Utilizing the Technology Readiness Level scale (TRL) for measuring social impact startups. Guatemala's National Innovation Prize

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Introduction

Latin America faces countless pressing challenges that are exacerbated by structural problems of their economies, particularly as they relate to significant inequalities across different societal groups and sectors. In Guatemala, these inequalities manifest themselves on several dimensions, including in an 18.5% illiteracy in its population. Moreover, similarly to other countries in the region, Guatemala is a very culturally diverse country, it has 23 languages, 25 ethnic groups where the Mayan, Xinka, Garífuna, indigenous and ladino people coexist. As many developing countries, Guatemala has witnessed numerous social impact projects that have failed, understating the cultural aspects.

These structural problems of inequality can be counteracted in new ways through innovation and specifically science and technology. Hence, in 2020, the National Secretariat of Science and Technology (SENACYT) in Guatemala joined forces with four **strategic allies** –the United Nations Development Programme (UNDP), the Ministry of Economy, the United Nations International Children's Emergency Fund (UNICEF) and Korea International Cooperation Agency (KOICA)– to promote the **national innovation ecosystem** through a renewed National Innovation Prize (PNI by its acronym in Spanish).[1]

The PNI contributes directly to the achievement of SDG 17, as it seeks to promote science, technology and innovation (STI) projects with a positive impact in Guatemala and the region. All adults are welcome to apply, independently of their sector. There are eight categories defined for the PNI promoting innovation in all SDGs:

1. Industrial innovation
2. Business innovation
3. Innovative entrepreneurship
4. Development innovation
5. Childhood and adolescence innovation
6. Education innovation
7. Health innovation
8. Public management innovation

This paper explains the process and the results of the 2021 PNI for adopting and applying TRL criteria to identify STI start-ups with potential for social impact. The paper is organized as follows: Section 1 reviews the PNI and its relation to the TRL scale. Section 2 exemplifies the use of TRL scale for two identified Guatemalan emerging technologies. Section 3 summarizes the main observations and lessons learned from the identified emerging technologies based on the TRL findings. The last section concludes with a hypothesis formulating the potential effect of enhanced PNI mechanisms for identifying high quality national innovations contributing to the SDGs.

Section I: PNI design and its relationship with TRL

For the 2021 PNI, the need to fulfill the assessment of the development stages was addressed through the Technology Readiness Level scale (TRL). The TRL was introduced by NASA in the 1970s to measure the maturity of complex technology developments. In 2001, the United States Department of Defense adopted this scale for its procurement programs[2], continuing its use to date[3].

The TRL unfolds in 9 stages[4]:

1. Basic principles observation and report

[1] The PNI was created by SENACYT in 2013 and promoted annually, but without partner organizations, with fewer categories and a more limited number of applicants.

[2] Olechowski, Alison; Eppinger, Steven D. and Joglekar, Nitin. "Technology Readiness Levels at 40: A Study of State-of-the-Art Use, Challenges, and Opportunities." 2015 Portland International Conference on Management of Engineering and Technology (PICMET), August 2-6 2015, Institute of Electrical and Electronics Engineers (IEEE), September 2015 © Institute of Electrical and Electronics Engineers (IEEE)

[3] Martínez-Plumed, F., Gómez, E., & Hernández-Orallo, J. (2021, May). Futures of artificial intelligence through technology readiness levels. Retrieved April 8, 2022, from https://www.sciencedirect.com/science/article/pii/S0736585320301842

[4] Dunbar, B. (2015, May 6). *Technology readiness level*. NASA. Retrieved April 8, 2022, from https://www.nasa.gov/directorates/heo/scan/engineering/technology/technology_readiness_level

2. Technology concept and/or application formulation
3. Analytical and experimental critical function and/or characteristic proof-of-concept
4. Component and/or breadboard validation in laboratory environment
5. Component and/or breadboard validation in relevant environment
6. System/subsystem model or prototype demonstration in a relevant environment (ground or space)
7. System prototype demonstration in a space environment
8. Actual system completed and "flight qualified" through test and demonstration (ground or space)
9. Actual system "flight proven" through successful mission operations

These stages have been adopted by technology companies. It should be clarified that for the PNI the TRL evaluations were made to the projects as a whole, instead of evaluating the components as it is usually done with a technology readiness assessment[5].

Considering that the TRL scale faces a list of challenges in modern TRL implementation[6], and that the PNI evaluates projects and not just the technological components, the following criteria was used complementing the TRL to find disruptive and promising innovations.[7][8]

Table 1. Complementary criteria to TRL

Criteria	Measurement
Novelty	State-of-the-art search and benchmarking
Impact	Aligned to the SDGs with a considerable number of recipients/users
Scalability	Available, accessible and total markets
Team	Comprehensive disciplines and adequate skills of each member of the group
Technological maturity	Technology Readiness Level scale
Suitability	The solution fits the problem and specially their **users**

While the challenges encountered in modern TRL implementation focus on "interface maturity" to consider a technology to be successful, the additional PNI criteria (Table 1) focus mainly on 'suitability' emphasizing the bidirectional relationship between the user and technology.

The 2021 PNI specified in its "Terms and Conditions" that all applicants needed to reach a minimum level of TRL6 to be considered for evaluation. It is important to note that 38% of the 74 applications submitted did not meet this requirement. Owing to this reason, national judges had the faculty to disregard the requirement in proposals they considered disruptive.

Each admitted application went through three stages of evaluation:

1. **Internal evaluation**. An innovation team from SENACYT analyzed the TRL of the proposals and verified the completeness of the online application

[5] U.S Government Accountability Office, Persons, T. M., & Sullivan, M. J., GAO-16-410G, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects (2016).

[6] Olechowski, Alison; Eppinger, Steven D. and Joglekar, Nitin. "Technology Readiness Levels at 40: A Study of State-of-the-Art Use, Challenges, and Opportunities." 2015 Portland International Conference on Management of Engineering and Technology (PICMET), August 2-6 2015, Institute of Electrical and Electronics Engineers (IEEE), September 2015 © Institute of Electrical and Electronics Engineers (IEEE)

[7] Boburg, L. (2021, December). *ESTRATEGIA DE APOYO AL EMPRENDIMIENTO DE BASE CIENTÌFICO-TECNOLÒGICA EN GUATEMALA*. Retrieved April 8, 2022.

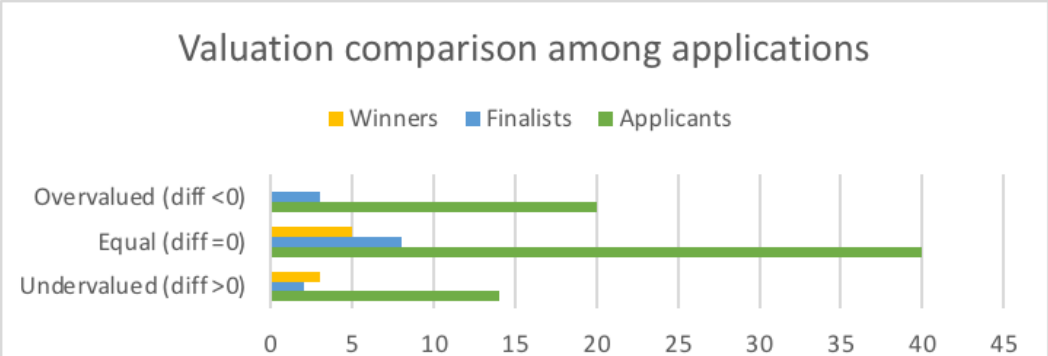
[8] The Terms and Conditions document can be consulted in the following link: https://www.senacyt.gob.gt/portal/attachments/premioinnovacion2021/bases_pni2021.pdf

form. The proposals categorized as TRL6 or above were selected.

2. **External national evaluation**. National judges (subject matter experts nominated by the PNI´s strategic allies), selected the top three proposals for each category.
3. **External international evaluation.** An international judge for each category[9] (also nominated by the PNI's strategic allies) and a member of the innovation team from SENACYT evaluated the pitches of the finalists' projects and selected one winner for each category.[10]

In addition to the TRL evaluation carried out by SENACYT in the first stage, each applicant was required to complete a self-evaluation of the TRL. A TRL evaluation comparison between the self-evaluation and the SENACYT evaluation shows that out of the total applications 19% (14) were undervalued and 27% (20) were overvalued, among the finalists 15% (2) were undervalued and 23% (3) overvalued, and among the winning proposal 38% (3) were undervalued and interestingly 0% (none) overvalued, as shown in Figure 1.

Figure 1. Valuation comparison between applications



	Undervalued (diff >0)	Equal (diff =0)	Overvalued (diff <0)
Winners	3	5	0
Finalists	2	8	3
Applicants	14	40	20

Furthermore, as shown in Figure 2, total applications have a wider TRL range, while finalists present a narrower range and winning proposals a more concentrated TRL, suggesting a positive correlation between TRL and the quality of the proposals.

After the three stages of evaluation concluded, the PNI was awarded to 3 systemic solutions and 6 technology-based projects.[11] From these 6 projects, 2 were identified as disruptive social impact emerging technologies[12], which are explained in Section II.

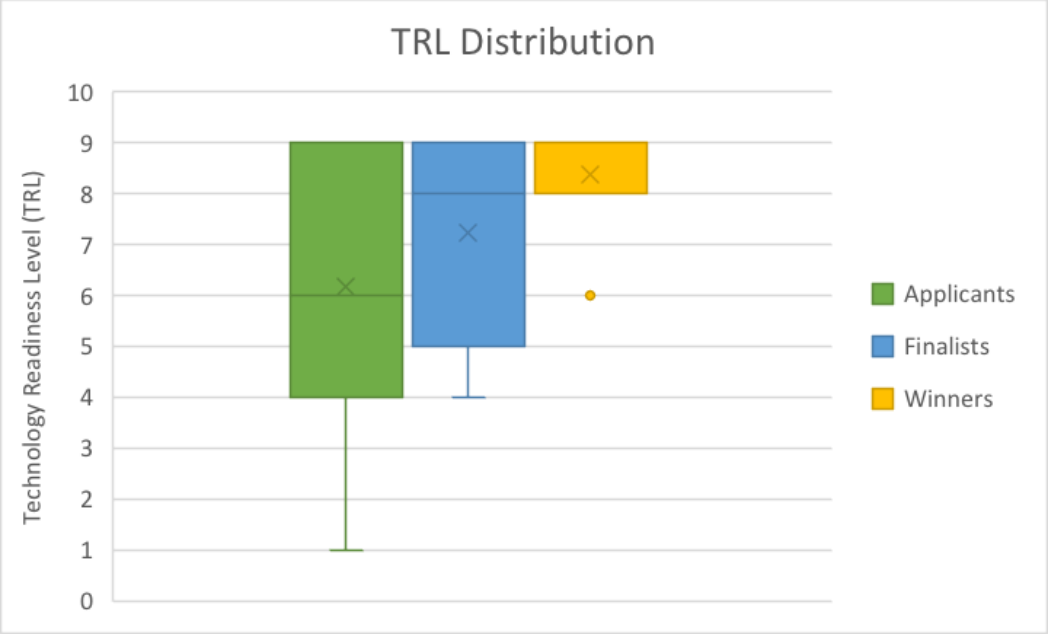
Figure 2. TRL Distribution

[9] The international judges were: Roberto Quintero Vega (business innovation), Vincenzo Placco (education innovation), Claudia Olmedo (development innovation), Beatriz Ferreira (industrial innovation), Remo Betta Olivares (public management innovation), Allison Quesada (public management innovation), Mayra Álvarez (health innovation), Paula Véliz (childhood and adolescence innovation) and Alejandro Zúñiga (innovative entrepreneurship).

[10] A winner was chosen for each category except one, in which an honorific mention was awarded. The list of winners can be consulted in the following link: https://www.senacyt.gob.gt/portal/index.php/informate/actualidad/91-pni-ganadores-2021

[11] Full list available here: https://www.senacyt.gob.gt/portal/index.php/informate/actualidad/91-pni-ganadores-2021

[12] Disruptive technology is understood as a solution that displaces an established product or service and its industry with a ground-breaking product. Social impact technologies are understood as ventures that generate positive social or environmental impact with an expected financial return.



Section II: Examples of emerging technologies

The first identified winning emerging technology is called Kingo. In off-grid villages, where access to energy is a challenge, Kingo offers decentralized solar energy services to families and businesses under a prepaid modality, contributing to SDG 7. Kingo has installed 53,578 units in 4,583 communities.[13] These products contain anti-theft technology that blocks their use and disables their internal and external components in the case of an attempt to steal Kingo's equipment or solar power. Its Internet of Things (IoT) technology enables relevant data to be obtained on the operation of the equipment in real time and remotely, thus obtaining information for business intelligence and preventive maintenance.

Kingo optimized the efficiency of its operating model by developing and implementing new technologies in its solar energy solutions. In recent years, the capacity for larger individual hybrid solar systems such as DC+AC,100W of power and above, have been developed. This response also provides more powerful solutions to serve new markets in its B2B and B2G business models, and the ability to design comprehensive and appropriate solutions to the energy consumption needs of each project without incurring cost overruns that affect the beneficiaries. Kingo is expected to continue to explore emerging technologies embodied in new types of solar panels and lithium batteries.

*Source:*https://www.latinspots.com/sp/noticia/ogilvy-mather-colombia-y-guatemala-destacan-el-trabajo-de-kingo-energy-/46980

The second identified winning emerging technology is called Bitmec.[14] Bitmec has developed an IoT telemedicine booth that facilitates access to high-quality primary care in underserved areas in Guatemala, contributing to SDG 3. The booth occupies a small footprint (1.20 m2), which allows it to be installed in almost any indoor or outdoor environment, like pharmacies, community centers, etc. The booth is wirelessly operated by a Point of Sale (POS) Terminal that unlocks the booth at the point of care. While sitting inside, the patient interacts with a set of speakers, a high-resolution camera, a 20-inch screen, and medical-grade sensors. Amongst the measurements collected by sensors are heart rate, blood oxygenation, height, weight, blood pressure and body temperature. On the

[13] For more information see their website: https://www.kingoenergy.com/

[14] For more information, see: https://www.bitmec.com/

other hand, remote primary care professionals (nurses and doctors) can guide the patient through the process, view these measurements in real time, and document the encounter through a proprietary telemedicine platform that has an incorporated digital medical record module. Once the consultation is concluded, prescriptions, lab orders and references can be printed through the POS terminal. Follow-up visits can also be scheduled if needed.

As for security measures, the booth has automatic disinfection and refrigeration systems and a security lock. To ensure stable internet connectivity, the booth has a built-in SIM card which only requires access to a 110V power outlet. Solar power integration will soon be added.

Finally, a Network Operations Center at Bitmec headquarters keeps track of various parameters like internet speed, consumable level and sensor conditions in real time to maximize booth uptime. The combination of hardware and software offered by Bitmec´s telemedicine booth allows patients to conveniently and reliably receive comprehensive remote care with a near face-to-face experience that is applicable to almost any setting, particularly for underserved populations.

Source: https://www.bitmec.com/

Both technologies are positioned at TRL 9 and 8 respectively. Because they are social in nature, they have a particular user profile. Designing for users in rural areas of developing countries can be a great challenge, since user profiles often vary from one region to another, so physical, cultural, ethnic and anthropological aspects must be taken into account. Both projects stated that they have empirically discovered improvements to the interface, which refers to the bilateral interaction that exists between the user and the technology, so that the user feels more comfortable and attracted to the proposed solution and, the technology works as expected in interaction with the user.

Kingo has relaunched different versions of its products based on learnings like theft and ease of use, while Bitmec has made iterations of its cabin based on field tests in which they notice behaviors from their users that signal a need for change. Both adopt user-centered practices such as design thinking taking into account social aspects.

Conclusions

The 2021 National Innovation Prize (PNI) in Guatemala highlighted the challenges for evaluating the cultural suitability of startups. Ensuring suitability from the design phase is important to avoid obstacles being identified during the implementation of the product.

Although TRL can help identify startups with potential for social impact, the TRL mechanism excludes intrinsic characteristics of emerging technologies for social contexts. Ideally, methodologies such as Creative Capacity Building and co-design of solutions such as those proposed by the MIT D-Lab should be employed. Even so, in the Guatemalan context this might be non-viable due to various limitations to apply these methodologies. Instead, SENACYT has designed a checklist to apply in each TRL evaluation. The checklist, detailed in Annex 1, intends to be a guide on product development for social impact startups and suitable to use in developing countries.

Based on the results of the 2021 National Innovation Prize, for years to come, we expect the following: National judges will no longer have the faculty to disregard TRL requirements, according to presented data it is expected that higher TRL levels are related with the finalists and winning proposals, SENACYT could consider increasing the TRL minimum to a TRL7 requirement for applications in 2022.

A new strategic ally will be joining the PNI22, the support from the Pan American Health Organization (OPS) will be acquired for the winning project of the Health Innovation category.

References

1. J. Mankins, Technology readiness levels, A White Paper, NASA, Washington, DC, 1995.

2. Kantis, H., & Angelelli, P. (2020). Emprendimientos de Base Científico-Tecnológica en américa latina: Importancia, Desafíos y Recomendaciones para el Futuro. https://doi.org/10.18235/0002156

3. Martínez-Plumed, F., Gómez, E., & Hernández-Orallo, J. (2021). Futures of artificial intelligence through Technology Readiness Levels. Telematics and

Informatics, 58, 101525. https://doi.org/10.1016/j.tele.2020.101525

4. Olechowski, A., Eppinger, S. D., & Joglekar, N. (2015). Technology readiness levels at 40: A study of state-of-the-art use, challenges, and opportunities. 2015 Portland International Conference on Management of Engineering and Technology (PICMET). https://doi.org/10.1109/picmet.2015.7273196

5. Aase, G., Roth, E., & Swaminathan, S. (2018, April 23). Taking the measure of Innovation. McKinsey & Company. Retrieved April 8, 2022, from https://www.mckinsey.com/business-functions/strategy-and-corporate-finance/our-insights/taking-the-measure-of-innovation

6. British Standards Institution - Project. (n.d.). Retrieved April 8, 2022, from https://standardsdevelopment.bsigroup.com/projects/9020-03986

7. Ministry of Culture, Politica-nacional-para-la-transversalizacion-del-enfoque-intercultural-final.pdf (n.d.).

8. Ministry of Culture, ENFOQUE INTERCULTURAL PARA LA GESTIÓN PÚBLICA: HERRAMIENTAS CONCEPTUALES (2013). Lima.

9. Carballo Villagra, P. (2013). Evaluación de la pertinencia cultural de los servicios y productos de la UNED dirigidos a estudiantes indígenas. Retrieved April 2022, from https://www.uned.ac.cr/viplan/images/ciei/INVESTIGACIONES_2016/Investigaciones_actualizadas_11_mayo_2017/INFORME_FINAL_Pertinencia_cultural_de_los_servicios_universitarios_CIEI-012-016.pdf

10. Ministry of education , & Guorón Ajquijay, P., Guía Práctica para la Pertinencia Cultural y Lingüística (2019).

11. U.S Government Accountability Office, Persons, T. M., & Sullivan, M. J., GAO-16-410G, Technology Readiness Assessment Guide: Best Practices for Evaluating the Readiness of Technology for Use in Acquisition Programs and Projects (2016).

12. Hoffecker, E. (2021). Understanding inclusive innovation processes in agricultural systems: A middle-range conceptual model. World Development, 140, 105382. https://doi.org/10.1016/j.worlddev.2020.105382

13. Héder, M. (2017). From NASA to EU: the evolution of the TRL scale in Public Sector Innovation. The Innovation Journal: The Public Sector Innovation Journal, 2017, , Volume 22(2). Retrieved from https://www.innovation.cc/discussion-papers/2017_22_2_3_heder_nasa-to-eu-trl-scale.pdf.

14. Hoffmann, D., Freese, A., Hernandez, C., Moscherosch, M., Dietzel, L., Cruz, T., & Capili, J. (n.d.). Aguajira - The Practice of Co-design for Technology Transfer.

15. Martínez-Plumed, F., Gómez, E., & Hernández-Orallo, J. (2021, May). Futures of artificial intelligence through technology readiness levels. Retrieved April 8, 2022, from https://www.sciencedirect.com/science/article/pii/S0736585320301842

16. Mankins, J. C. (2009). Technology readiness assessments: A retrospective. Acta Astronautica, 65(9-10), 1216–1223. https://doi.org/10.1016/j.actaastro.2009.03.058

Annex 1: Checklist for social impact startups

Checklist for social impact startups	
About the context for which I design	
1.	I know the sociopolitical context of the place
2.	I know the sociopolitical context of the place
3.	I know the geographical limitations of the place
4.	I know the idiosyncrasy of the place
5.	I know the average number of members per family in the place

6.	I know the language that is spoken
7.	Has the approval of the community leader
8.	I know the cultures I design for
9.	It is a product that adapts to different cultures
10.	What influence does my competition have on users?
11.	I know which actors can be negative leaders
12.	I know who could be a possible ally
About the user	
13.	I consider that my user may be illiterate
14.	I know the economic limitations of my user
15.	I know the age of my user
16.	I know the autochthonous values. Knowledge and traditional knowledge are valued and taken in account (collective memory of the group)
17.	I know what can make my user feel discriminated
18.	I know how familiarized my user is to technological devices
19.	The user is certain that their privacy is not violated
20.	I know the anthropomorphic dimensions of my user
21.	The aesthetics of my product was designed around the tastes of my user
About the interface	
22.	My user has been a part of the design process
23.	The community has a been part of the design process
24.	My user has been a part of the validation process
25.	The community has been a part of the validation process
26.	My user understands the use of the product and the problem it solves
27.	Information is presented that ensures that my project and team is known by the user
28.	My user understands the benefit of using the product
29.	My user understands the differentiating value of my product
30.	My user shows interest in using the product
31.	The use of technology makes my user uncomfortable
32.	My user knows how to use the product

33.	The usage time of the product is reasonable
34.	I make the use of symbols and colors that simplify use
35.	The product is available when the user needs it
36.	User experience is recommended

It is highly suggested to take in account other aspects[15]

Operations	
37.	Customer acquisition cost (CAC)
38.	Customer lifetime value (CLF)
39.	Churn

[15] As Martínez-Plumed, Gomez and Hernández-Orallo mention in their "Futures of artificial intelligence through technology readiness levels" paper, other factors affecting pace and adoption of a technology as financial costs of deploying solutions, labor market dynamics, economic benefits, regulatory delays, **social acceptance** etc. should be taken in account.