the framework might give us signals as to how to merge different kinds of communities around innovation – albeit this will produce tensions itself as well. In any case, increased alignment is needed due to the inevitable links between security and sustainability: Without secure and resilient societies, it will be difficult to advance sustainability transitions. And without sustainability transitions, there will be far worse insecurities and security crises in the future.

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