MANAGEMENT OF TECHNOLOGICAL INNOVATION FOR SUSTAINABLE GROWTH: AN ONTOLOGICAL META-ANALYSIS

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ABSTRACT

The concept of sustainable growth has been gaining momentum globally due to the need to manage limited resources like energy, food and air while at the same time sustaining the growth of economies for the wellbeing of the people. Technological innovations are the key to optimizing the use of resources in societies pursuing sustainable growth. The interest in managing technological innovations for sustainable growth (MOTISG) is emerging from different groups of stakeholders who bring their own approaches, frameworks or biases to study the problem. The challenges of sustainable growth under these partial perspectives and particular lenses generate narrowly focused knowledge in the respective stakeholders' domains. But such knowledge may not be necessarily compatible across domains, when seen from a more comprehensive perspective. For example, technological innovations to use green energy in manufacturing for sustainable economic growth may adversely affect the local farmers' agricultural practices and hence their social and cultural growth.

A systematic and systemic approach is needed to inclusively understand, assess, plan, manage and monitor the effectiveness of strategies, policies, and practices of sustainable growth. Such a complex ecosystem is not amenable to simple, fragmented analysis. Also, the results of the analyses have to be comprehensively synthesized to orchestrate the efforts and measure the consequences of decisions. Thus, our central questions are: How to represent in an integrative framework the knowledge generated to manage technological innovation for sustainable growth? Are there emphases or gaps in the knowledge generated and transferred among communities of science and practice for technological innovation for sustainable growth?

The authors propose an ontological framework for MOTSIG and conduct a meta-analysis of the available literature and systematically map the scientific publications of the last five years in this

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area. The ontology has five dimensions derived from the definition of the domain – Stakeholder, Management, Innovation, Technology, and Growth. Each dimension is defined by a taxonomy of constituent elements. A taxonomy may be extended by adding categories, reduced by eliminating them, refined by adding subcategories, and coarsened by aggregating them. The dimensions are arranged left to right, with adjacent suffixes and prefixes, such that one can construct a natural English sentence by concatenating an element from each dimension with the suffixes/prefixes.

By mapping and meta-analyzing papers indexed in a comprehensive, curated bibliographic database, we identify areas of knowledge that have received more attention in the period of the search, but also the areas where knowledge generation and transfer are missing. We thus identify the 'bright', 'light', and 'blind/blank' spots in MOTISG research. Thus, using the ontological maps the efforts of researchers, policymakers and practitioners can be aligned to satisfy the agendas of national innovation systems.

Key words: Ontological framework, technological innovation, sustainable growth, research agendas.

INTRODUCTION

The introduction of the concept of sustainable growth has gained momentum due to the need to manage scarce resources like energy, food, healthcare services and many others in the scenario of population increase and natural resources overexploitation (Harrison, 1998; Huesemann and Huesemann, 2008). Several technological innovations are being developed to optimize the use of these resources in societies pursuing socioeconomic growth (Ayres, 1996; Jacobsson and Johnson, 2000; Tsoutsos and Stamboulis, 2005). The interest manifested in the technological innovation for sustainable growth is emerging from different groups of stakeholders who bring their own approaches, models, frameworks or biases to study the challenges of sustainable growth under partial perspectives and particular lenses, generating new knowledge in the same stakeholder's domains, but not necessarily compatible in a more comprehensive environment. For example, technological innovations to use green energy in manufacturing for sustainable economic growth could be disconnected from the scientific, and/or cultural growth. In an emerging knowledge area, it is expected to start generating knowledge from different origins and fields, under the constraint of making sense to define and mature a new discipline. In this line, connections and disconnections of topics affect research agendas, and therefore, the harmonic development of the technological innovations for sustainable growth.

In order to understand, assess, plan, manage and monitor the effectiveness of strategies, policy or practices in an inclusive fashion, a systematic and systemic approach is required. The problem of such complex ecosystems is not manageable by simple analysis, but at the same time synthesis is necessary to encompass and orchestrate the efforts and monitor the consequences of the decisions made. Then our central questions are: a) how to represent in a holistic and interactive framework the construction of knowledge in technological innovation for sustainable growth? and b) are there emphasis or gaps on the knowledge created and transferred among communities of science and practice for technological innovation for sustainable growth?

The authors propose an ontological framework for the management of technological innovation for sustainable growth (MOTISG) that allows us to conduct a meta-analysis of the available literature and systematically map the scientific production of the last years in this area. By mapping papers contained in a comprehensive source of bibliographic databases, we aim to identify areas of knowledge that received more attention in the period of the search, but also identify the areas where knowledge generation and transfer is missing.

The information produced with the study of the areas of knowledge generated/missing can be of use for the reflection on the emphasis of research, and to create agendas for the advancement of the areas related to technological innovation for sustainable growth. In this way, efforts of researchers, policymakers and practitioners can be aligned to satisfy the agendas of national innovation systems.

THEORETICAL FRAMEWORK

Climate changes in the last decades have evidenced the environmental degradation caused by humans who overestimated their technological achievements and ignored their limitations (Clow, 1998). However, the environmental problems caused by the effects of economic activities on the natural environment are just one of the problems that researchers foresee to collapse the social-biological-economic systems during the second half of the 21st century. Back in 1996, Ayres posed several questions about the kinds of technological innovations that would be needed for a truly sustainable future, highlighting that welfare may not be explained only and directly by economic growth, but also by the scientific and technological progress. These are interesting views, since welfare not only means economic power, but making people happier or improving their standard of living by having free time or enjoying trips, and the socioeconomic system that optimizes the allocation of resources creates concentration of economic resources in reduced minorities whereas the majority works in 'unsustainable' schemes according to the welfare definition (Ayres, 1996).

Attending the concerns of a varied nature – environmental, social, cultural, population growth, educational, technological, and more – it is claimed to demand the improvement of policy and practices for the corporate, academic, and governmental spheres to avert the global collapse and foster the sustainable growth (Huesemann and Huesemann, 2008; Rochon et al., 2010). As a response to the dilemmas of economic development and sustainable growth, technological innovations are seen as a source of solutions for the generation of ecologically friendly environments for production of goods and services, but it is also recognized that technological innovations do not emerge spontaneously in the right direction, and therefore need political guidance to push societies towards an ecological modernization (Huber, 2000). In such a complex and urgent necessity, and recognizing a lack of theory or experience that act as a guide to policymaking (Bhat, 2005; Harrison, 1998), the authors of the present study propose an ontological framework to systemically and systematically guide the generation and transfer of knowledge on technological innovations for the sustainable growth.

CONSTRUCTION OF AN ONTOLOGICAL FRAMEWORK

MOTISG is an ill-structured, complex problem. An ontology is a way of structuring and deconstructing the combinatorial complexity of the problem. A detailed description of ontological meta-analysis and synthesis is provided by Ramaprasad et al. (Ramaprasad and Syn, 2013; Ramaprasad et al., 2014a; Ramaprasad et al., 2014b).

The dimensions (columns) of the ontology are derived directly from the statement of the problem. They are: (a) Management, (b) Innovation, (c) Technology, and (d) Growth. The fifth dimension – Stakeholder – is implied in the statement; it is who manages the technological innovation for sustainable growth. Each dimension of the ontology is expressed by a taxonomy of its constituent elements. The taxonomies are derived from the common terminology in body of knowledge on each dimension, especially in the MOTISG domain. Thus, the three primary stakeholders in the ontology are the Government, Industry, and the University – the three components of what is sometimes called the Triple Helix (Ranga and Etzkowitz, 2013). The Government is further subcategorized as Global, Regional, National, and Local highlighting the potential importance of each of these on MOTISG. The taxonomy of Management consists of Strategies, Policies, Practices, and Monitoring. We have explicitly included Monitoring in recognition of the importance of feedback and control in management. Decisions, which are often seen as following from strategies and policies, are subsumed under Practices. They could be separated in a future ontology should the distinction between the two be important for studying MOTISG. The taxonomy of Innovation derived from the literature includes Generation, Incubation, Application, and Evaluation of an innovation. The taxonomy of Technology is primarily derived from the call for papers of IAMOT Conference 2015 and supplemented by the present concerns in the literature. Last, sustainable Growth is articulated as a composite of Scientific, Technological, Economic, Social, and Cultural Growth. Figure 1 presents an Ontology of MOTISG; three illustrative components derived from the ontology are listed below it, and further below is the glossary of terms in the ontology. (Note: Terms referring to the dimensions and the elements of the ontology in the text are capitalized; the same terms used as a normal part of the discourse without reference to the ontology are not capitalized.)

The five dimensions are arranged left to right with adjacent symbols, words, and phrases such that reading left to right concatenating a category from each dimension forms a natural English sentence. Each such sentence is a potential component of MOTISG. Three illustrative components are shown in Figure 1 – the subcategories of a taxonomy are shown as subscripts. They are:

i. Government $_{\text{regional}}$ strategies for generation of agricultural technology for sustainable scientific growth;

ii. Industry practices for evaluation of global medical technology for sustainable social growth; and

iii. University policies for incubation of energy technology for sustainable technological growth.

These three and 5277 others encapsulated in the ontology are logically the potential components of MOTISG. The ontology presents the combinatorial complexity concisely and thus helps us take a systemic view of the problem of MOTISG systematically.

A component may or may not be instantiated or researched in a particular context. Studying across contexts, some components may be instantiated frequently, some infrequently, and others not at all. By the same token, some components may be researched frequently, some infrequently, and others not at all. We will label the frequently instantiated/researched components the ‘bright’ spots; the infrequent ones the ‘light’ spots, and the overlooked ones the ‘blind/blank’ spots.

The luminosity of each spot is a product of two opposing dynamics. A ‘bright’ spot may be so because it is effective and important; it may also be a consequence of habit and herd effect, irrespective of whether is effective or important. A ‘light’ spot may be so because it is ineffective and unimportant; it may also be a consequence of difficulty of implementing or studying it, irrespective of its potential effectiveness or importance. A ‘blind/blank’ spot may have been simply overlooked by design or by accident; or, it may be infeasible.

Knowing the ‘bright’, ‘light’, and ‘blind/blank’ spots in practice and research and the antecedent reasons will help develop more systemic and systematic approaches to the challenge of MOTISG. In the following we present an ontological map of research in MOTISG in the past five years (2010-2014 both inclusive), highlight the ‘bright’, ‘light’, and ‘blind/blank’ spots, and discuss possible reasons for the same. Before presenting the results, we will first describe the method we used for mapping. In the conclusion we will present the potential implications of this program of research and the planned extensions to what is presented here.

Stakeholder		**Management**		**Innovation**		**Technology**		**Growth**	
Government	**[+]**	Strategies	**[for]**	Generation	**[of]**	Agriculture	**[technology for sustainable]**	Scientific	**[growth]**
Global		Policies		Incubation		Biological		Technological	
Regional		Practices		Application		Communication		Economic	
National		Monitoring		Evaluation		Education		Social	
Local						Energy		Cultural	
Industry						Industrial			
University						Information			
						Manufacturing			
						Medical			
						Tourism			
						Transportation			

Illustrative components (total = 6*4*4*11*5 = 5280):

Government$_{regional}$ strategies for generation of agricultural technology for sustainable scientific growth.

Industry practices for evaluation of global medical technology for sustainable social growth.

University policies for incubation of energy technology for sustainable technological growth.

Glossary:

Stakeholder: An entity with a stake in MOTISG.

Government: The public agency responsible for governance, regulations, law, etc.

Global: A government agency with a global coverage. For example, a UN agency

Regional: A government agency covering a segment of the globe. For example, Latin America, Africa.

National: A country's government.

Local: A state, city, municipality, village, etc. government.

Industry: Private and public enterprises which collectively produce and distribute goods and services.

University: Institution of higher education.

Management: The process of realizing technological innovation for sustainable growth.

Strategies: Systematic principles for MOTISG

Policies: Guidelines for MOTISG based on srategies.

Practices: Actions for MOTISG based on policies and strategies.

Monitoring: Assessment and feedback on outcomes of practices, policies, andd strategies.

Innovation: The intorduction of something new for sustainable growth.

Generation: Generation of a new idea or artifact.

Incubation: Nurturing of the new idea or artifact.

Application: Translation of the new idea or artifact into practice.

Evaluation: Assessment of the new idea or artifact in practice.

Technology: The domain of innovation.

Agriculture: Farming for crops, animals, fish, etc.

Biological: Innovations about/based on the biology of plants, animals, and people.

Communication: Innovations for exchange of information between people, organizations,etc.

Education: Innnovations for the generation, transfer, and application of knowledge.

Energy: Innovations related to the production, distribution, and use of different forms of energy.

Industry: Innovations related to the production and distribution of goods and services.

Information: Innovations related to the techologies and systems used for information processsing.

Mnaufacturing: Innovations related to the production of goods.

Medical: Innovations related to the delivery of healthcare services.

Tourism: Innovations related to the services for visitors.

Transportation: innovations related to the movement of people and goods.

Growth: The type of sustainable growth catalyzed by innovation

Scientific: Growth in scientific knowledge for sustainable growth.

Technological: Growth in sustainable technology.

Economic: Sustainable growth of the economy.

Social: Sustainable social advancement.

Cultural: Sustainable cultural advancement.

Figure 1: Ontology of Management of Technological Innovation for Sustainable Growth

METHOD

We searched Scopus for all articles with 'technology AND innovation AND sustainable AND growth in Title, Abstract, and Keywords'. Scopus is an extensive curated database managed by Elsevier. The search term was finalized after experimenting with a few alternatives and perusing the results. The search yielded 375 articles of which 190 were for the period 2010-2014. It included all the relevant articles from Technovation, Technological Forecasting and Social Change, and other key journals. These represent the population of articles for the period.

We downloaded the title and abstract of the 190 articles into an Excel tool developed by one of the authors to aid coding. Using the tool a coder can map each article, based on the title and abstract, to the elements of the ontology it addresses.

The final coding was based on a consensus of two student coders and their supervising instructor (one of the authors of this study). The two student coders independently coded all the articles. If their coding was in agreement it was finalized as such by the instructor. If they were in disagreement, the final coding was based on a discussion between the instructor and the two coders.

We note that an article may instantiate multiple components, a component, parts of multiple components, or part of a component of the ontology. Thus, there was no restriction on how many elements of the ontology could be encoded with reference to an article, or a requirement that an article should be encoded with reference to all the dimensions of the ontology. Thus an article could be encoded to: (a) an element from each dimension, (b) multiple elements from each dimension, (c) an element from some dimensions, or (d) multiple elements from some dimensions. Of the 190 articles all but two were coded on all the dimensions. A total of 708 components out of the possible 5280 (13.4%) in the ontology are instantiated in the corpus. The 708 instantiated components occur 1298 times in the corpus. Five partial components occur once each.

We also note that the coding was binary – whether the element (or its synonym) was present or not in the title and abstract. The coding was not weighted; each article and each element was assigned equal weight.

The data were analyzed using the same Excel tool used for coding to generate the following ontological maps of the MOTISG domain: (a) the frequency of occurrence of each element (monad) in the ontology, (b) the frequency of occurrence of each pair of elements (dyads) in the ontology, (c) the frequency of occurrence of select triads in the ontology, and (d) a heat map of the top forty components. These maps are presented and discussed in the section below.

RESULTS

Monads

The frequency of occurrence of each element (monad) in the ontology is shown in Figure 2. For example, we can see that the most studied Stakeholder element is Industry and the least studied is Government $_{\text{Regional}}$. In Management, the most studied element is Practices and the least studied is Monitoring. Likewise, in Innovation the most studied element is Application and the least studied is Incubation. In Technology, the most studied element is Industrial and the least studied is Tourism. Finally, in Growth dimension the most studied element is Technological and the lone not-studied element is Cultural. The frequently studied elements in each dimension are its 'bright' spots, the less frequently studied elements its 'light' spots, and the unstudied elements its 'blind/blank' spots. There is only one 'blind/blank' spot in Figure 2. The criterion for distinguishing the 'bright' and 'light' spots is subjective and not fixed. Thus, for example, among Stakeholders Industry and Government $_{\text{National}}$ may be considered as 'bright' spots and the rest as 'light' spots. And, in Management all but Monitoring are 'bright', Monitoring is 'light'.

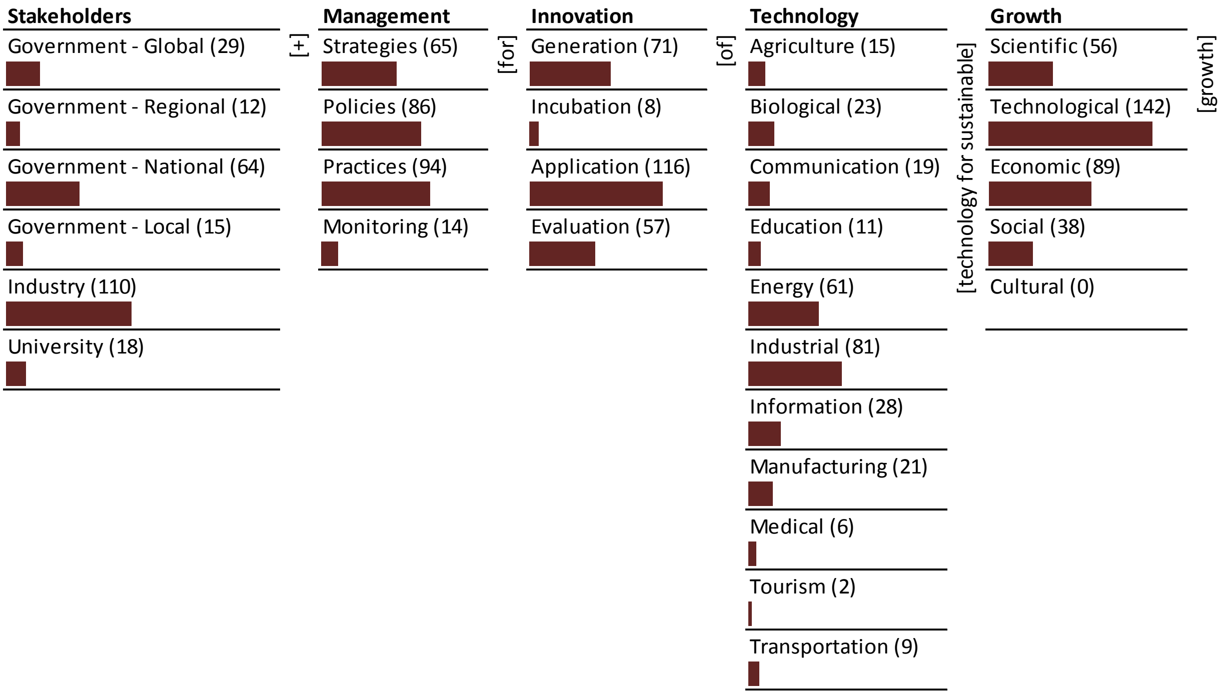


Figure 2: Ontological Map of Monads of Management of Technological Innovation for Sustainable Growth

The relative luminosity of the elements in each dimension of the ontology provides insights and raises questions about the focus of research in MOTISG in the past five years. Among Stakeholders, the studies are concentrated on analysis of the Industry and Government $_{\text{National}}$, but very few studies analyze the effects of Government $_{\text{Local}}$ and Government $_{\text{Regional}}$, or the influence that may come from Universities as centers of creation and diffusion of knowledge and technological innovations. From the ontological map we cannot infer whether the above emphasis in research corresponds to that in practice, and whether it is the most appropriate. However, at the very least one may suggest a significant gap in the research on Stakeholders given the increasing decentralization (emphasis on Government $_{\text{Regional}}$ and Government $_{\text{Local}}$) of MOTISG efforts, and the increasing role of Universities in it.

In Management, the emphasis on Strategies, Policies and Practices but the lack of emphasis on Monitoring suggests a lack of attention to feedback and learning in MOTISG. This lacuna represents an important challenge in that it implies a lack of studies that look into short and medium-term results in MOTISG to correct its course.

In Innovation, Application, Generation and Evaluation are widely studied, but Incubation is not. If the four elements of Innovation are seen as sequential, the lack of emphasis on Incubation could be a critical weak-link. This is particularly surprising given the emphasis on incubators by all the

Stakeholders. If all that is to be known about incubation of innovation has been discovered then the relatively low emphasis on Incubation may not have been surprising. It is not likely. The ‘light’ emphasis on Incubation may simply be a consequence of lack of attention to it or the difficulty of studying it.

In Technology among the eleven elements two– Industrial and Energy – comprise more than 50% of the total count. They are the ‘bright’ spots of MOTISG. The second group – Information, Biological, Manufacturing, Communication and Agriculture – representing another 40% of the instantiated components are the ‘light’ spots. Finally, the third group consisting of the remaining elements may be considered the ‘blind/blank’ spots of MOTISG. Again, the ontological map portrays the relative emphasis of the research. It neither suggests the reasons for the emphasis nor the consequences of the same. However, based on the map one may pose the questions about the right portfolio of technologies for research and practice for MOTISG. For example: should there be greater emphasis on Education and Information?

In the final dimension, Growth, Technological and Economic growth are the ‘bright’ spots; Scientific and Social growths are ‘light’ spots; and Cultural growth is truly a ‘blind/blank’ spot. The highest emphasis on Technological growth, given that the object of study is MOTISG, may be tautological. Yet, in the context of sustainability the lack of emphasis on Social and especially Cultural growth appears paradoxical. One may pause and pose the question whether Technological growth can be sustained without Social and Cultural growth.

In the following section we will further refine these insights by studying the frequency of dyads and triads in the ontology.

Dyads

The frequency of co-occurrence of each pair of elements (dyads) in the papers is shown in Figure 3. All the possible pairs in the ontology, within each dimension and between all dimensions, are shown in the figure. The figure highlights the ‘bright’, ‘light’, and ‘blind/blank’ dyads. The highest frequencies are of studies relating Industry and Technological growth, which is found in 87 of the 1303 instantiations of the full/partial components in our sample. Similarly, another combination of a dyad that is also frequently analyzed is that of Application of innovations with Technological growth, which occurs in 83 instantiations in our sample.

In Figure 3, the dyads with the highest number of instantiations are:

(87) Industry and Technological growth
(83) Application of innovations for Technological growth
(66) Industry and Application of innovations
(66) Practices for Technological growth
(66) Energy technologies for Technological growth
(65) Policies for Technological growth
(61) Industry Practices
(61) Practices for the Application of innovations
(60) Generation of innovations for Technological growth

These may be considered the ‘bright’ spots among dyads.

In the same vein, dyads which occur slightly less frequently are:

(57) Application of innovations for Economic growth
(55) Strategies for Technological growth
(55) Technological and Economic growth
(54) Policies for the Application of innovations
(53) Energy technologies for Technological growth
(51) Industry and Industrial technologies
(50) Industry Strategies
(49) Industry and Economic growth
(46) Policies and Economic growth
(45) Government $_{\text{National}}$ Policies
(44) Industry and Generation of innovations
(44) Practices and Economic growth
(43) Government $_{\text{National}}$ and Application of innovations
(43) Government $_{\text{National}}$ and Technological growth
(42) Application of innovations for Industrial technologies

		Stakeholders						Management				Innovation				Technology											Growth				
		Government - Global	Government - Regional	Government - National	Government - Local	Industry	University	Strategies	Policies	Practices	Monitoring	Generation	Incubation	Application	Evaluation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Scientific	Technological	Economic	Social	Cultural
Stakeholders	Government - Global																														
	Government - Regional																														
	Government - National	1																													
	Government - Local			1																											
	Industry	11	5	22	6																										
	University		1	8		6																									
Managemen	Strategies	7	8	17	3	50	5																								
	Policies	20	4	45	10	31	8	18																							
	Practices	9	7	28	7	61	11	17	24																						
	Monitoring	3	1	4		10	1	2	5	5																					
Innovation	Generation	14	8	20	2	44	7	33	35	29	7																				
	Incubation		2	5		4	5	4	4	5	1	4																			
	Application	16	5	43	11	66	10	35	54	61	10	21	2																		
	Evaluation	7	4	20	3	34	5	14	24	30	9	11	1	23																	
Technology	Agriculture	3	2	9		7		3	9	10		5	1	10	1																
	Biological	6	1	8		15		9	11	12	1	9	1	16	8	5															
	Communication	2		5		12	3	8	8	10	2	8	1	12	2	2	1														
	Education	1		2	1	2	7	1	4	8		3		4	5			2													
	Energy	11	2	21	6	34	5	13	34	32	4	21	1	41	21	3	8	2	1												
	Industrial	13	8	28	7	51	8	32	37	38	9	36	5	42	26	1	3	2	2	18											
	Information	3	1	11	1	16	5	10	12	14	2	10	3	16	6	2		15	2	3	4										
	Manufacturing	3	1	5	2	13		5	8	11	3	9		14	5		1	1		8	9	1									
	Medical	1		1		4	1	1	2	4		2		6	1				1		1										
	Tourism					2		1		1		1		1																	
	Transportation		2	2	2	7	1	3	4	5		3		5	2				1	3	1										
Growth	Scientific	11	5	16	1	34	8	19	21	29	4	25	2	30	16	4	12	5	5	22	20	6	4	4		3					
	Technological	25	10	43	8	87	12	55	65	66	12	60	6	83	41	9	15	16	5	53	66	20	19	1	1	6	40				
	Economic	14	8	38	5	49	7	29	46	44	6	36	4	57	27	12	8	5	4	25	39	13	15	2	2	1	12	55			
	Social	5		16	7	14	8	6	23	15	4	11	3	26	14	2	2	5	6	9	16	7	1	4		2	6	19	21		
	Cultural																														

■ Highest Frequency (87)

□ Zero Frequency

Figure 3: Ontological Map of Dyads of Management of Technological Innovation for Sustainable Growth

(41) Application of innovations for Energy technologies
(41) Evaluation of innovations for Technological growth
(40) Scientific and Technological growth

These may be considered the ‘light’ spots among the dyads.

Dyads with frequency less than 40 can be read directly from Figure 3 and may be said to represent ‘lighter’ spots in the MOTISG literature.

Lastly, Figure 3 also lets us see combinations of pairs of elements that are nonexistent or rarely analyzed and researched. These ‘blind/blank’ spots mean that they are elements that in combination receive little attention in scientific research. It is important to be clear about this, as it would explain that not every area of study in MOTISG is interesting to analyze, be it for their low social or economic impact, because they are neither attractive for study in the public arena nor in the private, or simply because there is lack of awareness or omission by researchers that have limited their development. Knowing those elements that define trends in academic research, as well as those that have not attracted interest until now, may allow us to know precisely which areas to support in order to push the edges of scientific knowledge about a particular topic.

Triads

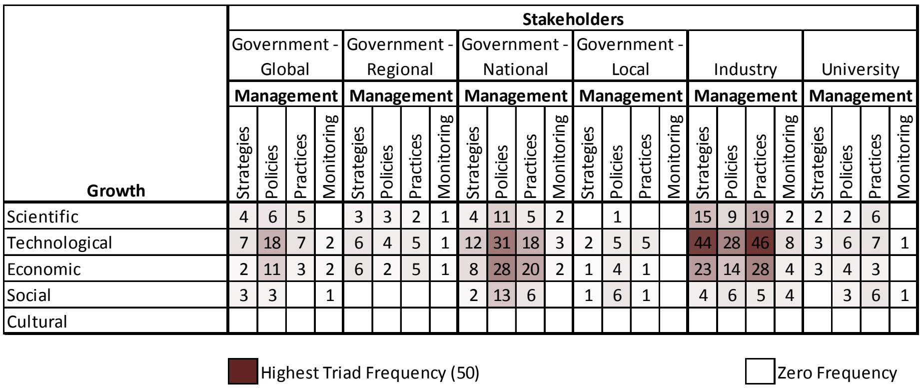
To continue the exploration of the complexity of MOTISG, we analyze select triads in the ontology (Figure 4). From the maps of triads it is possible to identify the ‘bright’, ‘light’, and ‘blind/blank’ spots of combinations of elements from three different dimensions. For example, in the Stakeholders-Management-Growth triad Industry Practices for Technological growth (46) is a ‘bright’ spot. Similarly, Industry Strategies for Technological growth (44), and Government $_{\text{National}}$ Policies for Technological growth (31) are also ‘bright’ spots. Combinations with a lower, but still significant frequency counts, such as Government $_{\text{Global}}$ Polices for Technological growth (18), can be classified as ‘light’ spots. Other combinations, such as Government $_{\text{Global}}$ Monitoring for Cultural growth (0), or Government $_{\text{Local}}$ Monitoring for Economic growth (0), can be classified as ‘blind/blank’ spots in MOTISG.

Heat Map

Finally, Figure 5 shows a heat map of the top forty components from which one can identify those with the greatest frequency in the sample of papers analyzed.

It may be noted that the components studied in the sample under analysis is rather small, leaving a large number of components unstudied. The latter could be very interesting for the researchers to explore. On the one hand, knowing which components have been studied most, allows us to recognize different perspectives on a topic, find common ground, and build upon the scientific foundations to push the limits of knowledge. On the other hand, with this information it is possible to recognize which areas of study are either unattractive, or have been off the radar of researchers but may need attention. Particularly, it is noteworthy that the most attractive component approached by researchers in MOTISG is the Government $_{\text{National}}$ Policies for the Application of Energy Technology for Sustainable Technological Growth.

Stakeholders-Management-Growth

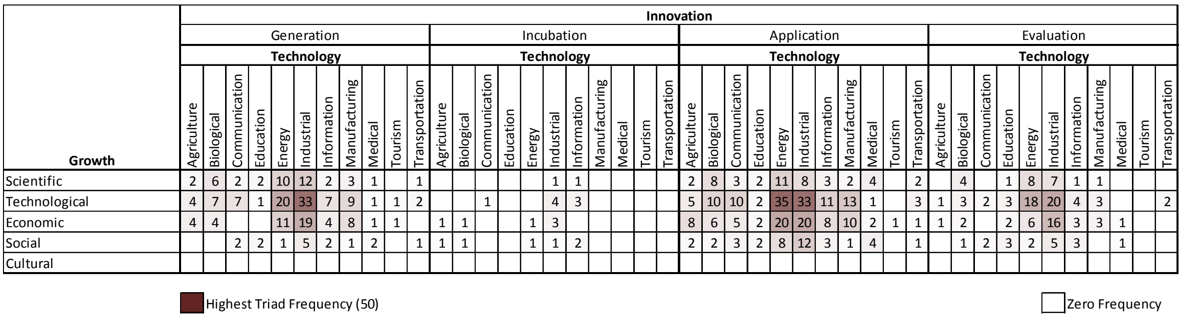


	Stakeholders																							
	Government - Global				Government - Regional				Government - National				Government - Local				Industry				University			
	Management				Management				Management				Management				Management				Management			
Growth	Strategies	Policies	Practices	Monitoring	Strategies	Policies	Practices	Monitoring	Strategies	Policies	Practices	Monitoring	Strategies	Policies	Practices	Monitoring	Strategies	Policies	Practices	Monitoring	Strategies	Policies	Practices	Monitoring
Scientific	4	6	5		3	3	2	1	4	11	5	2		1			15	9	19	2	2	2	6	
Technological	7	18	7	2	6	4	5	1	12	31	18	3	2	5	5		44	28	46	8	3	6	7	1
Economic	2	11	3	2	6	2	5	1	8	28	20	2	1	4	1		23	14	28	4	3	4	3	
Social	3	3		1					2	13	6		1	6	1		4	6	5	4		3	6	1
Cultural																								

▇ Highest Triad Frequency (50)

☐ Zero Frequency

Innovation-Technology-Growth

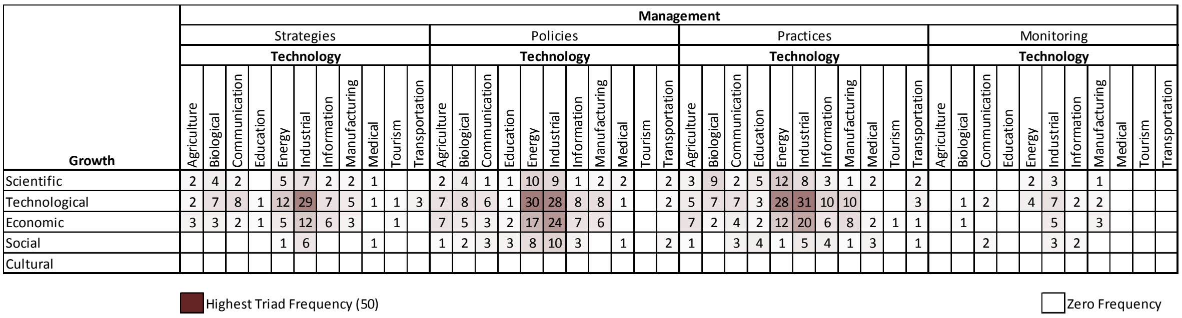


	Innovation																																												
	Generation											Incubation											Application											Evaluation										
	Technology											Technology											Technology											Technology										
Growth	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation
Scientific	2	6	2	2	10	12	2	3	1		1						1	1					2	8	3	2	11	8	3	2	4		2		4		1	8	7	1	1			
Technological	4	7	7	1	20	33	7	9	1	1	2			1			4	3					5	10	10	2	35	33	11	13	1		3	1	3	2	3	18	20	4	3			2
Economic	4	4			11	19	4	8	1	1		1	1			1	3						8	6	5	2	20	20	8	10	2	1	1	1	2		2	6	16	3	3	1		
Social			2	2	1	5	2	1	2		1	1	1			1	1	2					2	2	3	2	8	12	3	1	4		1		1	2	3	2	5	3		1		
Cultural																																												

▇ Highest Triad Frequency (50)

☐ Zero Frequency

Management-Technology-Growth



	Management																																												
	Strategies											Policies											Practices											Monitoring										
	Technology											Technology											Technology											Technology										
Growth	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation	Agriculture	Biological	Communication	Education	Energy	Industrial	Information	Manufacturing	Medical	Tourism	Transportation
Scientific	2	4	2		5	7	2	2	1			2	4	1	1	10	9	1	2	2		2	3	9	2	5	12	8	3	1	2		2					2	3		1			
Technological	2	7	8	1	12	29	7	5	1	1	3	7	8	6	1	30	28	8	8	1		2	5	7	7	3	28	31	10	10			3		1	2		4	7	2	2			
Economic	3	3	2	1	5	12	6	3		1		7	5	3	2	17	24	7	6				7	2	4	2	12	20	6	8	2	1	1		1				5		3			
Social					1	6			1			1	2	3	3	8	10	3		1		2	1		3	4	1	5	4	1	3		1			2			3	2				
Cultural																																												

▇ Highest Triad Frequency (50)

☐ Zero Frequency

Figure 4: Ontological Map of Select Triads of Management of Technological Innovation for Sustainable Growth

DISCUSSION AND LIMITATIONS

The ontology provides a comprehensive lens to explore the combinatorial complexity of MOTISG. It is systemic. It is also a systematic way of deconstructing the interactions of the elements in the ontology. Mapping the state-of-the-research onto the ontology reveals its 'bright', 'light' and 'blind/blank' spots. It shows how the knowledge generated-documented-published in the academia on MOTISG is concentrated on a small number of possible topics. In fact, only 708 (13.4%) of the possible components of the ontology are instantiated in the last five years of publications. It raises the question whether the remaining 4,572 (86.6%) possible areas of study have been overlooked, or simply omitted because they are uninteresting, have low impact in the development and implementation of technological innovations for sustainable growth, or are unfeasible. It would be very interesting to know the reasons for not attending to such a broad spectrum of the MOTISG areas. Research agendas can be designed to attend to the relevant and feasible issues among them. For example, the role of University in Monitoring the Incubation of innovations to be applied to almost any Technology (Medical, Education, Transportation and/or Tourism) to foster Social and Cultural growth of societies is a 'blind' spot in the available literature. Perhaps it has to be made a 'bright' spot.

Government - National Policies for Application of Energy technology for sustainable Technological growth	14
Industry Strategies for Generation of Industrial technology for sustainable Technological growth	13
Industry Practices for Application of Energy technology for sustainable Technological growth	11
Industry Practices for Application of Industrial technology for sustainable Technological growth	11
Government - National Policies for Application of Industrial technology for sustainable Technological growth	10
Industry Strategies for Application of Industrial technology for sustainable Technological growth	10
Industry Practices for Evaluation of Industrial technology for sustainable Technological growth	10
Government - National Policies for Application of Energy technology for sustainable Economic growth	9
Industry Policies for Application of Energy technology for sustainable Technological growth	9
Industry Policies for Application of Industrial technology for sustainable Technological growth	9
Government - National Policies for Application of Industrial technology for sustainable Economic growth	8
Industry Practices for Generation of Energy technology for sustainable Technological growth	8
Industry Practices for Generation of Industrial technology for sustainable Technological growth	8
Government - National Policies for Generation of Industrial technology for sustainable Technological growth	7
Government - National Policies for Generation of Industrial technology for sustainable Economic growth	7
Industry Practices for Application of Information technology for sustainable Technological growth	7
Industry Practices for Evaluation of Industrial technology for sustainable Economic growth	7
Government - Global Policies for Generation of Industrial technology for sustainable Technological growth	6
Government - Global Policies for Application of Energy technology for sustainable Technological growth	6
Government - National Policies for Evaluation of Industrial technology for sustainable Economic growth	6
Government - National Practices for Generation of Energy technology for sustainable Economic growth	6
Government - National Practices for Generation of Industrial technology for sustainable Economic growth	6
Government - National Practices for Application of Energy technology for sustainable Technological growth	6
Government - National Practices for Application of Industrial technology for sustainable Technological growth	6
Industry Strategies for Generation of Energy technology for sustainable Technological growth	6
Industry Strategies for Generation of Industrial technology for sustainable Economic growth	6
Industry Strategies for Evaluation of Industrial technology for sustainable Technological growth	6
Government - National Policies for Generation of Energy technology for sustainable Economic growth	5
Government - National Policies for Application of Energy technology for sustainable Social growth	5
Government - National Policies for Application of Information technology for sustainable Economic growth	5
Government - National Policies for Evaluation of Energy technology for sustainable Technological growth	5
Government - National Policies for Evaluation of Industrial technology for sustainable Technological growth	5
Government - National Practices for Generation of Energy technology for sustainable Technological growth	5
Government - National Practices for Generation of Industrial technology for sustainable Technological growth	5
Government - National Practices for Application of Agriculture technology for sustainable Economic growth	5
Government - National Practices for Application of Energy technology for sustainable Economic growth	5
Government - National Practices for Application of Industrial technology for sustainable Economic growth	5
Government - National Practices for Evaluation of Industrial technology for sustainable Economic growth	5
Industry Strategies for Generation of Biological technology for sustainable Technological growth	5
Industry Strategies for Application of Biological technology for sustainable Technological growth	5

Figure 5: Ontology Components Heat Map (top 40)

A major limitation of the study is the sample of five years. We propose to extend it in the future. A longer timeframe will also permit us to study changes in the 'bright', 'light', and 'blind/blank' spots over time.

While we have focused on the state-of-the-research we could also map the state-of-the-practice based on documentary and interview data from those practicing MOTISG. Such a mapping, in addition to revealing the gaps in each state will also yield insights about the gaps between the two states. A 'bright' spot in research may be a 'blind/blank' spot in practice, or a 'bright' spot in practice may be a 'blind/blank' spot in research – two different manifestations of the know-do gap.

CONCLUSION

The paper presents a comprehensive ontological framework for envisioning MOTISG. The framework is systematic, systemic, and synoptic. It logically deconstructs the combinatorial complexity of MOTSIG and presents it parsimoniously in natural English. As such the framework is easily understandable to the researcher, the practitioner, and the lay person. Any of them can derive the components of MOTISG from the framework and judge its application to research and practice.

Using the ontological framework as a lens and matching it to the extant literature on the topic over the past five years reveals a few 'bright', some 'light', and many 'blind/blank' spots. It is not clear whether the differences in luminosity are by design or by accident. Our guess is that it is more the latter than the former. Herd effects in research, ease/difficulty of conducting certain types of research, gatekeeper (for example, journal editor) preferences, and other similar factors often drive research on particular topics and in particular directions. The same is likely true of MOTISG research too. Such research may add to the researchers' productivity but not to the research's effectiveness in achieving MOTISG. The ontological framework and the associated mapping can redirect the research on MOTISG to be both productive and effective.

Some omissions are striking. Technological innovation for sustainable growth exerts influence not only on technological and economic aspects but also on social and cultural aspects of the society. The first two issues (influence on economic and technological aspects) have been studied extensively by researchers in the last five years, but the effects on the social and cultural aspects have received little or no attention in the same period. The lack of empirical studies analysing the participation of universities to support the process of development and dissemination of technological innovations that promote sustainable growth, is also intriguing, especially when models like the Triple Helix have positioned the role of universities as engines for innovation (Ranga and Etzkowitz, 2013). Another example of the lack of interest of researchers in certain areas MOTISG is the small number of papers with focus on the monitoring of innovations in technologies for Tourism, Medical, Transportation, Education and Agriculture. Greater dedication to the monitoring of technological innovations on education could make significant and necessary improvements on social and cultural problems that today limit sustainable growth. The large gap between what is reported as research possibilities in contrast to what really is being investigated (mainly industry and energy technological innovations) ought to be a subject of analysis in the academic community, particularly those that are part of increasingly committed to sustainable development economies, as indicates the triple helix model. Both the errors of commission and of omission can be systematically assessed and corrected using the proposed ontological meta-analysis.

A reason for the gaps in research may be the fragmentation facilitated by the absence of a systemic framework and a systematic approach. The proposed ontology provides a systemic and systematic framework for thinking about what topics are being studied and what are not. We have illustrated the application in the context of MOTISG, but the method can be extended to other domains and systems. Ontological meta-analysis can be used to assess the present state of MOTISG and develop a roadmap for its future.

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