

Article

Triple Helix Twins: A Framework for Achieving Innovation and UN Sustainable Development Goals

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Abstract: This study invents a Triple Helix of university-public-government for sustainable development, as a complement to the Triple Helix of university-industry-government for innovation. Twinning the two retains the dynamic properties of a tertius gaudens in the framework which addresses environment, resource protection, social change and equality issues. Adding a risk space and raising the “Triple Helix Spaces” concept to the world level are also proposed as a methodology to fulfill related Sustainable Development Goals (SDGs) through joint projects transcending national borders. A project for collaborative world region development of advanced solar photovoltaics is then suggested as an exemplar. Achieving the UN SDGs requires education institutions, governments, non-government organizations and individuals to commit to collaborations, adopting dynamically interacting triple helices to unite innovative development and sustainable development. Debate over expanding the Triple Helix model has focused on whether the fourth and fifth helix might improve or disrupt the triadic model. Although a four-actor system is far away from satisfaction, an expanded model is required to incorporate the critical issues of reconciling innovative and sustainable development. Harnessed together, the Triple Helix twins provide a framework for SDGs attainment.

Keywords: triple helix twins; innovation; UN Sustainable Development Goals (SDGs); university-public-government triple helix (U-P-G); risk space; world SD triple helix spaces



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1. Introduction

In recent years, achievement of sustainable development has increasingly received attention even as innovative reconstruction has long been a highly sought-after goal. The two objectives have often been viewed as mutually contradictory, and a zero-sum debate has ensued over which one should be prioritized at the expense of the other. The alternative is a synthesis that combines and even reinforces both objectives, but where is such an ideal to be found? The 2030 Agenda for Sustainable Development, adopted by all United Nations Member States in 2015, which set 17 Sustainable Development Goals (SDGs) [1], provides a unified blueprint. Now and into the future, how must we act to end poverty, improve health and education, reduce inequality, spur economic growth, tackle climate change and preserve nature? How can a mutually reinforcing dynamic between innovation and sustainable development, empathized in harmony simultaneously, be attained?

Technological progress has both positive and negative effects on humanity and the planet, bringing with it a persisting and unresolved controversy over the balance between reward and risk. Science and technology offer many tools for improving the understanding of risks and possibilities and for guiding different lines of action [2]. Rapid technological change such as big data, the Internet, machine learning, artificial intelligence, robotics, 3D printing, nanotechnology and renewable energy represents a significant opportunity to achieve the SDGs [3,4] but poses new challenges for (human) resource markets and environmental carrying capacity, raising ethical questions about perpetuating inequalities [5,6]. It is dangerous to isolate sustainable development without using innovation, vice versa.

Humanity must find creative solutions to address significant challenges, both in innovation and sustainable development. This needs multi-actors interacting at various organization levels, from village to the world.

Could the Triple Helix model, derived from knowledge-based economic development, be adapted to achieve broader social, ecological, and humanistic and cultural goals? This article addresses the attainment of the UN Sustainable Development goals that are typically viewed separately, using conventional metrics. Rather than critiquing the SDGs as internally contradictory for positing both growth and sustainability, we see a preeminently “wicked problem” open to novel solutions.

Responsible innovation is a noteworthy attempt to provide guidelines to distinguish between positive and negative technological advances, but as with many general guidelines, it is not always clear what criteria should be used, and therefore, one person or country’s “responsible innovation” may be another’s irresponsible innovation. For example, France and Germany have taken radically different paths with respect to nuclear energy, with a secure source of energy to one viewed as a catastrophe in the making for the other, with continued development and phase-out, the alternative paths of neighboring countries, both being key members of the European Union, that is, thus unable to develop a common energy policy. On the assumption that nuclear energy is closely regulated, responsible innovation advocates avoid addressing this dilemma [7]. Europe is apparently locked into an irresponsible energy strategy, relying on fission for 26% of its energy and looking toward fusion, rather than moving full-force to a renewable future, based on innovation and sustainability [8].

Our premise is that fields of technological development can be identified that at one and the same time deliver both objectives, resolving the zero-sum dilemma. The Triple Helix twins expand the model from a single to a dual set of triple helices, simultaneously achieving innovative and sustainable development, while retaining the unique triadic engine of the original concept. In the following, the twins’ framework is further explored and brought to bear a proposal to realize SDGs through worldwide collaboration.

The goals of the paper are:

- Differentiate the triple helix innovation *model* from the innovation *system* theory: the triple helix has its own theoretical system but cannot be included into the “innovation system”.
- Develop a framework of triple helix twins for innovation and sustainable development: first interpreting why and how the U-P-G works for the SDGs, then including it into the new frame.
- Explore how the triple helix twins work: a triple helix risk space concept is added, and a world SD triple helix spaces concept has been adapted to handle global issues.

2. Triple Helix and Sustainable Development

It is meaningful to think of a triple helix as “targeting what” and “consisting of what.” A triple helix for innovation is composed of three institutional spheres (University-Industry-Government) as the primary actors. The basic insight is that there are multiple triple helices, with various actor candidates. Proponents of other salient societal objectives generate their own triple helices, for example, the government–industry–labor triple helix for solving employee benefits. During the depression of the 1930s, a grand compromise between capital and labor was brokered through government legitimation of unions in the US. Such arrangements were even more explicit in Europe, where, for example, during the post-war, by West German law, unions held a significant proportion of seats on company boards of directors [9]. On a more micro-level, a triple helix for corruption may involve bank, industrial corporation and audit department; a triple helix for an urban renovation project could have the construction industry, municipal government and the public as the primary actors.

2.1. Triple Helix as a Spiral Tool to Develop an Innovation System

As a universal model [10], the Triple Helix can be used to address issues in micro, meso and macro levels. It is a significant scientific discovery and distinct contribution to innovation and entrepreneurship studies, as well as environmental philosophy [11]. The Triple Helix was identified in the early 1980s, through the analysis of an “entrepreneurial university” (MIT) and its role in resolving the dilemma of creative destruction in the renewal of the New England region in 1920–1940s [12,13]. The validity of the model was confirmed through observation of the co-evolution of Stanford University and Silicon Valley. Almost as soon as it was proposed, observers were tempted to add additional helices to address issues beyond innovation, vitiating the original purpose without providing a logical methodology other than simple additionality. It was questioned whether there is a fourth helix [14].

No matter the reason for the triple helix, it arises from interaction among representatives of different institutional spheres, each contributing from its special resources to the solution of a common problem through invention of a new organizational format to address the issue. The result is a new hybrid entity, synthesized from parts of the three spheres, that could collectively accomplish what neither could do individually. Each institutional sphere reinforced the other’s special contributions by extending from their primary area to others. For example, universities made supporting investments in the venture capital firm invented as part of the early 20th century New England regional renewal project, even as government changed the rules for investment entities to legitimize risky investments in start-ups, creating a space for the venture firm in the financial institutional universe.

Why is it a Triple Helix? Some studies on triadic factor dynamics in different fields have well supported this model. For example, the “triadic reciprocal causation” in psychology, introduced by Albert Bandura [15] refers to the mutual influence between three sets of factors: (1) personal factors (e.g., cognitive, affective and biological events); (2) the environment; and (3) behavior. These three factors play roles as three inter-related actors. Other examples include “Dynamic Triad” [16] in AI technology, “triad interactions” in Medicine [17] and “Triadic Dynamics between Government, OEMs and Suppliers” in Management [18]. Moreover, the triadic model is in line with the reasonableness parsimony criteria of Occam’s Razor. The best example is Chinese philosopher Lao Tzu’s discovery, stating in Tao Te Ching as that Tao begat one; One begat two; Two begat three; Three begat all things [19].

Nevertheless, since the Triple Helix model itself was often viewed as an expansion of the “double helix” genetic model, it is understandable that innovation researchers might see room for further expansion. Three actors act, interact and work together for the goal. Therefore, paying more attention to creating the capacity of university, industry and government as three primary actors in innovation and entrepreneurship is the key.

A mature triple helix consists of interrelated and overlapping institutional spheres that maintain increasingly complex relationships through networks that generate hybrid organizations such as the science park and the incubator. These novel organizational designs apply the “shared value” of two or more institutional spheres [20].

The initial Triple Helix dynamic is internal transformation in each of the helices, such as the development of lateral ties among companies through strategic alliances or an assumption of an economic development mission by universities. The triple helix has various variants that have three actors and similar functions. Different actors may be selected to target various topics. These triple helices are used to develop the elements and their functions of an innovation system, helping it grow (Figure 1).

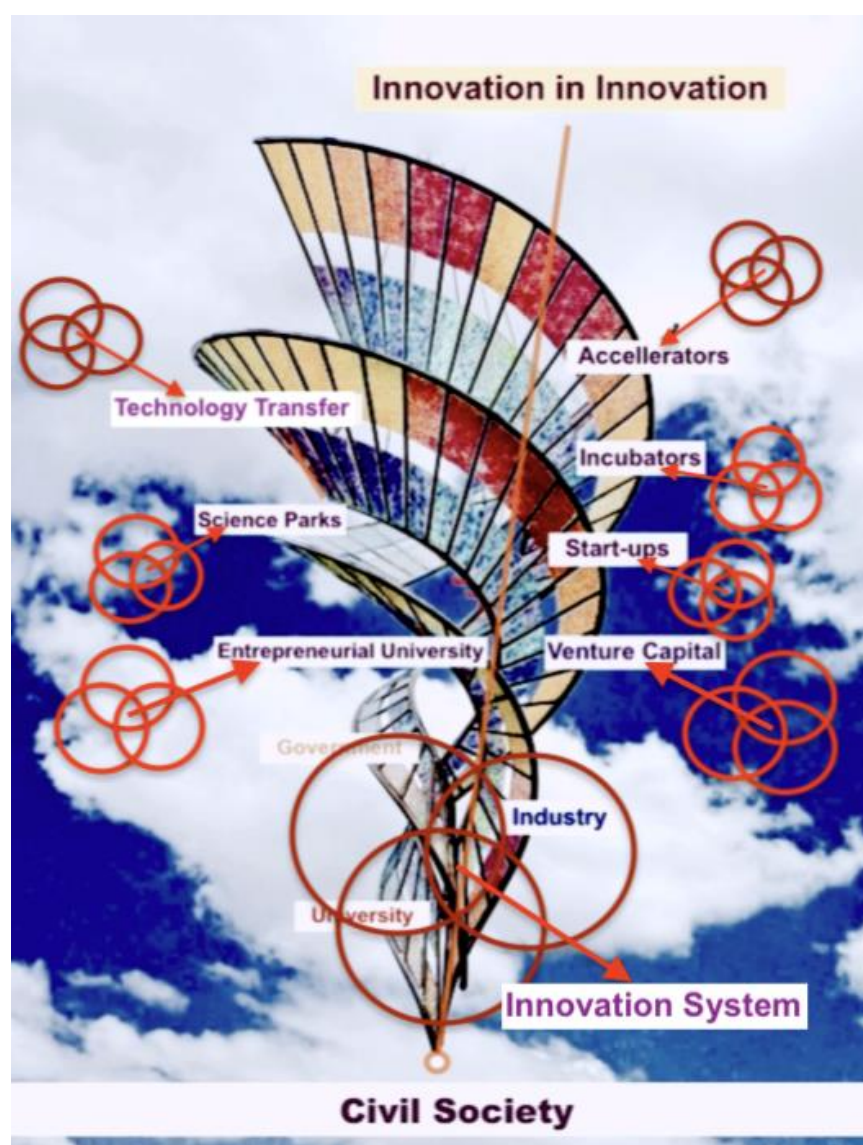


Figure 1. Triple Helix developing the elements/functions of an innovation system.

The Triple Helix is a dynamic innovation process. For example, “Brainport development shows that . . . , effective collaboration in the triple helix can deliver new initiatives and help speed up (new) cluster development on the edges of existing sectors, who cannot be identified by macro statistics” [21]. In this instance, the importance of a long-term frame in evaluating results was highlighted. The triple helix as a methodology works at a macro level of a region and also at a micro level concerning specific topics such as sustainability.

Instead of adding more actors to a triple helix, following the university-industry-government triple helix model for innovation (*U-I-G*), in 2006 we set forth the thesis to expand the triple helix model from a single to a dual set of helices—*Triple Helix Twins*, which concern innovation and sustainability together with a university-public-government triple helix for sustainability *U-P-G*. The Triple Helix model is thus twinned to resolve issues of sustainability in tandem with innovation. The public matters in the framework. Here, it is a collective term, representing non-governmental organizations and individuals. As an institutional sphere, it interacts with university and government, making a *U-P-G* triple helix [22].

2.2. Triple Helix for Sustainable Development

The United Nations Conference on the Human Environment in Stockholm in 1972 gave birth to the first true notion of sustainable development, then called “eco-development”, to reconcile conflict between the ecology and the economy. In 1980, the International Union for the Conservation of Nature (IUCN) published its world conservation strategy, one of the original sources of the expression “sustainable development”. According to the Brundtland Report, *Our Common Future* [23], sustainable development is defined as development that satisfies the needs of the present without compromising the ability of future generations to satisfy theirs. Originally applied to natural resource depletion, the concept has been extended to include economic development, environment, food production and social organization [24].

High-tech entrepreneurship, economic growth and improved quality of life might result in resource depletion, environment degradation, escalating inequality and population explosion. For example, in 2100, the world’s population will be close to 10 billion, pushing against limited resources, especially since individual consumption has been increasing considerably. Innovation, involving changes in the physical and social environment, inevitably raises issues of sustainability, the ability to meet, “... the needs of the present without compromising the ability of future generations to meet their needs.” The questioning of the unintended consequences of industrialization has expanded from the analysis of the side effects of agricultural and industrial production processes, such as chemical pesticides, to the ecological critique of depredations to the natural and human environment and economic growth as an end in itself [25].

Expansive, very often wasteful economic policy, impending global problems (demographic, epidemics, wars), treat the natural environment as a means rather than an end. Too often, even programs intended for improving environmental quality, like the UN International Maritime Organization, are captured by industry and used as a cover for continued depredation. Developing clean production and saving natural resources are often easier to be chosen and accepted, using sustainable development as an umbrella to continue unsustainable economic growth practices. Essentially, they are business programs for fund-raising under the SD umbrella.

Creating a fully balanced model of life, i.e., improving the quality of life all over the world without a wasteful overexploitation of natural resources, has been the subject of deliberation of political, scientific and ecological environments. What is being highlighted most of all is the need to integrate activities in the three main areas: economic growth and equitable distribution of benefits, protection of natural and environmental resources in order to preserve our environmental heritage and natural resources for future generations and social development.

Some developed countries such as the US have learned lessons from the UK, which enjoyed economic prosperity from the second industrial revolution but suffered the cost of lack of resources and environmental pollution. Developing countries have too often taken the unsustainable path to economic advancement. For example, highly polluting production equipment that has been abandoned by developed countries was imported. Sustainable development is assumed to be the one where the synergy of economic, environmental and social aspects is safe and beneficial for the human being, environment and economy. The triple helix model, based upon the interactions of actors, has been further developed, especially for addressing the SDGs.

2.3. N Triple Helices vs. N-Tuple Helix

To solve SD issues, quadruple and quintuple helices were proposed [26–28]. Both the quadruple and quintuple helices view the helices as “sub-systems”. For instance, quintuple helix describes political, economic, educational, natural, and public dimensions as sub-systems, rather than “actors” (The Quintuple Helix innovation model—global warming as a challenge and driver for innovation). This came from the notion that the triple helix is viewed as a system and describes the actors/helices as “sub-systems” [29], capitals [30] or

“elements” of system. The “helix system” thinking results in N-tuple helix idea, endless number of helices beyond three (Table 1). Such a confusion of actor and element concepts can not only make the triple helix’s value be underestimated but cause a misunderstanding by incorporating the Triple Helix as part of the Innovation System, misdirecting the development of triple helix theory.

Table 1. N-tuple Helix.

	Main Actors	Theme
Quadruple Helix	U-I-G-P or U-I-G-C (Civil Society)	The “fourth helix” is defined as the “media-based and culture-based public” [31]. 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.
Quintuple Helix	Political, economic, educational, natural, and public sub-systems	A further fifth dimension to innovation processes is added, highlighting the role of the natural and societal environment [26]. The fifth helix involves the (natural) environmental subsystem. Try to integrate socio-ecological transitions necessary for sustainable development.
N-tuple Helix (more than 5)		May appear in the future

The actors in the triple helix are human beings, with consciousness and motivation, comprising interacting institutional spheres, and are thus not equivalent to the mixture of elements (whether human or non-human) in the innovation system. We argue that there are N triple helices but no N-tuple helix. The quadruple, quintuple or even N-tuple helix, which view the actors of helices as sub-systems, compound the misunderstanding.

N-tuple helices view the actors in the triple helix as sub-systems (Table 1), just uses the term, helix. To be eligible, it is necessary to develop their dynamic mechanism and theoretical system, rather than only add the number of “the helices” or adopt system science method.

A follow-up question could be: what is the relationship between the triple helix innovation model and the innovation system theory? We hold that the two contributions are mutually exclusive: neither one of them can include or replace the other. They respectively contribute to innovation theory and practice. The triple helix is an innovation methodology to develop an innovation system. *The system is the goal of a Triple Helix process, not its means of realization.*

Innovation Systems delineates, “the flow of technology and information among people, enterprises and institutions”, with the multiple key elements, such as main actors, capital and innovation platforms on the same level [32]. Firms are the key actors in this model, with university, government and other actors in clearly subordinated and adjunct roles. According to the complex system theory, if a natural system does not meet the four conditions (openness, imbalance, non-linearity and fluctuation) for a self-organized evolution, innovation (evolution) may not happen. In practice, the four conditions are difficult to be met at same time. In our view, social systems are not determined by any combination of self-acting agents; they are always subject to change through human intervention.

In the Triple Helix, by contrast, the conditions to develop can be created; therefore, the evolution can take place always through novel organization. Our regional innovation experiment in Linyi of Shandong Province in China (2010–2016) also proved that regional innovation needs to be creatively organized. Three relatively equal actors interact with the ability to substitute for each other’s weaknesses in particular situations by combining multiple logics, which perform various dynamics, individually and collectively. For example, capital may arise from a variety of university, industry, government and other secondary actors [33]. Moreover, these actors may take a further step, inventing, adapting or repli-

cating a hybrid organization, such as a public, private or mixed science park (incubator), to institutionalize the innovative arrangement.

Although contemporary innovation systems theory has some terms similar to those in the triple helix, e.g., actors, relationships and interactions, it follows the “general systems theory (GST)”, including formal sciences such as complex systems, cybernetics and catastrophe theory.

Triple Helix Innovation is “... the result of an intellectual effort by an ‘innovative entity,’ ...” in other words, a human collaborative effort driven by intentionality and imagination [34]. We hold that N triple helices with different missions can be organized to address various goals and issues. For instance, the Triple Helix twins (two triple helices) are applied to address innovation and SDGs as alternate framework.

3. A U-P-G Triple Helix for Achieving Sustainable Development

Combining the SDGs with the triple helix results in higher commitment to achieving the SDGs. Gebhardt [35] provides a case study on how to improve the triple helix model for the future development of a municipality, showing how a social entrepreneur broadened the planning process by instigating the municipality to engage the public as well as other stakeholders in developing guidelines for future urban development. In some instances, the public does not have sufficient power of free speech to informally provide regulation through discussion and debate, nor are there independent media to expose and inform. Nevertheless, citizens use social media to perform some of these functions, expressing critique in the interstices of highly controlled platforms. As many tried to target sustainable development with the U-I-G triple helix [36–39], its limitation shows. The U-P-G triple helix model provides a possible methodology to address the SDGs.

3.1. The Public Matter with SDGs: “Everyone Must Participate”

As the expectations differ per partner, there is a critical interest conflict between industry, which chases maximum business performance, and a public that is committed to uphold a high quality-of-life standard. In human, natural and social protection, the university-industry-government triple helix does not always work for the solution of SD issues. Following the triple helix model’s original conception, we consider a Triple Helix of university-public-government as a twin to encompass sustainable development.

The “public” originating with the Latin term *publicus* (also *poplicus*), in general refers to some mass population (“the people”) focused upon some matter of common interest. John Dewey [40] defined “public” as a group of people who, upon facing a similar problem, recognize it and organize themselves to address it. This is similar to a “target group,” in which people’s involvement is necessary for achieving organizational goals. Following Dewey’s definition, James E. Grunig [41] classifies the “public” into the non-public (those who have no problem), the latent public (those who have a problem), the aware public (those who recognize that they have a problem) and the active public (those who do something about their problem).

Although “public” has been theoretically defined since the early 20th century, it has suffered from blurring in more recent years as a result of the conflation of the idea of a public with notions of audience, market segment, community, constituency and the stakeholder [42]. In public relations and communication science, the public is generally defined as groups of individual people in contrast to the sociological concept of the public sphere or *Öffentlichkeit* in Germany [43–45].

This paper defines the public as the collection of non-government organizations and individuals. SD objectives can be achieved through partnership among social group organizations (SGOs) representing the public. “Public concern” defined as speech about a matter of political, social or of common interest [46], plays a key role today in sustainable development, especially for developing countries where it is a relatively new issue. In developed countries, especially the USA, the organization and celebration of Earth Day in 1970 was a landmark of environmental awareness. Environmental groups, founded to coordinate

local conservation efforts, focused the nation's attention on pollution and other threats to the environment.

Public participation varies from the simple sharing of information to active engagement of citizens in the implementation and management of projects and services. The views of the citizens must not only be heard but also involved in developing decisions, thus making governments responsive and accountable to the community. Tools for public participation may vary in different countries or communities, e.g., including Study circles, Citizen Advisory Boards, Government Contract Committees, Public Hearings and Public Watchdog Groups in Kenya [47,48].

In China, the public typically refers to social groups that interact with social organizations, whose members face common problems, common interests and common requirements. Sometimes, it also includes individuals. The public now can balance between following the government and instigating the government to act to further the public's interest. Social movements that, over time, infiltrate conventional political dynamics are the conventional western approach to incremental change. When far-reaching change is required, going beyond individual society borders, an enhanced methodology of discontinuous innovation is needed.

3.2. U-P-G Triple Helix's Application

In Holland, the Rheden local triple helix experience, characterized by the development of networks, attempts to institute triadic configurations from a single perspective, with the municipality prescribing plans that the industry and academia are expected to implement, were ineffective, losing the interest and participation of the latter [49]. Thus, keeping the active involvement of all partners appears to be the condition of a dynamic Triple Helix. It is the same as in the U-P-G Triple Helix Model. Following it as the example, we can apply the U-P-G (Table 2).

Table 2. The U-P-G application following the U-I-G Triple Helix.

	U-I-G for Innovation	U-P-G for Sustainable Development
University's roles	Advanced-knowledge production, development and application; Academic technology transfer; Academic entrepreneurship; Contribute to the science parks/incubators/accelerators; Provide entrepreneurial education; Main role in the knowledge space.	SD knowledge production and application; (Green) Technology choice and transfer; Provide consultant and support for government policies/measures; Use internet to help build social media platform for collaborations and supervisions; Offer education in sustainable development; Main role in the SD knowledge space.
Government's roles	Make policies to support innovation; Organize SD platforms for collaborations and communication; Work as regional innovation organizer; Create or help create consensus space; Develop knowledge space and innovation space Most likely function as main role in the consensus space.	Reconcile industry and the public interest for SD; Organize SD platforms for collaborations, communication and supervision; Work as regional SD organizer; Create or help create SD consensus space; Develop SD knowledge space and SD risk space; Most likely function as main role in SD consensus space.
Industry's roles	Develop new technologies and apply them; Strengthen regional competitive; Foster start-ups; Main role in technological innovation and the innovation space.	
The Public's role		Supervise industry's negative effect on resources and environment; Expand the networks and non-government organizations for various SDGs; Disseminate SD knowledge through informal and formal medias and intermediates; Participate the formulation and estimation to SD policies/measures. Main role in the SD risk space.

Table 2. Cont.

	U-I-G for Innovation	U-P-G for Sustainable Development
Triple helix spaces	Consensus space Knowledge space Innovation Space	SD Consensus space SD Knowledge space SD Risk space

The Triple Helix thesis holds that in a knowledge-based economy, the university and its role in society are enhanced by translating knowledge into use, with feedback into theorizing and the opening up of new research questions being a positive consequence of such engagement. The universities are not only a significant actor in the case of the triple helix model, but they also have an outstanding role in the development of social innovation [50]. Sustainable development requires collective action from various stakeholders. “Through societal innovation, based on multiple value creation, external costs are being prevented or reduced because of innovation-oriented explorations within a wider frame (a societal improvement perspective), ascertained by the actors” [51].

The recognition that knowledge is simultaneously imbued with various attributes encouraged the multiple roles of academics and their involvement in addressing SDGs. Other educational institutions in various levels may also become involved, but the university’s role in new knowledge production puts it in a distinct place in the arena.

The role of the university incubator and accelerator facilities in social innovation and the arts suggests a two-step process of triple helix development, in which the public plays a key role in the early instigation stage before economic activity is created, while after it has been generated, the arts or creative occupations may be viewed as an industrial sphere in a mature phase. The transition of Ashland, Oregon, from a natural-resource-based town to a humanities town illustrates this progression [52].

The university has the responsibility to play a broader role in social development as educator of organizations of various types, e.g., NGOs, arts groups and community development projects. The expansion of Project Genesis, the incubator at the Pontifical Catholic University of Rio de Janeiro, from high tech to community and arts organizations shows how this is possible. The overlapping membership of the Campaign Against Hunger NGO and the Federal University of Rio de Janeiro’s Alberto Luiz Coimbra Institute for Graduate Studies and Research in Engineering (COPPE) inspired a creative institution-formation project, combining the principles of both groups, in the development of cooperatives for economic and social advance. The essential process of educating people to act organizationally, whether scientists, artists or illiterate favela dwellers is broadly applicable [53].

3.3. Targeting the UN Sustainable Development Goals

Sustainable financing needs to be ensured across sectors, including agriculture, forestry, energy, health and education, as well as across economic segments, such as small- and medium-sized enterprises, infrastructure and innovation, in both developed and developing countries. Policy coherence across multiple boundaries is crucial as international and regional policy agreements influence national strategies, while national policies need to be coordinated with international and regional frameworks.

U-P-G through public participation has been in practice worldwide. Beijing Municipal Government established “12345 Hotline” to collect appeals from the Public. During 2020, it received and handled 11 million appeals from 4.4 billion participants representing social organizations, medias and enterprises. Students and faculties of Beijing International Studies University provided the translation service as volunteers. Another case is Shenzhen’s public participation to the urban planning since early 1990s when it started to take off, from complaints about inadequate housing and lack of sufficient public facilities such as health centers, garbage stations, substations, and even hospitals, as well as urban roads, subway lines and other transportation facilities. These participations help the new city with well-educated citizens to be planned reasonably and become a beautiful metropolis [54].

Firms aiming at profit maximization must at the same time take responsibility for sustainable development, which requires the U-P-G and U-I-G triple helix twins to orient economic growth in favor of sustainable development that is more economical and “clean” in its use of raw materials and energy. Traditionally, firms could run only within the industrial institutional sphere. However, open innovation and development require them to interact with other actors in academia and government to achieve maximum benefits and avoid damage to nature, society and the environment.

The environmental movement can drive technological innovation through changes in individual consumption and political action. Economic and financial incentives for the creation and adoption of new technologies are needed, which may include innovative policy reforms. The proportion of renewable energy in our energy consumption must inevitably be greatly increased so that the public can make a contribution to sustainable development by choosing to use renewable energy sources.

One of the key issues raised in the SDGs is the apparent contradiction between sufficient energy and environmental degradation. The potential for addressing this issue has been apparent for some time through utilization of renewable energy technologies. Although their use has increased significantly, there is significant potential for increase, especially through global collaborative R&D projects to increase their efficiency while at the same time decreasing the use of non-renewable resources in their production. The solar cell, the sister invention to the transistor, has lagged development of its mate. Infusions of defense spending into miniaturizing battlefield communications equipment was many times the amount put into acquiring the relatively small number of solar cells required for space exploration, creating an imbalance in technological development that has yet to be redressed [55].

The project to achieve a circular economy [56] provides an opportunity, through advanced photovoltaics, to achieve the “energy source too cheap to be metered,” falsely promised by nuclear proponents, as well as environmentally benign, especially when tied to support hydrogen-based production and mobility systems through electrolysis of H₂O with no waste left behind [57].

Although photovoltaics use has expanded dramatically with sharp reductions in cost since 2000, this is largely the result of incremental advances in the first technological generation, primarily taking place in China. In 2000, a proposal was made to the Third International Triple Helix Conference in Rio de Janeiro to marshal the research resources of the global south, especially Brazil and South Africa, to collaboratively develop new generations of solar photovoltaics technology, with higher orders of efficiency and productivity and sparser use of non-renewable materials. The idea was reiterated in the 2019 Cape Town Triple Helix Conference but was still ahead of its time. A Latvian US collaboration illustrates the potential of this collaborative dynamic in nucleo [58].

Advances in photovoltaics technologies are regularly announced, but translational research to put them into use has lagged [59–61]. It is still timely for an international Triple Helix effort to address this blockage and reap the full potential of advanced research to achieve SDGs. We suggest that such a framework for joint project development, extending from innovation to sustainability across national borders, could enhance SDGs achievement, with significant spillover effects to attaining other SDGs. Another obvious topic for international cooperation, brought to the forefront of attention by the coronavirus pandemic, is vaccine development. The US Pfizer firm’s collaboration with BioNTech, a German university originated biotech start-up, supported in its growth by the German cluster initiative, suggest a model for replication and expansion. Brazil’s Fio Cruz Institute and India’s vaccine production firms are obvious candidates for South-South collaboration in the context of global patent sharing and enhanced technology transfer regimes that are at the cusp of realization.

4. Addressing the SDGs by the Triple Helix Twins

The twins' idea was inspired by the “Yin-Yang Tai Chi Diagram” (Figure 2) in Chinese philosophy, which combines two interlocking spirals with two dots, described as a pair of fish nestling head to tail against each other. The world consists of Yin Qi and Yang Qi and is their dualistic unity of opposites. It contains both Yin and Yang factors whenever and wherever, as a whole. If the picture is divided into two halves by drawing any straight line across the center of the circle, each contains the two factors of Yin and Yang. There is absolutely no isolated component without inherent contradiction. Tai Chi is the initiator of all motions.

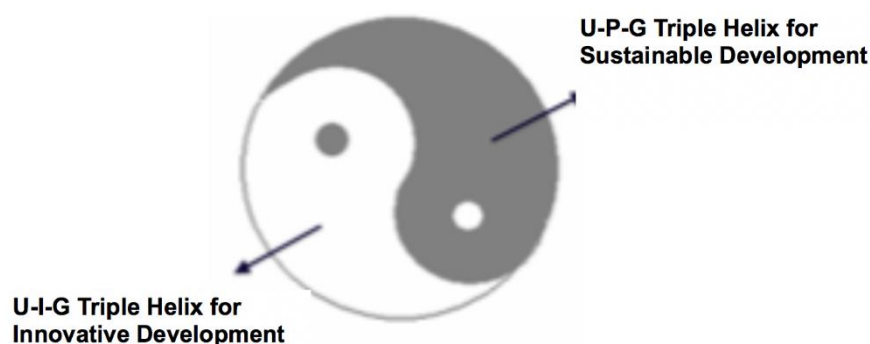


Figure 2. Yin-Yang Tai Chi diagram and the Triple Helices.

Absorbing the essence of this thought, in order to address innovation and sustainable development, we catch “a pair of fish”: the university-industry-government (U-I-G) triple helix for innovation to achieve knowledge-based regional economic and social development and a university-public-government (U-P-G) triple helix, obtaining the triple helix twinning, a dualistic unity of opposites. The U-P-G acts as the complement to the U-I-G, and vice versa. By creating a parallel interacting axis, a critical element can be introduced into the model without losing the dynamic properties of a *tertius gaudens* [62]. By contrast, a fourth helix model tends toward stasis with participants exercising veto power, without a *tertius gaudens*, a third member, to mediate among them.

4.1. Twinning the U-I-G and U-P-G Triple Helix for Growth and SDGs

University-industry-government relations, based on complementary yin/yang principles, turn the focus of S&T development in a positive environmental direction [63]. When contentious issues arise, the public may be expected to play a counter-balancing role, steering S&T development and innovation in an environmentally friendly direction. Thus, a university-public-government triple helix insures sustainable innovative development (Figure 3). Enacting this thesis, social movements and protests have utilized academia to achieve their goals.

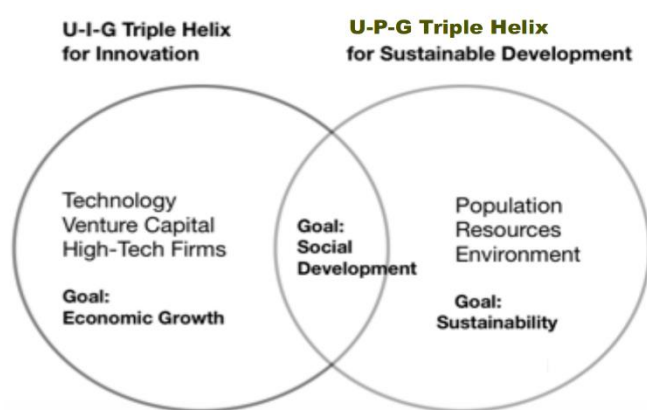


Figure 3. U-P-G Triple Helix as the complement to the U-I-G Triple Helix.

In the struggle of various communities against the spread of nuclear power, academics were recruited from universities and community colleges to assess potential deleterious effects. Other campaigns, such as the one against nuclear fall-out, originated within academia and involved the public through innovative stratagems such as collecting baby teeth from diverse locations and correlating them with fall-out dispersion in order to document radiation increase and raise consciousness. The interactions of academia, public and government in the rise of the 2nd women's movement are pervasive and continuing.

Any one among the three institutional spheres may take the lead as an Innovation Organizer in the U-I-G triple helix for innovation. The overall goals of the three actors are generally in alignment: all wish to achieve economic and social development though they may bring different ideas to the table as to how to achieve that goal. Thus, the university-industry-government triple helix is basically in accord. However, contradictions may emerge between the two triple helices. Mediation between the Twins may be necessary to attain balance, like two sides of a lever.

The Triple Helix twins provide a mechanism for synchronizing the innovation and sustainability projects. The U-I-G is realized through cooperative arrangements among university-industry-government to encourage innovation and entrepreneurship while the U-P-G represents the dynamic of controversies over technological innovation. For example, in the late 1970s, activist groups, in which academic scientists played a prominent role, questioned the safety standards of proposed biotechnology research laboratories at Harvard and MIT, on behalf of the public, and brought the issue to the Cambridge City Council for resolution [64].

Environmental activism was integrated with an entrepreneurial dynamic into civil society. As a result of the Council's deliberations, stringent standards were enacted for biotechnology labs. As it happened, these rules had a positive effect on biotechnology innovation since firms were assured that building compliant labs guaranteed their right to operate. Thus, the resolution of the controversy between the U-P-G and U-I-G helices paved the way for concentration of biotechnology research and development in the area, achieving economic development objectives, as well (Figure 4).

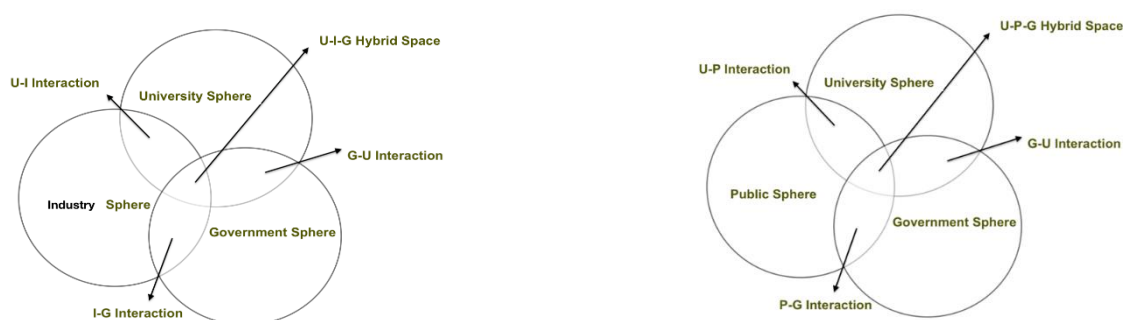


Figure 4. The Triple Helix Twins.

4.2. Triple Helix Twins for Innovation and Sustainable Development

U-I-G works to promote innovation and economic growth an engine; while U-P-G serves to ensure that the growth takes place in sustainable ways, as a balance wheel/speed regulator/brake. In the U-P-G, the public pushes the helix formation forward. When imbalances occur, such as the rapid development of the Los Angeles area in the 1950s that brought with it unhealthy air quality and life-endangering smog, a U-P-G arose. The coalition included a Cal Tech researcher who identified particulates from auto emission as a major cause of smog. Citizens groups pressured the government to put in place stricter auto-emissions standards in California that then became the basis for enhanced national air-quality standards. These requirements also encouraged technological innovation in the auto industry that increased efficiency as well as improved air quality. Each triple helix

twin exercises different power weight to drive innovative development and sustainable development (Figure 5).

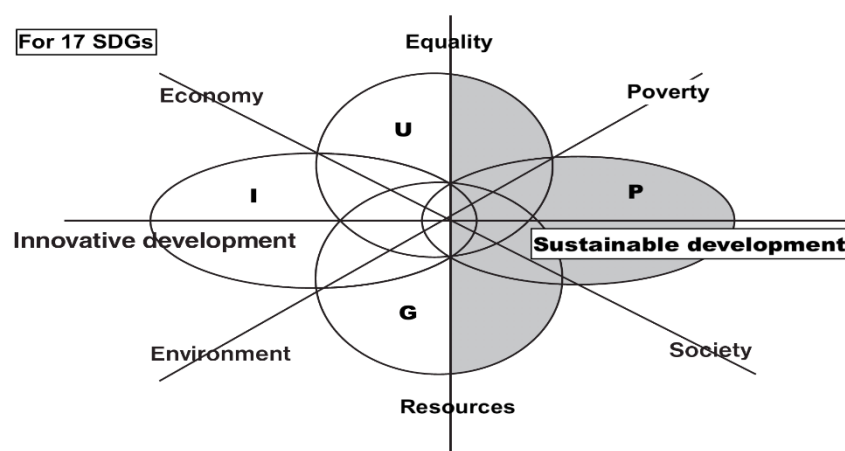


Figure 5. Triple Helix Twins for innovation and sustainable development.

The role of the university is increasingly salient in both Twins, generating potentially disruptive research findings [65]. Discontinuous industrial innovation is increasingly closely related to basic research in biotechnology and nanotechnology as opposed to consulting and contract work for industry typical of engineering fields allied with the mechanical and chemical industries. Indeed, emerging research areas, such as chemical informatics, re-introduces discontinuous innovation into apparently settled fields, opening the way for their environmental reconstitution.

In the U-I-G, entrepreneurial universities are expected to play a leading role in regional innovation and to encourage start-ups. Industry is expected to re-organize itself in a network mode to be more receptive to external inputs. In the U-P-G, civic universities also are expected to play important roles in sustainable development.

The public is expected to identify SD issues for avoiding risk and protest potentially dangerous decisions/projects. Government is expected to develop programs cooperatively with the twins playing dual roles, for both innovation and SDGs. The university works as a supporter to the public regarding sustainable development, monitoring firms' behavior and government's activities through the U-P-G triple helix interactions, while it acts as an innovator/entrepreneur to foster regional economic growth in the U-I-G triple helix. The government functions as a listener to the public to find various issues to solve and as a supervisor for industrial development concerning sustainable development, rather than relying on corporate social responsibility. Indeed, it also works as an innovation organizer playing critical roles in innovative development of a region. It is the twinning of the triple helices that makes simultaneous innovation and sustainable development possible. Rather than a quadruple helix, dual triple helices drive human, nature, economic and social development. We assort the SDGs into six groups of objectives (Table 3) and use the triple helix twins to achieve them (Figure 6). Whether one or both triple helices are applied depends on the specific case.

Table 3. Six groups of objectives of the SDGs.

Objectives	SDGs
Social objectives	1, 2, 8, 4, 7, 9, 10, 11, 12, 13, 16, 17
Economic objectives	2, 8, 4, 7, 9
Ecological/environment objectives	6, 7, 11, 12, 13, 14, 15, 17
Humanity/healthy objectives	5, 3, 8, 4, 6, 9, 10, 11, 12, 13, 15, 16, 17
Cultural objectives	4, 11, 14

Note: See Appendix A for the 17 SDGs.

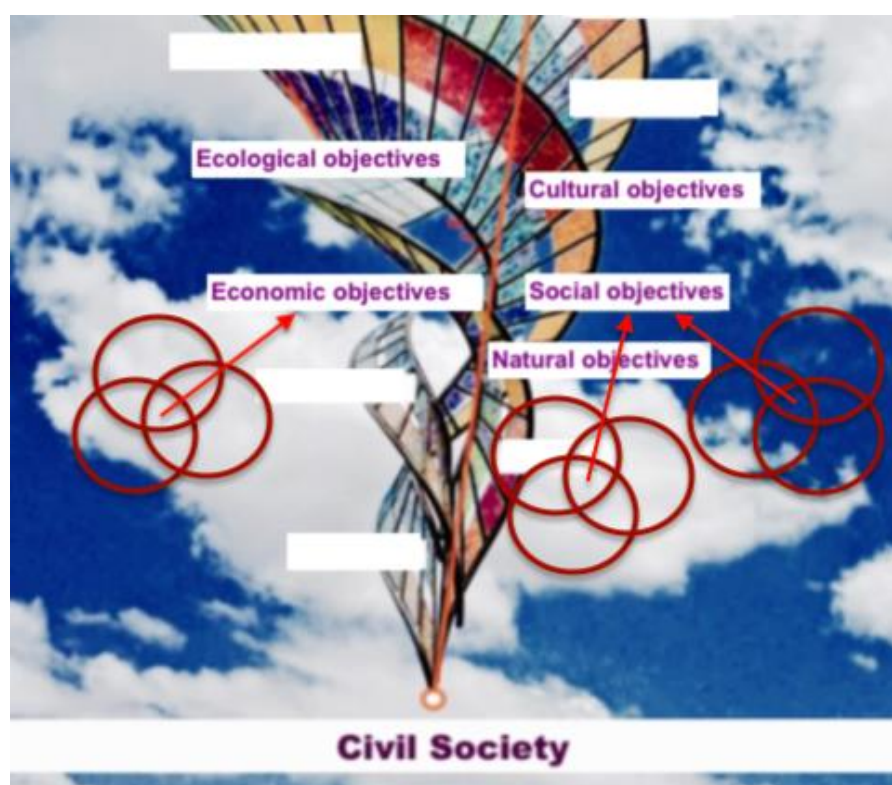


Figure 6. Achieving the objectives with the Triple Helix Twins.

5. SD Risk Space and World SD Triple Helix Spaces

The innovation process often questions existing boundaries and opens up the way to their creative re-working. Under certain conditions, boundary lines expand into “boundary spaces” in which hybrid organizations flourish and new initiatives are taken that could not be conceived, let alone implemented by individual actors [66].

The triple helix spaces include knowledge, consensus and innovation spaces in a region [33]. In the same way, SD knowledge space, SD consensus space and SD risk space are considered as the U-P-G triple helix spaces.

The narrow definition of risk is an external negative effect on an individual or organization. A risk space is an area of contestation between those who define an effect as negative and those who see it in a less threatening or even unthreatening or positive light. Thus, the conflict over chemical fertilizers and nuclear energy may be seen as occurring in a risk space in which publics engage with technology proponents to redefine a technology as too dangerous to utilize. The risk space is the arena of legitimation and de-legitimation in which both rational arguments and emotional appeals are used by contestants to convince others of risk or non-risk or at least acceptable risk [67]. As a strategy exercise, it may be viewed as analogous to the Risk board game.

In terms of the calculation of costs and benefits, risks and dangers (positive/negative effects) on rational rather than emotional criteria, continuous evaluation is warranted to assess effects. Government, the public and university are all active in seeking support to each other. In the U-P-G, it is essentially a space of controversy and dissensus in which opposing viewpoints and arguments rely on a mix of rational and emotive factors to prevail.

Beside the SD risk space, there are three other SD spaces (Table 4). The “SD innovation space” is the adaptation or creation of organizational mechanisms to fill a gap in the regional innovation environment. Such new mechanisms are typically hybrid organizations, synthesizing elements from different institutional spheres, e.g., venture capital firms, science parks and technopoles. The inclusion of actors from these various backgrounds in the strategy review and formulation process often provides access to the resources required

to implement the project. The innovation process is enhanced when one space becomes the basis for the development of another.

Table 4. Triple Helix's development.

	Primary Actors	Issues to Target	Vehicles	Operating Spaces
U-I-G	University, industry and government	Innovation (positive)	Entrepreneurial university; Research center (group); Technology Transfer Office; Science and Technology Park/Incubator; ...	Knowledge space: STEM -oriented; U-I-G Consensus space for innovation strategy; Innovation Space.
U-P-G	University, public and government	Sustainable development (negative)	Civic University; Research center (group, including social sciences and humanities); Knowledge/Technology Transfer Office; Social Innovation Park; Social Entrepreneurship Organizations/Platforms; ...	Knowledge space: PAVAM-oriented; U-P-G Consensus space for SPGs; Risk space.
Triple Helix Twins	U-I-G and U-P-G	Both Innovation and sustainable development	All the above. The triple Helix Twins couple and interact.	All the above. The dual Triple Helix Spaces overlap and co-exist to achieve an innovative and sustainable ecosystem.
N Triple Helices	TBD	Could be any	More than the above.	More than the above.

A region could be from a small town to the entire world. We upgrade a conceptual framework designed for the regional level and apply it at the world region level as a methodology to attain UN SDGs, too often left as a project for individual nations to contribute separately. The premise is that success in providing coherent and articulated strategies lies in the ability to encourage interaction and communication between innovation and sustainability actors.

Enhancing knowledge-based regional economic growth currently relies primarily on two main co-existing approaches: (1) Increase the knowledge base and (2) creating or expanding innovation mechanisms. The former may be viewed as a capacity-building long-term strategy, while the latter as a capability-building short-term strategy. Pursued together in a CERN-like format of large scale international collaborations, the two processes may be merged.

The “SD consensus space” is a neutral ground where the different actors, from different organizational backgrounds and perspectives, can come together to generate and gain acceptability and support for new ideas to promote economic and social development. The process of getting relevant actors to work together often includes the creation or modification of an organization to provide a home for brainstorming, analysis of problems and formulation of plans. At the world regional level, cross-national banks and continental organizations such as the African Union, the Pan American Union and the European Union may be expected to play a role as well as the UN in generating coalitions. Leadership can be exercised by an SD organizer, an individual/and or group that can set forth a future achievable objective and has sufficient prestige and authority to aggregate resources and initiate a project.

The “SD knowledge space” was initially used to analyze the effects of decentralization of government research laboratories from Mexico City to other Mexican regions following the mid-1980s earthquake. In their new surroundings, they realized a new potential, working on local problems, of becoming a resource for the region [68]. Similarly, a greater knowledge space (world-class) may be created by aggregating relevant resources across national boundaries.

6. Conclusions

The dichotomy between technological advancement and developmental sustainability has become a global human–natural–societal issue, addressed in diplomatic negotiations, academic research programs and corporate strategies. The nexus, between energy environment and economic growth, is offered as a breakthrough arena, through development of new generations of solar cell technology. Spillover from addressing this group of SDGs prepares the way to solve others, such as water, sanitation and urbanization.

Rather than increasing the number of helices to address a complex phenomenon, it may be more efficacious to harness congruent triple helices and raise the level of the playing field from sub-region to world region to develop coalitions and aggregate resources. By doing so, developing countries may play a greater role in creating relevant knowledge spaces on which to base collaborations. There are many proposals to complexify the model by adding additional helices but we believe this is a baroque and counterproductive strategy.

In this paper, we suggest instead to place the twins orthogonally to the SDGs and use a methodology to address them. The classic U-I-G model is insufficient to promote innovative technology that is not yet self-generating. An additional U-G-P configuration is needed to jump-start a higher-order innovation process that cannot be justified by traditional economic criteria.

Both triple helix twins may be used to address a particular issue in the framework. Each specific issue needs one or two triple helices, depending on the situation. In other words, the way to integrate and use triple helices is to select actors and design each of them according to the specific purpose. As in the twins' approach, we separately view each triple helix and then integrate them into a composite complementary framework.

As the Triple Helix is extended from innovation to targeting sustainable development, another actor is relevant in addition to the original U-I-G configuration. In each situation, it is important to determine who are the primary actors and organizers. If a new actor is more important than an old one, it should supersede it in the triple helix configuration. The U-P-G and U-I-G twins can balance between the innovative development and sustainable development.

Together, the Triple Helix twins can provide a motor for SDG attainment.

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Appendix A

The 17 Global Sustainable Development Goals

1. No Poverty: Access to basic human needs of health, education, sanitation
2. Zero Hunger: Providing food and humanitarian relief, establishing sustainable food production
3. Good Health and Wellbeing: Better, more accessible health systems to increase life-expectancy
4. Quality Education: Inclusive education to enable upward social mobility and end poverty
5. Gender Equality: Education regardless of gender, advancement of equality laws, fairer representation of women
6. Clean Water and Sanitation: Improving access for billions of people who lack these basic facilities

7. Affordable and Clean Energy: Access to renewable, safe and widely available energy sources for all
8. Decent Work and Economic Growth: Creating jobs for all to improve living standards, providing sustainable economic growth
9. Industry, Innovation and Infrastructure: Generating employment and income through innovation
10. Reduced Inequalities: Reducing income and other inequalities, within and between countries
11. Sustainable Cities and Communities: Making cities safe, inclusive, resilient and sustainable
12. Responsible Consumption and Production: Reversing current consumption trends and promoting a more sustainable future
13. Climate Action: Regulating and reducing emissions and promoting renewable energy
14. Life Below Water: Conservation, promoting marine diversity and regulating fishing practices
15. Life on Land: Reversing man-made deforestation and desertification to sustain all life on earth
16. Peace, Justice and Strong Institutions: Inclusive societies, strong institutions and equal access to justice
17. Partnerships for the Goals: Revitalize strong global partnerships for sustainable development

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