Nanotechnology in the Philippines: Development of framework for technology adoption

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Abstract. Groundbreaking advancements have driven significant industries to adopt and take advantage of the key technologies in order to thrive in these adjustments coming from the Fourth Industrial Revolution (FIRE). However, with the threat of the Coronavirus disease 2019 (COVID-19) causing catastrophic setback to the society and economy, scientific endeavors have shifted towards finding a solution to this pandemic. It is high time to evaluate how the current technology from the FIRE can help a country, such as the Philippines, survive such outbreaks and unforeseen circumstances. Advancements in the field of nanotechnology aim to develop smaller and inexpensive testers, and overall newer and more effective medical solutions. However, the extent on how these technologies can be realized depends on the interplay between the country’s policies, and the strong link between industry and academe. This paper raises policy recommendations from synthesizing the trends in nanotechnology and forecasting how it develops so as the country can readily adapt. Moreover, this paper identifies the barriers and constraints, as well as the factors necessary for the technology adoption in the country.

1. Introduction

With the promise of economic growth, and comfort of living, most technological innovations have seen productivity over the last decades [1,2]. These developments have been identified as significant factors in prosper and survival for any firm, company, or country [3-5]. As such, important attention must be placed upon emerging technologies to be able to anticipate the evolution and future applications of the technology [6]. Technological innovation systems have been developed to address the importance of several relevant actors such as firms, government, and academe, and the interactions surrounding the technology [7,8]. And with the advent of the Fourth Industrial Revolution (FIRE), several disruptive technologies have developed that substantially affected the productivity, and operational efficiency of industries [9]. Among these disruptive technologies, nanotechnology is acknowledged as one of the major worldwide technology research initiatives of the 21st century [10,11].

Nanotechnology, as defined by the U.S. National Nanotechnology Initiative (NNI), deals with the applications of particles within the size of 1 to 100 nm [12]. Additionally, the development, and manufacturing of materials with structures, fibers, or platelets smaller than 100 nm involves nanotechnology [13]. This includes the discovery of novel properties and material behavior in the nanoscale, as well as research and development of devices, methodologies, and system frameworks to
gather data on a nanomaterial [14]. Nanotechnology serves as a key to a promising future, paving the way for more advances in the fields of engineering, materials science, electronics, and other disciplines such as in energy, biomedicine, food, and environment [15]. Moreover, it can help in understanding nature, creating advanced manufacturing equipment, developing innovative medical treatments, and even disturb societal norms [16]. The nanoscale threshold is where the behavior of atoms or molecules are a function of the composition, structure, and size. It is within this level that fundamental properties are explored, and miniscule changes in the composition can produce novel properties that would considerably revolutionize the areas where the technology is applied such as in engineering, industry, safety and security [15].

The Philippines and the world have seen the rapid growth of technological advancements amidst the waves from the FIRe. Noticeable changes are observed in terms of economy and increase in industrial productivity; various business frameworks have been established to adapt to these shifts and thrive in the years to come. However, the scope of how to harness the advantages from these emerging technologies depend on the country’s ability to project the developments and adapt accordingly with the various disruptions brought about by the technologies [17]. The adaptation process would entail careful analysis of technological trends, observing how such advancements affect the stability of the society and economy. Additionally, this would require proper preparations and implementation from the stakeholders such as the government, research facilities, and industries.

The potential of nanotechnology has been acknowledged by the Philippines and as such was able to develop a technological roadmap on how the technology will develop and affect the lives of the Filipinos. That was 10 years ago, the previous decade focused the resources of the country on developing the 4 identified prioritization areas of nanotechnology which are: (1) energy, (2) food and agriculture, (3) environment, and (4) development of nanocomposite materials from local minerals [18]. However, with the presence of the COVID-19 pandemic that hinders the development of most industries, these previously drafted roadmaps and technological adoption plans are being impeded. The presence of the pandemic has and will continuously negatively affect the country’s economic performance and production capacity due to the disruption in the global supply chain and increase in mortality rate [19]. In line with this, the paper aims to raise policy recommendations for the development and adoption of nanotechnology in the Philippines that would anticipate the technology trends and identify how nanotechnology can help to combat pandemic.

The rest of the paper is constructed as follows. The Section 2 discussed the ongoing technological trends in the field of nanotechnology applications in the global and local scale. In Section 3, the several factors, barriers, and constraints for technology adoption were identified and briefly discussed, while Section 4 discussed the impacts of nanotechnology in other fields. Finally, in Section 5 laid out the policy recommendations that would aid in the adoption of nanotechnology in the country.

2. Trends in Nanotechnology Application

2.1. Global trends

Dealing with materials at the nanoscale (10-9), the study of tiny materials has huge impacts on several applications. The field of nanotechnology spreads its application in various fields; as the nanoscale control of structure, size, and composition have proved useful in terms of food and agriculture [20], biomedical applications [21], and drug delivery [22].

A SCOPUS search on nanotechnology trends over the last 5 years (2015-2020) was made and has resulted in over 1 402 papers, upon which 715 are journal articles, and 687 are review papers. The resulting papers scoped to different fields such as Materials Science, Engineering, Chemistry, Biochemistry, Chemical Engineering, Pharmacology, Physics, Medicine, Environmental Science, and Energy. Fig. 1 illustrates the correlation among the major keywords and topics with regards to nanotechnology trends. The figure is generated by calculating the amount of times the topics or keyword was mentioned or discussed in the identified papers. The size of the font and nodule indicates the relevance of the topic with respect to the network established on nanotechnology trends. From this
figure, four main clusters were identified: (1) disease and drug delivery, (2) sensors, and biosensors, (3) computational simulation of nanomaterials, and (4) experimentation on nanomaterial properties.

Medical applications of nanomaterials are one of the well researched fields of nanotechnology. Most of the studies in this cluster focus on drug delivery; particularly utilizing nanomaterials in chemotherapies that guide the treatment to identified cancer cells, directing the removal of tumors in tissues or organs, improving the effectiveness of radiation-based therapy [23-25], and the use of nanocarriers in treatment of Central Nervous System disease [22]. The cluster on sensors, and biosensors primarily focuses on the aspect of detection. Nanotechnology equipment and methodology are developed to detect pathogenic bacteria [26]. Gold nanoparticles are used for medical imaging and treatment management for pancreatic cancer [27]. In addition, scaffoldings for skin tissue are developed by fabricating nanofibers [28]. The cluster on computational nanotechnology delves on discovering new materials and designing it to have suitable properties for the intended applications. Research on custom tailoring the material properties of graphene for various applications [29] and designing superhydrophobic nano-based coatings [30] are some of the studies being explored in this cluster. On the other hand, the experimental side of nanotechnology deals with varying the structures and composition of materials at the nanoscale then finding new purposes and applications such as in epoxy nanocomposites [31], nano-biopesticides [32], and nanomaterials as antimicrobial agents for food safety [33]. Identifying the main clusters can help in determining and predicting the direction of the development in the field of nanotechnology.

2.2. Local trends
In 2009, the Department of Science and Technology (DOST) of the Philippines formally acknowledged the field of nanotechnology as one of the priorities for Research and Development (R&D). As such, 14 local scientists were gathered to develop a roadmap for nanotechnology in the Philippines that identified major areas of development that received attention and funding [18].

The applications of nanostructured solar energy devices were pursued in a collaborative effort from the top universities in the country and DOST. Solar cells were developed with embedded nanoparticles and graphene. Nanosensors that utilizes nanoparticles for environmental assessment and damage control were also researched. In the field of agriculture, Mesoporous Silicate Nanoparticles (MSNs) were used for enabling gene transformation in the plant and animal cells, several pesticides and fertilizers with nanoparticles were developed, and applications of nano-based sensors were made for precision agriculture [34]. Several funded projects funded by the DOST, aimed to utilize
nanomaterials produced from the naturally-occurring minerals such as development of nanocomposites using recycled polycarbonate and modified montmorillonite, synthesis of strong plastics from the introduction of carbon nanotubes, and development of halloysite-epoxy hybrid nanocomposite as molding compound in semiconductor industry applications [18].

StatNano, a statistics gateway founded to monitor the latest developments in the field of nanotechnology has reported that the Philippines currently has established 6 companies that have developed 23 products in the fields of automotive, medicine, construction, textile, and home appliance. In terms of research, the field of nanotechnology made up 4.53% of the total ISI-indexed articles of the country, and a total of 0.50% out of the total research articles published in 2019 [35]. With the low numbers in terms of research, for a field that is recognized by the country to be a billion dollar industry globally [34]; more attention and resources should be allocated to harness the advantages coming from this emerging technology.

In the government's effort to attain world-class nanotechnology laboratories in the country, the Nanolab was established to provide technical services for the different local industries, and to develop and implement research initiatives in the field of nanotechnology [36]. Several experts consider nanotechnology to be one of the important disruptive technologies, capable of incorporating the technology in early detection and prevention, as well as to enhance diagnostic and treatment capabilities [34]. The future aspects of nanotechnology are deemed bright with the attention that the government has placed early on to this technology. The top efforts for research in the next years are expected to focus on bioactive nanostructures for drug delivery, improved imaging techniques, filtration using nanomaterials, and applications for nanoparticles and nanocomposites that enhance the functionality of natural materials such as in silica, limestone, and clay [36]. The projected advancements on these researches would also imply that the spread of nanotechnology in the curriculum is necessary to produce essential human resources, and procure the appropriate equipment to upgrade existing laboratories focusing on nano research.

2.3. Role of nanotechnology in the pandemic

The presence of COVID-19 pandemic has caused devastating effects to the economy and society, as well as affecting productivity in various scientific fields and programs [37]. This provided opportunities for emerging technologies to be integrated in the current battle against the pandemic [38]. Nanotechnology-based approaches are one of the potential directions in combatting the pandemic. The potential advantages coming from the nature of the size and morphology of the nanoparticles, facilitate the drug delivery precision to minimize threats coming from the immune system response [39].

The nano-based approach towards infectious diseases have been previously studied. In a paper by Kerry, et al. [40], the different applications on viral sensing and antimicrobial properties of identified nanoparticles were presented. Additionally, major antiviral approaches that utilizes nano-based technology have been presented to aid in strategizing possible methodologies in combating pandemics. The review also provided some insights with regards to how the development of nanoparticles would not be enough until the pathogenesis of a virus is understood.

Nanotechnology has been taking its course and realizing its role in this pandemic; with its main role of developing means of virus detection, reliable personal protection equipment (PPE), and better medical response. Nanosensors were being developed that would enable to detect viral infection even before symptoms start to appear. An Israeli company, Scentech Medical have started testing the breath analyzer that was developed through the use of nanoparticles and aims to be able to diagnose in 10 seconds [41]. Attention is also being placed on improving the efficiency of the PPE such as the incorporation of nanofibers in the filters being used on the masks. Furthermore, research on the various antiviral properties of nanoparticles are being made.

3. Nanotechnology Adoption in the Philippines

Through the collective effort of researchers, engineers, and scientists worldwide, the development of a technology continues to move forward. Potential benefits and drawbacks may arise as the technology matures. And in order to fully harness the advantages from an emerging technology, proper actions
must be taken by the stakeholders to facilitate the entry of such technology to the society and market. For groundbreaking technologies such as nanotechnologies, several factors are identified that would positively influence the adoption of this technology in a country [42].

First factor to consider is the benefits that the technology brings to the country. What are the advantages gained once the technology is spread in the market? Secondly, gauge the usefulness or utility that the benefits provide; identify the practical use and application of the technology. Next, determine the needs of the country and how can the entering technology address it. Another factor that influences the entry of a technology to the country would be the maturity level and how readily available the current state of technology is. It is important for the technology to reach a maturity level that would allow easier adoption to the country. Lastly, the realness of technology and how it is to be communicated to a layman. Understanding the basic concepts of the technology would lead to the acceptance of the technology.

This section identifies the important factors to drive the adoption of nanotechnology in the Philippines and the barriers that are to be encountered to achieve the objective of harnessing the technological benefits nanotechnology provides.

3.1. Facilitating Factors
Nanotechnology has continued to prosper from the support of public and private sectors of different countries. The increase in efforts for adoption of its technology has also resulted in multiple commercialization failures [43]. As such, research frameworks and technological innovation systems are being developed to identify the key factors in nanotechnology adoption.

One of the major applications of nanotechnology involves sensors, and biosensors. In line with this, the potential growth of nanotechnology as a field and industry relies on the expansion of the electronics and opto-electronics industry [44]. The development of advanced electronic devices is in conjunction with the discoveries in the field of nanotechnology. As the semiconductor and electronics further improve, so is the involvement of nanotechnology; it would not take long for the public to acknowledge the benefits of nanotechnology and welcome its adoption to the country.

Ever since the initial applications of nanotechnology were realized, one of the concerning aspects are the environmental hazards the technology might bring forward. As such, it is important to also acknowledge and focus on the eco-friendly aspects of nanotechnologies to ease the adoption of the technology [45]. With the special properties being presented by nanomaterials, this leads to interesting applications that promises environmental protection as opposed to the current materials being used. The development of stronger and more durable materials would lead to the increase the life of a product, this translates to less additional constructions and maintenance. Moreover, nanomaterials are being used in building insulations to optimize the energy being used.

As one of the emerging technologies that has the potential to disrupt the daily activities in several industries and economic activities of countries, it is important that attention and support is provided for the field of nanotechnology. An increase in the gross domestic expenditure on research and development (GERD) and income level to promote corporate nanotech patent applications would play a substantial factor in the engagement activities in nanotechnology, as well as its adoption in the country [46].

3.2. Barriers and constraints for adoption
Aside from identifying the facilitating factors that would aid in the ease of adoption of nanotechnology in the Philippines, it is also important to determine the barriers and constraints that impedes, or even inhibits the entry of the technology in the country. As part of the technologies that have emerged in the FIRRe, nanotechnology is considered to be in its early stages, and to be part in that stage there are several barriers that might appear when the technology is to be adopted.

Technology transfer has been a major hurdle in any technological field that aims to be adopted and developed. For nanotechnology, it is estimated to be at least 3 years for the research to be commercialized [47]. This presents multiple financial risks and is not ideal for investors when a technology takes that long to be commercialized. In turn, this results in less attention and support to be placed in the field; ultimately delaying its progress for adoption.
Another problem with a technology in the early stage is that it progresses quickly. When several advances are being made, most of the equipment and devices become outdated. Moreover, research in nanotechnology requires proper infrastructures that are expensive such as laboratories and equipment to innovate further in the field.

In terms of the business sector, small businesses do not have the capacity to be able to access necessary equipment to adopt nanotechnology in their operations. Additionally, the public perception towards nanotechnology is that it is unsafe [47]. The involvement of the citizens and public approval play an important role towards adoption of nanotechnology in the country. Lastly, the lack of experts on the field of nanotechnology is negatively affecting its acceptance.

3.3. Philippines – Nanotech policy
In the 2018 Asia Nano Forum, the Philippines presented the status of nanotechnology in the country, the identified factors, and constraints for the technology transfer and commercialization [48].

The Philippine nanotech policy acknowledged that the adoption of nanotechnology in the country is highly dependent on funding from government agencies, government research institutions, and other research organizations. Identified barriers and constraints for adoption include the amount of time required for the realization of the R&D in the field of nanotechnology. In addition, most equipment required for nanotech research are costly making the investment towards the R&D to be extremely capital intensive. The local scene must also be wary towards the fast-paced developments in the global dimension of nanotechnology, efforts would be futile when more efficient methods or techniques are already developed in other countries. Lastly, the nanosafety issues from R&D to the end-product phase raises concern. As an emerging technology, there are uncertainties in terms of the long-term effect that the nanomaterials might bring towards human health and environment.

On the other hand, the nanotech policy recognizes the legal framework that would facilitate the technology transfer and commercialization of nanotechnology in the Philippines. Several policies are identified to help in this effort such as the Technology Transfer Act for ease of adoption in the market, Guidelines on Intellectual Property Validation to protect the scientists and researchers, Commercialization of Information Sharing to capitalize on important findings, and Technology Transfer Protocols for the systematic transfer of knowledge involve in the manufacturing, or development of products. Furthermore, under the nanotech policy, efforts are being made to market and promote nanotechnology towards the public and the industry. Small businesses and start-ups will be given access to technology experts to help commercialize the nanotechnologies and will also be given access to government funded laboratories.

4. Impacts of Nanotechnology
Aside from the analysis of how the technology has developed and where its future direction lies, it is also important in the development of policy recommendations to assess the impacts of the technology in aspects that would determine its viability for adoption. The development of nanotechnology would entail some influence on the different sectors such as economy, environment, and society.

4.1. Economic Impacts
Investments made towards R&D of a technology spreads throughout the entire economy of the country [49]. The development of nano-based products and processes is intensive for human and capital resources. The innovation cycles are fast-paced, and a knowledgeable workforce is required; several public and private funding were drawn by the promise of nanotechnology as a disruptive technology that will alter the current livelihood and operations in the world [50]. Billions of dollars of cumulative global R&D investments towards nanotechnology were estimated [51]. The United States alone has invested over $27 billion towards nanotechnology research since 2001 [52]. As a maturing technology, it would require several years before the economic benefit of nanotechnology to be realized. However, promise from the investment is shown as revenue generation in the European nanomaterials market has reached $2.5 billion in 2015 with a projection of $9.1 billion by 2022 [53].

Additionally, the development of the field would yield to growth in job opportunities [54]. As more nanomaterials are being discovered and advanced processes are developed, this would require
human resources to cater the needs for the advancements. The economic impact of nanotechnology in a country can also be viewed through a time lens [55]. Partnerships and linkages are one of the main benefits in the short-term for the development of nanotechnology in a country. Several research facilities and instruments would be acquired, and capacity building is of utmost urgency. In the medium-term once nanotechnologies have planted their roots; supply-chain structure would be established, skilled graduates are generated, the R&D cycle would be further enhanced, and commercialization of the nano-based technologies would be improved. This would lead to harnessing the economic benefits of nanotechnology in the long-term such as in the effect on the Gross Domestic Product (GDP) and faster rate of Return on Investment (ROI).

4.2. Environment impacts
The effect and impact of nanotechnology towards living organisms and the ecosystem has been researched since the emergent of the technology. Particular concerns and drawbacks from the technology have been raised early on such as the uncertainties and lack of knowledge with regards to the long-term effects, and the so-called nanopollution [54]. Undesirable health or environmental outcomes from an emerging technology leads to backlash and criticism from the public and key stakeholders, that would eventually lead to stricter regulations [56]. Major environmental concerns are being heavily investigated such as the effects of nanoparticles towards its surroundings. Engineered nanoparticles such as silver negatively impacts the quality as the nanoparticle binds with the solid particles of soil causing degradation of soil fertility [57]. Proper life cycle analysis must be made in the development and production of nanotechnology products to determine the amount of energy, water, and toxic chemicals involved. In addition, the production of carbon nanofibers contributes significantly greater towards global warming and ozone layer depletion than the production of conventional materials [58].

On the other hand, the positive economic benefits of nanotechnology include the potential to develop materials that are more ecofriendly than the current raw materials being used in the construction industry today [59]. The development of nanomaterials can boost the energy and resource efficiency in the chemical industry. Additionally, in terms of energy storage, a nanotechnology-based approach is being employed to optimize energy production that would significantly help in combating climate change [60]. Nanomaterials are also being developed as filters for wastewater clean-up and detection of chemical and biological agents in the air and soil [61].

4.3. Societal impacts
One of the alarming impacts that nanotechnology brings to society are the health-related concerns. The absorbance of nanoparticles in the bodily fluids or tissues of the body present some risks. Developed nanoparticles with particularly low solubility that were transported to a living organism could accumulate in the system for a long time [54]. Government funded nanotechnology research is also interested in the growth of the technology towards military applications. Applications such as atomically precise manufacturing are one of the interests in the development of nanorobotics and weapons for military affairs and surveillance [62]. Other societal impacts for the growing nanotechnology involve the domination of big companies with regards to the Intellectual Properties (IP) claims that are applied and patented [63]. This gives the big companies power to control the rate of advancement and adoption of nanotechnology in a country. The advancement of nanotechnology also impacts the demand for scientists, engineers, and technicians. Moreover, technologies would affect the capabilities of the government and important agencies in terms of citizen tracking and surveillance [64].

5. Policy Recommendations
The analysis of development and growth of nanotechnology, as well as its future directions is essential in determining potential policy recommendations in the adoption of nanotechnology in the Philippines. Moreover, the identification of facilitating factors, and barriers for adoption helped to focus on the drivers and address the constraints in the acceptance of the technology. In this paper, a framework was developed and proposed to identify and assess the roles of key actors in the development of
nanotechnology in the country as can be seen in Fig. 2. The main advancements in the field of nanotechnology has shown correlating characteristics to a General Purpose Technology (GPT) [65]. A GPT exhibits its potential from identifying and connecting key firms, industries, and other stakeholders across different sectors [66]. As such, the proposed framework aims to recognize important connections between varying sectors and how the interplay among them can benefit the advancement of nanotechnology. Key players were identified to be the academe, industry, and the government regulating bodies. Government policies play a crucial role in regulating the behavior and developments in the field, it would also control the flow of support and attention towards grants and funding supports. The regulating bodies are responsible for assessing the government policies and revise it in accordance with the progress in the maturity of nanotechnology. Moreover, a team of nanotechnology experts should be made that would coordinate and regulate the funding supports, as well as serve as the linkage between government and industry. Funding agencies from both the public and private sector would provide support to promising academic institutions, and research laboratories engaging in nanotech research; in addition, efforts towards conferences, workshops, and training to promote nanotechnology acceptance will be made. The financial support will also spur the formation of Research Innovation Hubs and Centers of Excellence for nanotechnology, that gives access for Micro, Small, and Medium Enterprises (MSME), and start-ups with adequate support from experts and access to relevant facilities. The academe side would focus on capacity building catering to the technological advancements and industrial needs. Knowledge generation would be the main driving force in this framework, by addressing the societal needs in terms of another outbreak or disaster, the research direction would be shifted accordingly coming from this framework. The advances in the field of nanotechnology coming from the knowledge of societal needs would challenge the current policies; the regulating bodies will formulate more appropriate policies and regulations to address the societal demands. By directing the efforts towards knowledge generation and listening to societal needs, nanotechnology in the Philippines is set to significantly aid in the country’s progress.

Figure 2. Proposed framework for nanotechnology assessment in the Philippines

5.1. Labor and employment
The development of the field of nanotechnology opens doors for more job opportunities. When a certain process is developed or discovered, skill specific jobs are required for the industry. The implementation of proper technological transfer protocols and information towards the society would
yield high returns to labor. Labor policies on promotion of employment and human resource development, as well as livelihood and entrepreneurship are important. Opportunities for all to venture and succeed in the field of nanotechnology is essential in its spread and acceptance in the country. Proper PPE must be always provided for employees that are exposed to harmful substances in the event of production and development of nanomaterials. Furthermore, measures for cases of pandemic or outbreaks should be in place to ensure the employment of workers.

5.2. Capacity building
In the path of advancement for nanotechnology, it would require human capital. The progress of nanotechnology needs the help of more hands and brains, as such this policy recommendation recognizes the importance of human resources and aims to provide proper support towards the force behind the development of nanotechnology. Proper support towards building programs that are fair to the skilled individuals and will enable their passion in exploring nanotechnology in this country must be provided. The lack of experts would severely factor in the reason as to why nanotechnology adoption in the country would take a longer time.

Government initiatives such as the Balik Scientist Program (BSP), that recognizes Filipino experts that have trained abroad to come back to the country and share their expertise, would be great in reinforcing the available human resources of the country. The knowledge transfer from specialists that have practiced their profession outside of the country is an essential help in guiding the current state of Science and Technology in the Philippines, as well as sharing insights on how other countries have tackled and adopted the emerging technologies.

On the other hand, the academe should also play a role in developing quality education that equips students with expertise and knowledge through technical training. Alignment to industrial needs would be beneficial overall.

5.3. Government policy and laws
A positive perception towards nanotechnology by the public will yield benefits in the adoption and progress of the field in the country. Consequently, public acceptance and decisions are highly affected by the level of trust placed upon the government, academe, and industries [67]. The interplay between the stakeholders defines the role of government to take care of policies to protect the society from potential risks [68]. Conversely, the researchers and industries manage the risks associated with nanotechnology. The relationship between government and its citizens remains crucial as the residents that trust the government to prioritize the interest of the public would be generally welcoming towards the technological campaigns by the government such as in the introduction of nanotechnology for future product applications [69].

In addition, policies towards fair opportunities on exploring nanotechnology should be the one of the main focus, such as providing necessary support and equipment access to small scale businesses, incentives for industries, and safety nets for investors. Moreover, support should also be provided in the early stages of manufacturing of nanomaterials as these are costly and a significant factor to the success of the technological adoption. Lastly, proper implementation from the responsible organizations must be done to ensure that these countermeasures will help in the progress of nanotechnology in the country.

5.4. Research development and innovation
Support should be given to research in nanotechnology, particularly in the field of microfabrication research where most advances are being researched and developed. The local trend of development of nanocomposites from naturally occurring minerals must be funded, as well as research on drug delivery, filtration systems, and medical imaging techniques.

Competitive grants will also spark the interest of further research in the field, as would lead to obtaining necessary equipment for research. The development of innovation hubs with regards to specific research categories on nanotechnology would boost its advancement. In line with the established government programs, the Niche Centers in the Regions for Research and Development
(NiCeR) would capacitate nanotechnology related research through substantial funding and would be a significant help in obtaining necessary infrastructure for the development of nanotechnology in the country. Lastly, open access to available nanotechnology research and findings. The availability of modern results would enhance the rate of progress in terms of research; additionally, the public would be given access to valuable data and would lead to further appreciation heading to the faster adoption and acceptance of technology in the country.

5.5. Policy interventions summary

From the identified barriers and constraints for technology adoption in Section III, and the proposed policy recommendations in Section V, a summary of how the policy recommendations can address the determined barriers and constraints is shown in Figure 3.

6. Conclusions

Nanotechnology is one of the emerging technologies that has the potential to disrupt the daily activities of various sectors at a global scale. Interesting trends on how the technology has evolved can be observed. Research on the nanoscale applications have caused uproars in huge industries such as in automotive, construction, and healthcare.

The potential of nanotechnology has been acknowledged by the Philippines, as such a technology roadmap was established 10 years ago to guide the development of nanotechnology in the country. However, the presence of the COVID-19 pandemic has drastically affected the timeline of most technological roadmaps. Several barriers and constraints for the adoption of nanotechnology in the Philippines were identified. On the other hand, the facilitating factors that would enable the acceptance of the technology in the country was also explored. Moreover, the impacts brought about by the advancements in nanotechnology towards major sectors such as the economy, environment, and society were also discussed. From the gathered information on the trends, factors for adoption and impacts of the technology, policy recommendations were raised to help establish the roots of nanotechnology in the country and support it in its technological maturity.
A framework was developed and proposed that takes into consideration the major stakeholders and the relationship amongst them that would enable the flourish of nanotechnology in the country. The knowledge driven framework aims to cope up with societal needs or in cases of pandemic/outbreaks. Furthermore, the policy recommendations aimed to address the identified constraints for technological adoption of nanotechnology in the country.

While policy recommendations are important to help the governing bodies in tackling the topic on technology adoption. It would be ineffective if there is no established trust between the stakeholders. Citizens would be scared to accept new technology if the government is not confident in the performance of that technology or due to flaws in the information relay between the researching bodies and common folk. On the other hand, when strong linkages are established between the key actors such as in academe and industry, a projection of increased productivity will be seen in the field of nanotechnology. It is critical to capitalize and invest on emerging technologies and its maturity level should match the capabilities of the country to minimize the potential risks. Furthermore, it is important to raise awareness towards the public and clearly define the advantages and disadvantages of nanotechnology to ease its acceptance in the society. It has been six decades since Richard Feynman proposed the idea of manipulating things on a small scale, now the technology previously thought of is taking shape and is preparing to take over the operations of the world. It is now within the realm of finding how to fully harness the technology through proper deliberation and policy making of the stakeholders can a country like Philippines move forward.

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