

König, Jonas; Suwala, Lech; Delargy, Colin

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Helix Models of Innovation and Sustainable Development Goals

Jonas König (Technical University Berlin, Germany)

Lech Suwala (Technical University Berlin, Germany / Jagiellonian University, Cracow, Poland)

Colin Delargy (Technical University Berlin, Germany)

Definitions

All Helix models are built on the assumption that knowledge and innovation, and their accelerated importance in so-called emerging knowledge- and innovation-based ecosystems have the potential to organize, educate, and integrate future societies. These ecosystems comprise various helices twisted together as intertwining strands intimately interacting – in an analogy with how DNA produces living cells in biology – with each other as sources of production and varieties of knowledge. The first helix is accredited to academia (historically also to the church) and the education subsystem as the dominant origin of knowledge production (e.g., universities, research institutions). The second helix includes industry, business, and markets (economic subsystem). The coupling of the education and economic subsystems during industrial revolution resulted in a double helix of knowledge production. The third helix is government and the public sector as the state subsystem. Conceived together with the other two helices they form the triple helix where the state possesses a strong role in developing innovation systems at various scales to support both industry and academia. The fourth helix represents the public or the civil society subsystem and results together with the aforementioned helices in the quadruple helix model of knowledge and incorporates civil stakeholders, art, and culture into the innovation amalgam. The fifth helix involves the (natural) environmental subsystem. The aggregated quintuple helix model of knowledge production and innovation is therefore capable to integrate socio-ecological transitions necessary for sustainable development (Leydesdorff and Etzkowitz 1996; Carayannis and Campbell 2010; UNESCO/IFAP and UNU-EGOV 2016).

Introduction

The Quadruple Helix model of innovation (Carayannis and Campbell 2009), like its predecessor, the Triple Helix (Leydesdorff and Etzkowitz 1996), and its successor, the Quintuple Helix (Carayannis and Campbell 2010), was developed both as an analytical model and a normative tool. As an analytical model, each Helix variation allows for the depiction and explanation of specific aspects of how (contemporary) societies produce, diffuse, and marketize knowledge. As normative tools, they have been used to inform policy makers from the local to the transnational level in fields such as academia, government, and society. Moreover, both the analytical and normative simplicity led to a widespread application of helix models within theoretical approaches in adjacent disciplines (e.g., territorial innovation models, Etzkowitz 2012; Brinkhoff et al. 2015). All that being said, helix models provide a possible starting point for reflecting on the Sustainable Development Goals (SDGs) in general, and for framing research and policies related to SDG 9 to build resilient infrastructures, promote inclusive and sustainable industrialization, and foster innovation in particular.

All helix models share characteristics of complex systems (Lewontin 2001). First, the models are simultaneously inter- and transdisciplinary, taking input, for example, from across natural and social sciences. Second, they acknowledge the role of innovation in knowledge-based societies and highlight the importance of (increasingly) intertwining multiple societal subsystems. Third, they are built upon an array of societal subsystems which are themselves dynamic and permanently evolving, with inherent tensions among themselves that forge new societal, institutional, organizational and spatial contexts and enable or hinder specific innovation processes. And fourth, they expand the understanding of the nature and extent of innovation processes beyond the mere technological and economic realm, reflecting on the involvement of and impact on different actors and social spheres encompassed therein (e.g., social, cultural, ecologic).

Helix models have been associated with two primary claims: first, the ability to describe and explain the growing interactions between different societal subsystems as a basic characteristic of contemporary innovation processes, and second, the ability to evaluate and to actively promote or revise the nature and interactions within and between the respective spheres (e.g., mission of research institutions). In this regard, the Triple Helix model has been particularly influential (McAdam and Debackere 2018). Apart from that, there have been high expectations for both the Quadruple and the Quintuple Helix models since the very beginning, not only to continue to inform policy making, but also as a “Proposed Framework for a Trans-disciplinary Analysis of Sustainable Development” as Carayannis and Campbell putting it in the title of their article that discusses the relationships of all helix models against the background of sustainable development (Carayannis and Campbell 2010). The link to sustainable development had already been made by Etzkowitz and Zhou in their proposal for a “Sustainability Triple Helix of university-public-government,” refocusing the original model towards sustainability rather than adding a fourth dimension (Etzkowitz and Zhou 2006). All these efforts point towards a strong intended connection between helix models and sustainable development, which makes their integration with SDGs, and in particular SDG 9 (infrastructure, industrialization and innovation) all the more intriguing.

Therefore, this chapter seeks to elaborate upon the relationship between Helix Models and Sustainable Development Goals (SDGs) by providing mutual starting points, to jointly conceive these two influential concepts. For this undertaking, the following section outlines origins and essential conceptual building blocks of all Helix models, namely: Knowledge and innovation, and their accelerated importance in so-called knowledge and innovation-based economies – a dominant paradigm of contemporary societies. The section “Triple Helix: The Original Framework” introduces the original Triple Helix model – in other words, the basic idea that the accelerated importance knowledge and innovation significantly alters the interplay between once merely isolated domains of university, industry and government and points to two strands of the pertinent literature. The section “Quadruple and Quintuple Helices: Adding the Civil Society and Environment(s)” summarizes attempts to extend this original model by adding two further helices – a fourth helix (the civil society) and a fifth helix (the environment) that allow for an explicit consideration of sustainability. This background sets the scene for section “From Helix Models of Innovation to SDGs” illustrating conceptual, practical and political bridges that were and could be built between these two powerful frameworks. Hereby, two levels of relationships will be analyzed: first Helix models and Sustainable Development Goals (SDGs) in general, and second Helix models and SDG 9 in particular. A final section makes some summarizing and critical observations.

Background: The Emerging Knowledge and Innovation-Based Economy

The Triple Helix model, originally formulated by Henry Etzkowitz and Loet Leydesdorff, was clearly not the first to recognize the significance of knowledge for economic prosperity and development. Drucker (1959), for instance, coined the term “knowledge worker” to refer to the increasing importance of mental skills on the labor market, and other scholars highlighted the contribution of corporate research, patents, and knowledge exchange for economic competitiveness. These observations also culminated in an appreciation of the crucial role of knowledge (among human capital and as a technologic property) for long-term economic growth in theoretical models. In 1996, the OECD concluded the knowledge-based economy to be the norm rather than a particularity of some technologically advanced states (OECD 1996). Simultaneously, interest in processes that have their origins in these forms of knowledge – i.e., the sources of novelty like learning, creativity, innovation, and entrepreneurship – also gained momentum (Suwala 2014). In particular, innovation was identified as the central driving force for dynamic or discontinuous development. From the 1980s on, this role of innovation was (re-)discovered in theory and practice. In academic theory, Grossman and Helpmann’s (1991) seminal book *Innovation and Growth in the Global Economy* provided a summarized account for incorporating innovation as an endogenous variable in neoclassical economic growth theories. In practice, policy makers realized that policy interventions in the field of research and knowledge production led to (national) systems of innovation (NSIs) that could enhance both innovation capacities and economic competitiveness of markets on the macrolevel of society (Lundvall 1992).

Who generates innovation and how is innovation generated from knowledge? Traditionally, this relation has been understood as a linear process in which universities or independent research institutions would conduct basic research to be followed by applied research and product development within corporations that would eventually introduce new products into the market (Godin 2006). In this model, processes necessary for innovation mainly build on existing combinations of knowledge; institutions responsible for generating this knowledge, e.g., universities, remain essentially independent spheres, and private companies among other non-academic organizations are ascribed to specific, separated tasks. This process was also referred to as “mode 1 of knowledge production” where (scientific) knowledge was developed prior to scrutinizing the applicability of the findings in the market, and where this knowledge remained organized in separate disciplinary silos (Gibbons et al. 1994; Godin 2006, see Fig. 1). The emergence of the knowledge-based economy challenged the linear model of innovation by propelling an increasing number of policy interventions and imperatives (e.g., the Bayh-Dole Act) that aimed at capitalizing on innovative potential of universities and research institutions (Etzkowitz 2003; Mowery et al. 2015). At the same time, the increasing significance of knowledge-based industries and the need for most businesses to embrace innovation in their activities began to forge linkages between industries, policy, and academia. Attempts to conceptualize these developments resulted in the “mode 2 of knowledge production.” This second mode is inherently transdisciplinary and interactive, taking place principally within the specific context of application and within diverse organizational settings (Hessels and van Lente 2008). The chain-linked model of innovation highlights those feedback loops and exchanges between all stages of research present in this knowledge production mode (Kline and Rosenberg 1986). New developments emphasize not only an increased interaction between industries, policy, and academia, but also the participation of the society in knowledge-production and innovation (e.g., creative class, wisdom of the crowds). These developments are characterized by the democratization of knowledge and interrelations between technological innovations and social innovations as well as by top-down and bottom-up innovation processes. These processes were summarized under the notion of “mode 3 of knowledge production” and open innovation models (Carayannis and Campbell 2010).

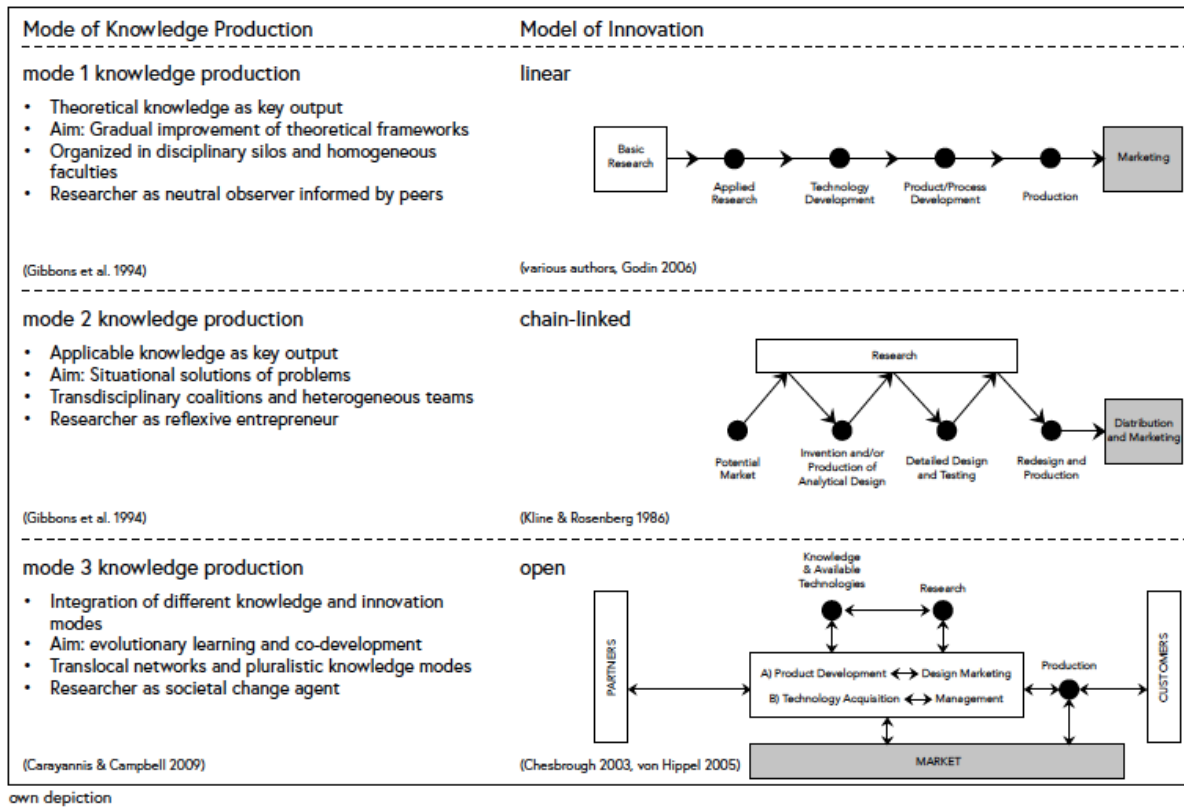


Figure 1- Modes of knowledge production and corresponding models of innovation

Triple Helix: The Original Framework

The original Triple Helix model focuses in particular on university-industry-government relations (see Fig. 2). It mainly builds on mode 2 of knowledge production and the chain-linked model of innovation, highlighting the dynamic and processual nature of contemporary knowledge production at the intersection of the three aforementioned dimensions: “the Triple Helix as an analytical model adds to the description of the variety of institutional arrangements and policy models an explanation of their dynamics” (Etzkowitz and Leydesdorff 2000, 112). In short, the systemic differences and opposing organizational logics of academia, business, and government among the different societal spheres necessitate bargaining; diverging expectations and shifting interdependencies guide the permanent reconstruction of institutional arrangements. The model accentuates the changing and pivotal role of universities as powerhouses of knowledge production. In contrast to the equilibrium-seeking dynamics of markets and the normative control mechanisms of the government, “the equilibrium upsetting dynamics of socially organized knowledge production” (Leydesdorff 2000, 26) add a momentum of permanent transformation and change which is considered typical for the knowledge-based economy. Interestingly, the model refrains from incorporating the role that geographical scale plays on these processes in any specific or practical way, assuming *ex ante* that knowledge diffusion and innovation take place predominantly at the national or regional level (Suwala and Dannenberg 2009). Instead, it is an “empirical question of whether a system has emerged at the national or regional level” (Leydesdorff 2012, 26) or whether it transverses territorial borders. The model, therefore, allows for navigating between micro-, meso-, and macro-levels of analysis. Research aiming to conceptually refine and empirically ground the basic tenants of the Triple Helix model has mainly evolved around two partially overlapping strands. An institutionalist strand focuses on the role of agents (agency) in the model within corresponding university-industry government networks, while a neo-evolutionary strand stresses structural relations and dynamics within the model, inspired by systems theory (Leydesdorff and Meyer 2006).

Institutional Networks Within the Triple Helix

Work on (emerging) university-industry-government networks and the networks of actors involved therein make up the majority of studies that are built on the Triple Helix model. A number of case studies have assessed positions of helix actors in a range of geographical and organizational settings in order to relate them to other output variables like product development or regional patenting (e.g., Farinha et al. 2016). Much of the pertinent work also points to the broad variety of Triple Helix configurations, with an emphasis on research institutions as indigenous carriers of knowledge and innovation (for a recent overview: Linton 2018).

The changing role of research institutions has widely been reflected by the notion of the “entrepreneurial university” (Etzkowitz 2003). In this realm, a “third mission” of universities is identified, next to classical Humboldtian tasks of research and teaching. This third mission is characterized by strong linkages to companies and by efforts to monetize research output, for example, through patent licensing or academic spin-offs (e.g., Brinkhoff et al. 2012). The effects of this third mission are argued to be ambiguous. The economization of the university has been criticized for making research dependent on market actors, blurring the boundaries between university, industry, and government and making original knowledge more difficult to distinguish. At the same time, the flexibility of research institutions offers opportunities for collaborative work, for example, when dealing with targets of SDGs and knowledge transfers with the private sector.

Neo-Evolutionary Dynamics Within the Triple Helix

From a system theory-based perspective, interactions within the Triple Helix are not only ingredients of contingent tri-lateral networks, they also generate outputs greater the sum of their parts, a fundamental property of complex systems (Lewontin 2001; Leydesdorff and Meyer 2006). What makes university-industry-government relations even more intricate is that they span boundaries between different societal subsystems that, according to system-theory, are hardly compatible with each other. Those subsystems each following its own logic, namely, knowledge production in the case of universities, wealth creation in the case of industry and normative control in the case of governments – with idiosyncratic coordination mechanisms, communication codes, and valuation or selection criteria (Fogelberg and Thorpenberg 2012).

The rationale behind this perspective is to temporarily stabilize and produce synergies between the three subsystems by fluid and hybrid institutional arrangements. The result of these attempts is often a non-straightforward refiguration and permanent reshaping of “the observable institutions in university–industry–government relations,” as well as of their organizational processes (Leydesdorff 2000, 253). One significant research strand within this perspective emphasizes the occurrence of new relational agreements at the intersection of the three subsystems, as well as the ongoing spread of novel, sometimes temporary systems and structures that span institutional boundaries, such as technology parks, incubator labs, or technology transfer offices (Lundberg 2013; Merkel and Suwala 2020).

Quadruple and Quintuple Helices: Adding the Civil Society and Environment(s)

As the designation indicates, Helix models differ according to the number of subsystems that are considered (see Fig. 2). Hereby, the original Triple Helix model refers to university-industry-government relations and highlights the development and contribution of research institutions and in particular of universities as new stakeholders in economic development. The Quadruple Helix model contributes further by including “the public,” i.e., “the media-based and culture-based public” in its original formulation, Carayannis and Campbell (2009, 218) or the (civil) society as a fourth and independent sphere (e.g., Marcovich and Shinn 2011). The Quintuple Helix model includes the “natural environment/environments of the society” as a fifth overarching sphere

(Carayannis and Campbell 2010, 62). These additional strands are assumed in their respective models to have an important impact on knowledge generation and innovation outcomes. The involvement of the civil society, for instance, has the potential to configure new types of knowledge (e.g., crowdsourcing) or to perform novel forms of innovation (e.g., user-oriented, environmental, or bottom-up innovations). The analytical and, to some extent, the normative uses of these extension models have been subject to debate, this despite their success in policy and practice (Shinn 2002; Etzkowitz and Zhou 2006; Leydesdorff 2012). The limitation of the Triple Helix model to three analytical dimensions had been questioned and several scholars, including Etzkowitz and Leydesdorff themselves, suggested broadening the framework or adding different components, for example via the n-tuple idea (Leydesdorff 2012). Hitherto, Carayannis, and Campbell's suggestions (2009) for a Quadruple and Quintuple Helix have been the most influential successors of the original model.

In a conceptual paper Carayannis and Campbell introduce a “fourth helix” that they define as the “media-based and culture-based public” (Carayannis and Campbell 2009, 206). In this realm, the crucial role of the media in framing and communicating “public reality” and in influencing the trajectories of knowledge-based economies is acknowledged (see also: Colapinto and Porlezza 2012). Moreover, the influence of culture and cultural values on innovation processes is discussed. The idea behind this influence is as follows: as societal norms shape public debates and, in turn, political decisions, they impact innovation and research policies and the priorities and limits that are ascribed to processes of knowledge creation. All these ideas mirror paradigms of the “creative class” and the rise of cognitive-cultural capitalism, where creativity and experience are the new imperatives (Pfeufer and Suwala 2020). It is no wonder that this fourth helix is thus associated with concepts of creative industries, culture, values, lifestyle, and art (Carayannis and Campbell 2009). This “enlightened” class not only acts as a passive recipient of knowledge products but is also an active creator of those products, employing new, often bottom-up knowledge combination settings to foster creativity and innovation (e.g., creative field approach, Suwala 2014). These settings include co-working, living labs, hacker spaces, among many other and are the harbingers of a Do-It-Yourself class (Merkel 2015).

The increasing involvement of this part of the “public,” which, in later generations of the Quadruple Helix model, has been renamed and extended to “civil society” as a whole, has both analytical and policy consequences (Arnkil et al. 2010; Miller et al. 2018). First, studies point to even more complex, dynamic knowledge and innovation processes based on coexistence, cooperation, coevolution, co-competition, and cross-fertilization, referred to as “mode 3 of knowledge production” (Carayannis and Campbell 2009, 206ff, see Fig. 1). Second, it is important to highlight that there is not one Quadruple Helix, but a continuum of models, or at least varieties where different additional spheres become the focus: a “Triple Helix” +1) users model, +2) firm-centered Living Lab model, +3) public sector-centered Living Lab model and +4) citizen-centered model” (Arnkil et al. 2010, 52) or simply private-public-people partnerships (PPPP) (MacGregor et al. 2010). Third, proponents advocate that the involvement of civil society actors attempts to foreground societal needs instead of technical affordances (e.g., intuitive and user-friendly interfaces, internet of things) in knowledge and innovation processes (Arnkil et al. 2010). Fourth, the Quadruple Helix is argued to facilitate democratic forms of process knowledge and innovation that are legitimized by and open to larger parts of civil society (e.g., citizen and communities), instead of government institutions only (von Hippel 2005). Fifth, the Quadruple Helix affords a broader understanding of knowledge and innovation, including gradual, cross-referenced, interactive, hidden, social, and nontechnical knowledge and points to the changing roles of stakeholders, for example, from consumer to prosumer (Miller et al. 2018).

The Quintuple Helix model of innovation adds a further fifth dimension to innovation processes, highlighting the role of the natural and societal environment through (social) ecology (Carayannis and Campbell 2010, 201–203). By natural environment, the authors understand the sum of natural resources, plants, variety of animals that provide the other four helices with “natural capital”. The natural environment is not only another inspirational source of knowledge and innovation but argued to be the most critical as it serves as the backdrop for the preservation, survival, and vitalization of humanity. “Nature” becomes a central and equivalent component of and for knowledge production and innovation, where ecologically sound knowledge and processes serve as “outputs” of the natural environment. Societal environments can be regarded as the *sinus milieus* of a society, which comprise the total sum of groups of like-minded people that converge around certain lifestyles (e.g., social ecologists, hedonists, traditional, etc.) (Schwarz and Ernst 2009). The output of the natural environment is accompanied by an input of new knowledge about the nature and a green (greener) lifestyle within the subsystem of public or society (the fourth helix). A precondition for this, however, is that the public is capable of receiving and responding to this new input. The latter is much easier in democracies, where a larger part of the society has at least the chance to participate in such initiatives. According to this model, concerns about the environmental and ecological sensitivity or environmental protection against the background of climate change should predominantly be regarded as key drivers of democratic societies as only in these realms all strands of the helix have equal opportunities to unfold their potentials (Carayannis and Campbell 2019).

A question that remains mostly unsolved within the Quintuple Helix model is how to connect the five helices and the respective knowledge and innovation regimes in general. In particular, the connection of the environmental helix with the other four helices is a challenge. A convenient solution centers around the notion of ecology, which can be understood as the interdisciplinary analysis either of relations between living organisms (social ecology) or of relations between living organisms and their environments (natural ecology). The amount of those relationships is subsumed under the heading of ecosystems. All these ideas converge into currently contemporary concepts that have gained some recent notoriety by emphasizing society-nature interactions in favor of socio-ecological or sustainability transitions (Markard et al. 2012). Finally, the circulation of knowledge and the evolution of society based on the coevolution of society and nature may be approaches that lead to a novel harmony between the two, with less exploitation, destruction, contamination, and wastefulness (Grundel and Dahlström 2016). The main rationale of the Quintuple Helix frame is to translate environmental and ecological issues of concern into potential opportunities by identifying them as possible drivers for future knowledge production and innovation based on eco-innovation and eco-entrepreneurship (Carayannis et al. 2012). In this light, the task of research institutions in their traditional role as initial drivers of knowledge is subject to change. This change involves becoming not only more entrepreneurial, as in previous shifts, but also more open, visible, interactive and ecological, increasingly producing responsible knowledge that addresses and, in part, cross-fertilizes with the demands and needs of civil society and the environment in order to maintain and gain legitimacy and justification within an informed society.

Both the Quadruple and to some extent the Quintuple Helix models of innovation have rapidly gained policy relevance (for an overview: De Oliveira Monteiro and Carayannis 2017). The United Nations and the European Union, various suborganizations of these, as well as national and regional administrative bodies, for instance, have referred to it when producing guidelines or handbooks on future knowledge generation, innovation and regional policies (e.g., UNESCO/IFAP and UNU-EGOV 2016; Millard 2018). It has also been referred to as a key action model for promoting open innovation approaches. Most prominently, the Quadruple Helix has been recognized as a critical approach for the development of the European “Research and Innovation Strategies for Smart Specialization.” In these strategies, participatory engagement of

civil society is regarded as a basic element for regional innovativeness (European Commission 2012). These policies all have in common that the settings in which knowledge and innovation are produced are based on governance principles that rest on collective interaction and decision-making process among relatively equal stakeholders targeting a mutual problem. The public, civil society, and the environment can be perceived as decision-making correctives that question the ethical, normative, and ecologic dimension of knowledge and innovation; they contribute to a more balanced, but also a more complicated channeling of funds and resources to areas that would have been neglected in a Triple Helix governance regime. The Quadruple and Quintuple Helix frameworks emphasize the societal and environmental impact of companies, governments, and research institutions and echo notions of civic, academic and corporate social, spatial and environmental responsibility (Suwala and Albers 2020).

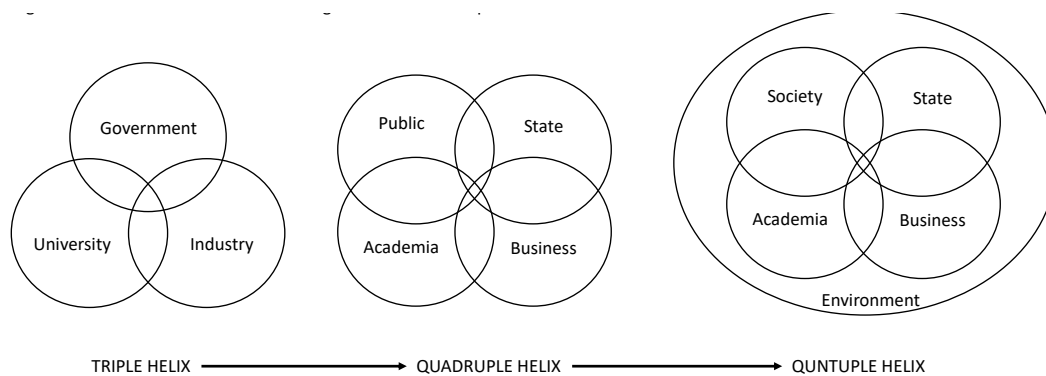


Figure 2- Helix models of innovations and intertwined sub-systems

Helix Models of Innovation and SDGs

The following section deals with the relationship between Helix models and Sustainable Development Goals (SDGs) in general, and in particular with the relationship between Helix models and SDG 9: “Industry, Innovation and Infrastructure.”

General

One of the first rapprochements to seriously take up the issue of sustainability within the Helix Models was undertaken by Etzkowitz and Zhou in their proposal for a “Sustainability Triple Helix of university–public–government” as a complement to the “Innovation Triple Helix of university–industry–government.” Within this proposal, the authors acknowledge that “innovation involves changes in the physical and social environment and therefore raises issues of sustainability” (Etzkowitz and Zhou 2006, 78). Departing from the basic idea that sustainability comprises the ability to meet the needs of the present generation without compromising future generations, the authors employ a broader definition of sustainability that spans both nature and society. By introducing the twin Triple Helix components of innovation and sustainability, a dual set of Helix Models are proposed that should effectively control, counteract, and balance one another. Within this dual system, controversies are needed and welcome. The metaphor of “ying and yang” is helpful here to express how and to what purpose “the two helices operate in tandem. The university–industry–government Triple Helix works to promote innovation and economic growth, while the university–government–public one serves as a balance wheel to ensure that innovation and growth take place in ways that will not be harmful to the environment and health (. . .) in the sustainable Triple Helix, the public, as the subject, pushes the helix formation and evolution” (Etzkowitz and Zhou 2006, 80). Therefore, both helices “the public and civil society” as well as the “physical and social environment” that appear in later expanded Helix Models are already

predicted here. While the authors do consider an expansion of the Triple Helix Model, they refrain from this step, arguing that a “fourth helix might cause the triadic model to lose its creative dynamic” (Etzkowitz and Zhou 2006, 79). Although this study does not take a strong position with regard to the United Nations framework, a later study by one of the principal researchers links the Helix Model to the Millennium Development Goals (MDGs, the predecessors to SDGs) by underlining that the Triple Helix Model can provide a method to operationalize the United Nations Millennium Project (UNMP) recommendations for an intersectoral approach, for example, through multiyear planning frameworks to ensure the expected impact of investments.

Later approaches that emphasize the relationship between Helix models (within the Quadruple Helix and the Quintuple Helix models) and sustainability and in particular the MDG/SDG frameworks are growing in number (e.g., Carayannis and Campbell 2010; Maldonado Mendes 2010; Gouvea et al. 2013). There are various conceptual attempts that have been suggested, for example, the quadruple green helix (Gouvea et al. 2013, 225), university-government-industry-third sector collaboration (Maldonado Mendes 2010), or even an entire “proposed framework for a trans-disciplinary analysis of sustainable development” (Carayannis and Campbell 2010). A detailed look at this proposed framework calls for three main pillars of sustainable development. First, quality management standards for promoting sustainability are based on the creation of new knowledge, know-how, and innovation in balance with nature and social values in society. Second, natural and social environments challenge but also encourage and inspire knowledge production and innovation. Third, openness and democracy of knowledge and innovation are supportive – in other words mutual recognition of different components of the Helix Models is necessary (Carayannis and Campbell 2019). Studies also explicitly refer to pertinent UN Human Development Reports or to individual SDGs, e.g., SDG 13 on climate change (Carayannis et al. 2012). Probably the most thorough account of attempts to juxtapose Helix models and SDGs is provided by Millard, who also co-authored the UNESCO Knowledge Societies Policy Handbook (see Fig. 3; 2018). This handbook makes a strong connection between Helix models and SDGs, especially in knowledge-based societies, and extends existing models by a sixth helix, the InfoComm subsystem, where information and communication technologies (ICT), Internet, and media ecologies are granted an equal status besides the existing Helix dimensions (UNESCO/IFAP UNU-EGOV 2016, 59–75).

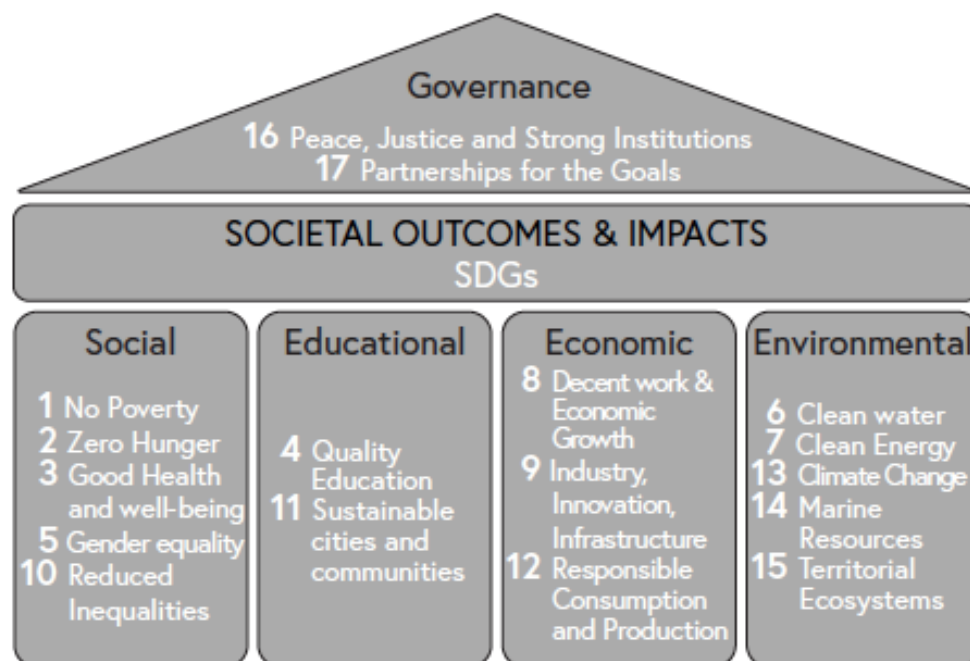


Figure 3 UN 17 Sustainable Development Goals and dominant Helix properties (own depiction based on ideas of UN 2016, Millard 2018)

By and large, all of these approaches build on a few assumptions. For one, the strengthened coevolution of helices as a consequence of openness and democracy allows for the main building blocks of knowledge and innovation to be recursively influenced by mutual cross-learning processes. Knowledge and innovation become accountable for addressing issues of sustainable development, while sustainable knowledge and innovation practices reflect on the performance of all other helices, including the social and natural environment (e.g., Carayannis and Campbell 2019). Therefore, expanded Helix models have the potential – and in some cases have already been used – to serve as analytical tools for pursuing SDGs as a whole (UNESCO/IFAP and UNUEGOV 2016; Millard 2018) or with regard to individual goals such as SDG 5 “gender equality” (Lindberg et al. 2012) or SDG 13 “climate action” (Carayannis and Campbell 2010).

SDG 9: Industry, Innovation, and Infrastructure

This section takes a look at the relationship between Helix models and SDG 9 and its eight sub-targets (9.1-5 and 9.A-C). Since these sub-targets are rather fine-grained and the Helix models consist of abstract frameworks to be filled with life, the objective of this section is to provide general points of departure. Helix structures and processes have and will continue to contribute to sustainable development and to supporting SDG 9’s overarching target to “build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation” in manifold ways (e.g., theory, empirics, policy making). What is equally important from a sustainability standpoint are not only the main topics of infrastructure, industrialization, and innovation but also the ways in which these issues are approached and presented: by means of resilience, inclusion, and sustainability. At first glance, one would locate SDG 9 squarely within the “second helix” – i.e., industry and business (the commercial market) representing concerns of the economic subsystem. Given the systemic and overarching approach intrinsic both to Helix models and within the SDG framework, it is no surprise that the targets of SDG 9 will also have to be thought in a more integrated and comprehensive way than this traditional approach would suggest, moving to an understanding not of sectorized economic subsystems but of economic ecosystems that incorporate all Helix dimensions. Through these lenses, Arnkil et al. propose a “firm-centered Living Lab model” – basically a Quadruple Helix model with a central focus on the second helix, industry and business (2010, 54). Adding a fifth helix of environment here, the following principle can be formulated from their model: the “sustainable firm-centered Living Lab model” aims for the development of commercially successful sustainable and responsible innovations for infrastructure and industrialization by combining various knowledge bases and leading to inclusive and resilient infrastructure.

Industry: With respect to industry or better (sustainable) industrialization (9.2, 9.4, 9.b), studies on Quadruple Helix models illustrate how partnerships with civil society actors have the ability to benefit sustainable industrialization and trigger positive employment effects (SDG 9.2). Drawing on a sample composed of 4215 manufacturing companies, Campanella et al. (2016) show that Quadruple Helix relations, that is, the incorporation of social and civil society actors, positively impact firm profitability. Hasche et al. (2019) further demonstrate how Quadruple Helix dynamics create jobs and add value to civil society. Helix structures also have positive impacts on entrepreneurship and firm formation (Arnkil et al. 2010). Apart from these traditional understandings, the efficacy of Helix models for promoting sustainable industrialization needs a more thorough elaboration, especially when it comes to assessing new industry paradigms such as Industry 4.0 and collateral phenomena like artificial intelligence (AI), new kinds of knowledge management (KM, scrum), and small-scale manufacturing (3D printer). In an emergent industrial shift, characterized by cross-fusion of infrastructures, the lines between the physical, digital, and biological spheres are blurred, and the role of civil society in a new industrial paradigm needs to be assessed.

Innovation: What role does innovation play in Helix Models and within the SDG 9 framework (in particular, 9.5 and 9.b)? In both frameworks, innovation is ranked among the most crucial ingredients to economic prosperity and development. Given the fact that innovation is a direct consequence of combined knowledge, innovation represents a top-tier nexus between the two frameworks. It is no wonder then that a plethora of work has illustrated how helix organizations and dynamics generate innovation (Hessels and van Lente 2008). Resonating with SDG 9.5, newer helix models advocate that innovation can take various on forms beyond technical ones, e.g., service and product innovations (Campanella et al. 2016) and that innovation is highly contingent on other contextual factors (McAdam and Debackere 2018). Lindberg et al. (2012) point to alternative “creative knowledge environments” that contribute to social innovations. Studies have illustrated both favorable and hindering conditions for the involvement of civic society in initiating “pull” society-driven or social innovation, which is particularly important in remote, rural regions where Triple Helix agents are scarce (Kolehmainen et al. 2016).

Infrastructure: Helix Models and infrastructure (9.1, 9.3, 9.a,9.c) – referred to as fundamental facilities serving an area – can be conceived together on various levels and in various realms. The UN Handbook on Knowledge Policies considers ICT infrastructure even as an independent sixth helix encompassing the InfoComm subsystem (UNESCO/IFAP and UNU-EGOV 2016). Apart from that, (economic) infrastructures (e.g., transportation, finance, ICT as in the SDG 9 framework) have to be contemplated more broadly to avoid the pitfalls of a narrow-minded, technology-driven innovation society. The issue is particularly prevalent when it comes to the current overhaul of ICTs. Referring to the Quadruple Helix and the implementation of “smart city technologies,” Borkowska and Osborne (2018) advocate for the participation of citizens and active users in decision-making within a Quadruple Helix and point out ways in which infrastructure benefits local communities and vice versa. They stress that a public and citizen-oriented evaluation of infrastructure facilitates social inclusion and learning opportunities. Within this model, user and community engagement can contribute to accessible infrastructure that brings human wellbeing to the center stage (SDG 9.1).

Resilience, Inclusion and Sustainability: Unlike its title suggests, SDG 9 is not only focused on the three areas of Industry, Innovation, and Infrastructure. In the specification of the goal itself, there are modalities and means and how this goal should be accomplished, namely, resilience, inclusion, and sustainability. Within this context, resilience, inclusion, and sustainability need to be treated beyond their origins in biology, social, or environmental sciences in order to link them to economic goals. Studies using Helix models already provide a framework for establishing this linkage. It has been outlined how, by incorporating civil society agents, existing industries may be retrofitted and made more sustainable, with increased resource efficiency and greater adoption of clean and environmentally sound technologies (SDG 9.4). Gouvea et al. (2013) illustrate how Quadruple Helix models provide the framework for designing and expanding water-intelligent economies. Grundel and Dahlström (2016) show that sustainable transformations may lead to resilient forestry-based bio-economic innovation networks. Although inclusion is a vital part of pursuing SDG 9, equal stakeholder and geographic participation cannot be assumed. Most academic research has been conducted in OECD countries (for a review see: De Oliveira Monteiro and Carayannis 2017). So far, work originating from or focusing on developing countries is scarce, although this would allow for an assessment of the pathways that might connect helix models of innovation with the achievement of SDGs 9.A, 9.B, and 9.C.

Summary and Conclusions

Both the Helix Models and the Sustainable Development Goals framework are powerful instruments for organizing, educating, and integrating future societies. Apart from that, the two frameworks operate with very different logics. Helix models provide abstract, conceptual, and evolutionary frames based on cross-fertilized knowledge and innovation from stakeholders like universities, industry, government, society, and the environment. The UN SDGs formulate practical, hands-on and fine-grained targets in multiple realms (social, educational, economic, environmental, political) with the goal of implementing more sustainable practices by 2030. Figure 3 shows how these frameworks can nevertheless be juxtaposed and intertwined using a shared classification logic (UNESCO/IFAP and UNUEGOV 2016; Millard 2018).

As far as the actual content of the frameworks is concerned, thematic starting points for mutual learning between the models are sustainability (in the case of the SDGs in general) and industry (for SDG 9 in particular). Against the background of SDGs in general, the Quintuple Helix model offers the most favorable baseline conditions as it integrates sustainability through comprehensive natural and social environments in its underlying framework. Nevertheless, its predecessors the Triple Helix (e.g., Etzkowitz and Zhou 2006) and Quadruple Helix (e.g., Grundel and Dahlström 2016) also acknowledge the role of sustainability within their extensions. Against the background of SDG 9, all Helix models invite a reassessment of the role of industry in business for pursuing resilient, sustainable, and inclusive ecosystems (see Table 1).

... build <i>resilient</i> infrastructure (9.1, 9.3, 9.a, 9.c) ,	<ul style="list-style-type: none"> - evidence-based policy making, - user-orientation, - community evaluation, - accessible higher education.
... promote <i>inclusive</i> and <i>sustainable</i> industrialization (9.2, 9.4, 9.b) ,	<ul style="list-style-type: none"> - employment and profitability, - “greening” of existing structures, - smart and green technologies, - spatial and social inclusiveness.
... foster innovation (9.5, 9.b, 9.c) ,	<ul style="list-style-type: none"> - new products and services, - hybrid organizations, - customer involvement, - bottom-up approaches, - multidimensional valuation criteria, - alternative knowledge bases.

Table 1 Starting points for supporting the Sustainable Development Goal 9 Through Helix Models

Summarizing both conceptual and empirical studies, Table 1 points to the multiple ways that Helix models contribute to the achievement of SDG 9. The pertinent work indicates that there are multiple pathways for how knowledge, innovation, and economic policies might contribute to building resilient infrastructure, promoting industrialization and fostering innovation by forging relations between different spheres. Some studies, however, also points to pitfalls, tradeoffs, and practical challenges that thwart an easy transfer between Helix Models and SDGs.

The general extension of the original Triple Helix model of innovation to civil society or the natural environment has been criticized for losing conceptual clarity (Leydesdorff 2012). From the system-theory perspective, for instance, it is still unclear how key functionalities and coordination mechanisms of the civil society or the environment can be defined. Methodologically, the availability of data and the specification of indicators challenge a coherent and rigorous appreciation of the model in shaping innovation processes. Even if the Quadruple and the Quintuple Helix models of innovation are utilized by policy makers, build upon empirical evidence

and reflect “the development and increasing complexity and change of modern economic systems” (Miller et al. 2018, 11), the scale and scope of the corresponding transformation cannot yet be fully evaluated. The comprehensiveness of this transformation is also unclear; bridging the different helices, for example, by integrating civil society in research and innovation, is not an easy task. Hybrid organizational structures, contradicting self-logics and rivaling decision criteria, that appear in debates around the Triple Helix model are also not entirely understood in the expanded models. Schoonmaker and Carayannis (2013), for instance, show that knowledge and innovation networks within three prototypical regions continue to operate within Triple Helix structures and rarely include civil society actors. Likewise, a study by MacGregor et al. (2010) on the readiness of 16 European urban innovation ecosystems for a Quadruple Helix approach illustrates that regions lacking science-based industry also lag behind in pursuing civil sector engagement. Rodrigues and Teles (2017) point to a gap between policy discourse and practice in these realms. In a similar vein, Selada (2017) levies the critique of smart city projects in her context of Portugal that these tend to be characterized by Triple Helix relations concluding that the involvement of civic society would require a more inclusive and sustainable infrastructure. Overall, it is only by appropriately integrating and understanding all helices in a given Helix Model together that the SDGs can be addressed and pursued – a task potentially as difficult as the SDGs themselves.

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