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Technology Assessment Framework: Methodology Note

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Executive Summary

Technology plays a crucial role in realising the sustainable development goals of India. In this context, the government has introduced various policies to support indigenous development of technology, and strengthen collaborations with foreign entities for technology sourcing and development. However, technology implementation may have some negative impact on the environment during various phases of development.

Therefore, to achieve its development goals, India needs to identify technologies that are sustainable with a reduced impact on the environment. In this context, CSTEP has developed a technology assessment framework (TAF) to assess the applications and sustainability of various technologies.

This framework proposes to use six performance indicators—technical, economic, resource availability, policy and regulatory, social, and environmental impact to evaluate the performance of any technology. In addition, a risk assessment will be performed to analyse the risks associated with a particular technology. In order to facilitate the performance assessment of technology, these criteria are further simplified into suitable metrics and assigned with measurable units.

It can be a useful tool in making informed decisions pertaining to the applications and feasibility of any technology of interest.

Introduction

Science and technology have played a vital role in the economic and social development of India. Government policies, such as the Scientific Policy Resolution, 1958; the Technology Policy Statement, 1983; the Science and Technology Policy 2003; and the Science, Technology and Innovation Policy 2013 have been instrumental in supporting the indigenous development of technology, technology sourcing, and collaboration with foreign entities for development (GoI, 2020). In 2020, India ranked 48 in the Global Innovation Index (GII & WIPO, 2020). The Science, Technology and Innovation Policy 2013 underlines the indigenous development of technology as one of its core objectives. It aspires for an India that can become a global leader in science, technology, and innovation.

Science and technology in India have progressed significantly in various sectors such as information technology, aerospace, biotechnology, nuclear science, automobile engineering, chemical engineering, electronics, computer science, etc. In the past few years, there has been a push for digital innovation, and the use of artificial intelligence (AI) in agriculture, healthcare, and manufacturing technologies. Moreover, investments in research and development in these sectors are projected to increase in the coming years.

Technology plays a crucial role in economic development, but comes with a price. Kuznets curve (Figure 1) explains this effect in a better way.

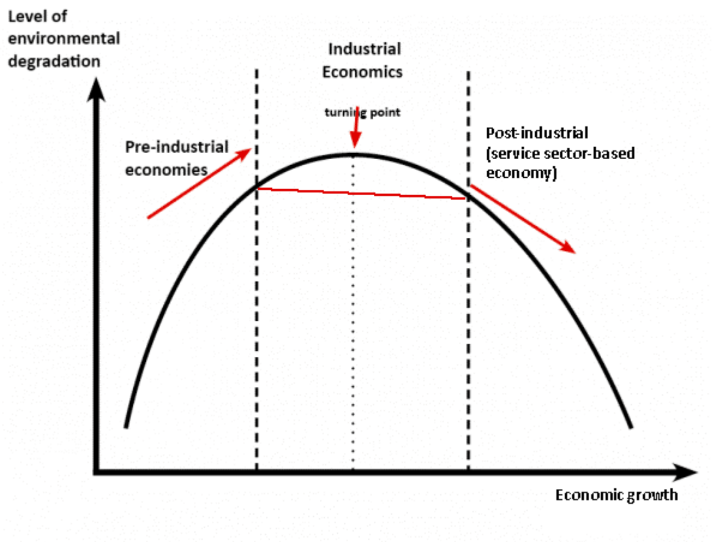

Figure 1: Kuznets curve for economic development

As seen, Kuznets curve explains the three phases of industrial development (pre-industrial, the industrial age, and post-industrial). As a consequence, the degradation levels of the environment also vary, following the same trend. The developed countries have gone through this transition at the cost of the environment. In order to achieve its development goals, India too will tread the same path unless environment-friendly technologies are chosen. Therefore, it is crucial to identify technologies that are sustainable and cause less harm to the environment. This ensures that we avoid the peak of environmental degradation during this process of development (Katsoulakos, Misthos, Doulos, & Kotsios, 2016).

The current study aims to develop a technology assessment framework (TAF) to examine the usefulness and sustainability of various technologies (existing and emerging). This framework will provide crucial insights to relevant stakeholders and help them in making informed decisions pertaining to investments in any technology.

Methodology

Indicators to Assess the TAF

In this methodology, we propose the usage of key performance indicators to assess the performance of any technology. Typically, for such technology assessments, depending upon the requirements, around four to six key indicators are used (IEA, 2016) (Li-bo & Tao, 2015). Figure 2 provides a schematic representation of various evaluation indicators. These indicators are explained in detail below.

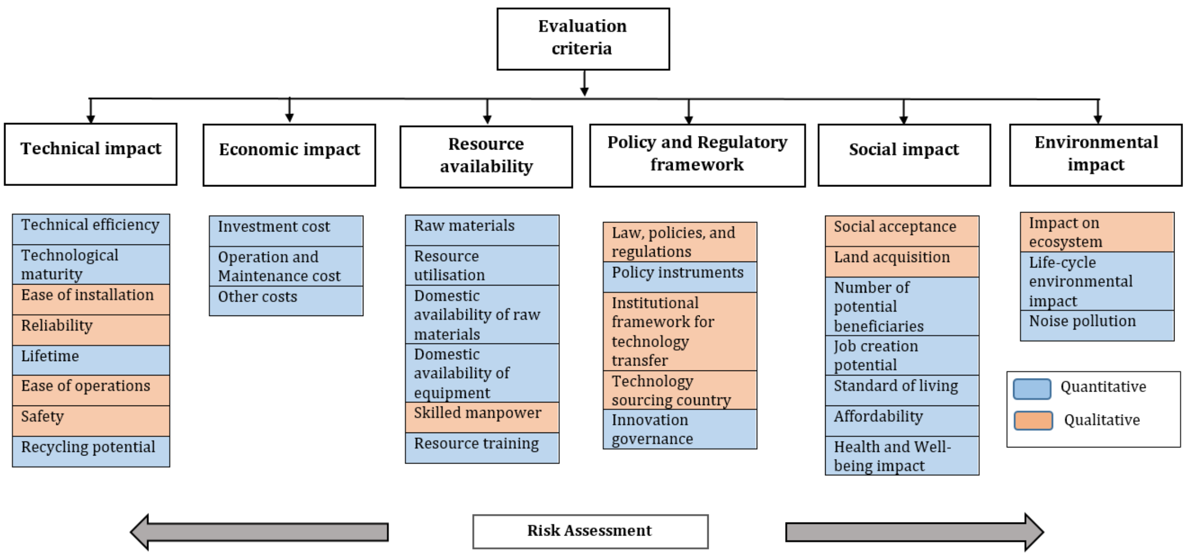

Figure 2: Evaluation indicators for technology assessment

Technical Impact: This indicator evaluates the performance of any technology in terms of various technical parameters—technical efficiency, technological maturity, ease of installations, reliability, lifetime, etc. (Maddox, Boozer, & Forte, 2014) (Hou, Lu, & Han, 2008).

Economic Impact: Evaluates the economic factors related to a specific technology, such as investment costs and operational costs on the implementation of any technology (Vera Solutions, 2019).

Resource Availability: Estimates and analyses the resource requirements (raw materials, equipment, manpower, etc.) during the various stages of technology development and use (manufacturing and operation) (Daim & Intarode, 2009).

Policy and Regulatory Framework: Examines the existing policy and regulatory frameworks and gaps, and assesses the impact of any technology adoption and deployment (IRENA, 2014).

Social Impact: Assesses the impact of technology on society/the community, which includes social awareness and societal benefits (job creation, affordability, health impacts, etc.). It examines the pros and cons of technology deployment on the community. (Siksnelyte-Butkiene , Zavadskas, & Streimikiene , 2020).

Environmental Impact: Evaluates the impact of technology on the environment, with a focus on lifecycle emissions, associated degradation impacts on land, water, air, etc. (Ghosh & Bhowmick, 2014).

Risk Assessment: This criterion analyses the level of risks associated with a given technology. This includes technology risk, financial risk, risk with resource availability/sourcing, etc. (Siksnelyte-Butkiene , Zavadskas, & Streimikiene , 2020). As shown in Figure 1, risk evaluation is done across all the criteria, as applicable.

Further, each of the above-mentioned criteria is decomposed into suitable metrics and assigned with appropriate measurable units. The objective is to break down the theoretical and complex criteria into simple and quantifiable criteria. The table below provides the details of decomposition.

Technical Impact

Parameters	Metric	Units
Technical Efficiency: It represents the performance efficiency of a technology (conversion efficiency, and instantaneous efficiency, capacity utilisation/plant load factor, availability factor[1]).	Ratio of output to total input	Percentage (%)
Technological Maturity: Assessment of readiness levels and maturity of a technology at the global level	Technology readiness level	TRL 1–9[2]
Reliability: To evaluate the ability of a technology to perform in a given period of time without any failure. It is measured by frequency or impact of failures.	Mean time between failures/Mean time between repairs	Time (hours) [3]
Installation: How easily the components of the technology can be installed	Ease of set up[4]	1–3 (1=very easy, 2=easy, 3= difficult)
	Average installation time	Time (days)
	Installation efforts[5]	Person hours
Operation: Level of simplicity/sophistication of operations w.r.t any technology	Resource requirement	Skilled, semi-skilled, unskilled
	Failures/fault rate	Hours per month/year
	Throughput rate	Total units produced/time
	Maintenance cost	INR/unit
	Safety	Number of accidents/incidents per year or throughout the lifespan of technology
Recycling Potential: Potential for recycling and reuse	Recycling technology availability	Available or not available
	Material recovery rate[6]	Percentage (%)
	Resource requirement	Land (acres), Energy (Wh/kWh), Water (Litre/Kilo litre), manpower (number of skilled, semi-skilled, and unskilled)
	Reusability potential	Percentage (%)[7]

[1] Availability for operations.
[2] 1-Basic Research; 2-Technology concept formulation; 3-Experimental proof of concept; 4-Validation in lab; 5-Tech validated in relevant environment; 6-Tech demonstration; 7-System prototype demonstration; 8-System complete and qualified; 9-Actual system proven in operational environment.
[3] Lesser the meantime, more reliable is the technology.
[4] Levels of easiness.
[5] Number of persons and their time efforts required.
[6] Ratio of weight of materials sent for processing/weight of products recycled.
[7] Quantity of recycled/recovered material that can be reused.

Economic Impact

Parameters	Metric	Units
Investment Cost (Capital expenditure): Investment expenditure required to acquire a technology (equipment cost, service charge, duties, etc.)	Cost of land	INR/acre
	Cost of building	INR/sq. ft.
	Cost of plant and machinery	INR/unit
Operation and Maintenance Cost: Costs associated with operations and maintenance of any technology/project (raw materials, fuel, labour, etc.)	Cost of raw materials	INR/unit
	Labour cost	INR/hour or INR/month or INR/year
	Energy cost	INR/unit
	O&M cost	INR/unit
	S&G[8] cost	INR/unit
Evaluation Metrics		
Return on Investment: Annual return as a percentage of the capital cost	Investment returns/profitability rate	Percentage (%)[9]
Internal Rate of Return: Rate of return that the investment is expected to yield	Investment returns/profitability rate	Percentage (%)[10]
Net Present Value: Difference between the present value of cost and benefit. It is used to determine the return on investment in any technology/project.	Investment returns/profitability rate	Percentage (%) – positive, negative, zero[11]

Resource Availability

Parameters	Metric	Units
Raw Materials: Nature of raw materials (processed, unprocessed; critical, or easily available) required to build any technology or project. It includes materials for both upstream and downstream supply chain levels.	Physical availability (reserves – processed or unprocessed)	Scarce or abundant in earth's crust/quantity (Mt)
	Geographical concentration[12]	Percentage (%) – distribution across various geographical regions
	Technology for extraction/processing,	Available or not available
	Price/processing cost	INR/unit
	Applications in other sectors	Yes/No/with customisation
	Potential substitutes	Available (to be specified), not available, customisation required

[8] Sales and general expenses.
[9] Calculated as annual cash outflow/initial investment.
[10] Rate at which the NPV of a project = 0. It signifies a no profit or loss state for the project/investment.
[11] Positive – profitability; negative – loss; zero – no profit, no loss state for the project/investment.
[12] Extent to which the reserve base and mine production are concentrated in one or a few countries.

Resource Utilisation (land, water, energy): Assess the quantity of resource consumption – land, water, and energy for any particular technology. It could be during operations of a manufacturing facility or power generating plant.	Land/footprint	Acres/hectares
	Water	Litres (L) or Kilo litres (KL)
	Energy input	Watt-hour per day, or kWh per month, Joules
Domestic Availability of Equipment: Assess the domestic availability of technology or equipment required to build a manufacturing plant/power plant	Availability	Available or not available (if available, provide a list of equipment)
	Performance[13] and quality[14]	Percentage (%)
	Domestic share	Percentage (%) addition in total value chain
Skilled Manpower: Level of skills required to operate the technology	Skill level	Skilled, semi-skilled, unskilled
Resource Training: Need to train the workforce with crucial skills, to be able to operate the technology	Training cost	INR/employee

Policy and Regulatory Framework

Parameters	Metric	Units
Policies, Laws, and Regulations: A policy outlines what a country aims to achieve and the methods and principles it will use to achieve them. Law and regulations set out standards, procedures, and principles with legal implications.	Policy targets or regulations for monitoring and control	National-/State-level, short-term/long-term, no specific targets
Policy Instruments: Includes policy support, regulations, and standards to promote any technology. Following are the details: • **Command and Control (Regulation and standards):** Sets the standards and legal boundaries for any technology • **Quantity Instruments:** A market-based mechanism to target absolute quantity for any particular technology/deployment of technology, and let market decide the price	Quality control, standards, guidelines, prohibition, quota, ban, etc. (Direct support,[15] indirect support[16]) Environmental taxes and charges	Exist (Yes/No) If yes, mention adequacy on a scale of 1–3 INR/unit

[13] Peak performance of the system.
[14] Greater the quality score, lesser will be the defects.
[15] Direct support – Supporting a particular technology by removing economic barriers, to increase the demand.
[16] Indirect support – Supporting a particular technology by putting restrictions on other.

• **Price Instruments:** A market-based mechanism that creates a favourable price regime for a particular technology, and let market determine quantity	Fiscal incentives (Capital subsidy, investment tax credits, production tax credits, production-linked incentives/feed-in-tariff—preferential tax, purchase obligation, power purchase agreement, etc.)	INR/unit, % of capex subsidy, performance incentives (PLI scheme)
Innovation Governance: Government's intervention in supporting research & development and innovation for new technologies	Support for technological innovation	Budget allocated (Yes/No) – INR
	R&D support	
	Technology upgradation funds	
Technology Sourcing Country: Assess the ease in technology transfer/sourcing from global tech providers	Geographical distance[17]	Physical distance (in kilometre)
	Technical excellence[18]	1–3 (1=very good, 2= good, 3= bad)
	Regulatory issues[19]	1–3 (1=simple, 2=complex,3= highly complex)
	Trade restrictions/barriers[20]	Exist or not; if yes:1–3 (1=high level, 2= moderate level, 3= low level)
	Cost[21]	Unit cost
	Geopolitical issues	Geopolitical risk index
	Intellectual property rights (IPR) protection	Strong/Weak[22]
	Engineering risks[23]	1–3 (1=high level, 2= moderate level, 3= low level)

17 Farther the partners/sourcing countries, more difficult would be the process.
18 If the partner is known for technical excellence, the risk of failure/breakdown would be lower.
19 Countries follow different standards, laws, regulations, and business practices.
20 Embargo, exchange control, import quota, protective tariffs etc.
21 Cost of sourcing (planning, transportation, and implementation costs).
22 Strong IP protection can make access to technology more problematic and vice versa.
23 Technical risks (material specifications, design, and complexity of the system) should be low.

Social Impact

Parameters	Metric	Units
Social Acceptance: Level of awareness among society/Acceptance of any technology or project by local stakeholders	Awareness[24],	Yes/No/Partially
	Evaluation of costs, risks, and benefits	Yes/No/Partially
	Transparency in decision making[25]	Yes/No/Partially
	Local context[26]/direct local improvements	Yes/No/Partially
	Public trust	Yes/No/Partially
Land Acquisition and Physical Displacement of a Community: Aspects such as conversion of agricultural land to build a power plant or physical displacement of habitation due to project construction	Conversion of agricultural land	Yes/No/Partially
	Physical displacement of local habitat	Yes/No/Partially
	Loss of means of livelihood	Yes/No/Partially
	Disruption of economic activities	Yes/No/Partially
	Compensation	Early/late/adequate/inadequate/no compensation
Number of Potential Beneficiaries: Number of people/members benefitting from the technology/project	Direct and indirect beneficiaries[27]	Number of persons
Job creation potential: Includes quantity and quality of jobs created	Number of direct and indirect jobs, induced jobs,[28] full-time, part-time jobs,	Number of jobs
	Job security and job satisfaction	Job security index[29] and Job satisfaction scale[30]
Standard of Living: Potential to improve the standard of living of citizens by providing access to essential services	Income levels	Per capita income (INR)
	Employment opportunities	Percentage/Number of employees
	Wealth levels	Ownership of assets (INR)
	Number of paid vacations	Number of days[31]
	Life expectancy	Number of years
	Cost of goods & services	Per capita expenditure (INR)
Affordability	Cost of goods & services	Per capita expenditure (INR)
Health Improvement: Ability to minimise negative health impacts	Quality of air & water	Air quality index (AQI) and Total dissolved solvents (TDS)
	Waste management	Mechanism exists or not

[24] People's awareness about the technology and its impacts.
[25] Influences how public will assess a technology/project. Involvement of public in procedures and decision making.
[26] People's fear/perception about the negative impacts of the technology need to be addressed. Deployment benefits, such as financial compensation, direct local improvements, etc. can be shared with the local community.
[27] Direct beneficiary-closely linked to the technology/project whereas indirect are secondary beneficiaries (not directly linked to the project).
[28] Generated by employees (by local spending on goods and services).
[29] Measuring an individual's cognitive appraisal of the future or his/her job w.r.t. the perceived level of stability and continuance of this job. Higher the index, higher would be the security level.
[30] Measuring an employee's satisfaction with his current job.
[31] Percentage of population employed in the organised sector.

Environmental Impact

Parameters	Metric	Units
Impact on Ecosystem: Impact of technology on the natural habitat of various living beings	Impact on biodiversity[32]	1–3 (1=High, 2=Medium, 3=Low)
	Local air quality	Air quality index (0–500)
	Aquatic/Marine impact[33]	1–3 (1=High, 2=Medium, 3=Low)
	Impact on land[34]	1–3 (1=High, 2=Medium, 3=Low)
	Resource depletion	1–3 (1=High, 2=Medium, 3=Low)
Life Cycle Environmental Impact: Quantify the impact of local pollutants and greenhouse gas emissions/Assess the level of GHG emissions throughout the lifespan of a technology (raw material procurement to end of life)	NO_x & SO_x emissions	Parts per million
	GHG emissions (scope 1, scope 2, scope 3)[35]	kg CO_2 e per unit
Noise pollution: Assess the level of noise pollution	Sound levels	Decibels[36]

[32] Impact on living beings (flora and fauna).
[33] Release of industrial waste into local water bodies.
[34] Deforestation, landslides, floods, land pollution, etc.
[35] Scope 1: Direct emissions from any technology/source; Scope 2: Indirect emissions; Scope 3: All indirect emissions from various other activities at the source.
[36] A noise level above 65 dB is considered as noise pollution.

Risk Assessment

Parameters	Metric	Units
Technology Risk: Assess the potential for losses due to technology failure	Supply chain risk Change in technologies/technology upgradation/technology obsolescence Competing emerging technologies (cost competitiveness, efficiency, etc.) Policy and regulatory changes, etc.	1–3 (1=High, 2=Medium, 3=Low)
Financial Risk: Involves various financial risks[37] associated with any technology or project	Investment Operational costs Payback period, return on investment Project financing Regulatory/legislative changes Market risk[38] Political risk and uncertainty	1–3 (1=High, 2=Medium, 3=Low)
Resource Risk: Assess the potential risk associated with key resource availability	Raw material availability Dependency on imports Global supply chain disruptions/international trade restrictions Land and water availability Labour requirement Raw material price/price volatility Policy and regulatory framework Environmental law and regulations	1–3 (1=High, 2=Medium, 3=Low)
Policy and Regulatory Framework: Assess the risk of change in policy, laws, and regulations on technology/project	Policy targets Change in policy, regulations, and laws Change in price and quantity of instruments	1–3 (1=High, 2=Medium, 3=Low)
Social Risk: Potential loss to the society on adoption of any technology/project/service	Long-term impact on a community/habitat Impact on environment Impact on employment Impact on quality of life, affordability, health impacts	1–3 (1=High, 2=Medium, 3=Low)
Environmental Risk: Potential harm to the environment caused by any technology/project	Long-term impact on the ecosystem, GHG emission potential, noise pollution, etc.	1–3 (1=High, 2=Medium, 3=Low)

[37] Possibility of losing money/investment in any technology/project

[38] Fluctuation in prices of market instruments (foreign exchange, interest rate, etc.)

Applications of the TAF

This framework can be used to assess both emerging and mature technologies in various sectors such as energy, water, healthcare, digital transformation, biotechnology, etc. It can be applied to examine the performance of any individual technology as well as to compare multiple technologies in similar or different domains. For example—assessment of solar technologies or a comparative analysis for all renewable technologies.

Beneficiaries of the TAF

TAF can benefit the industry, policymakers, academicians, and others in making informed short-/long-term decisions pertaining to the applications and feasibility of any technology of interest. It can also be used to identify blue-sky technologies, emerging, and disruptive technologies. A proper assessment would assist in identifying investment opportunities for entrepreneurs, researchers, and decision-makers.

Outcomes of the TAF

The following outcomes are expected from this analysis:

1) Selection of suitable technology for implementation
2) Direction for policymakers:
    a. To provide key insights into optimal utilisation of resources and capital
    b. To facilitate strategic planning for resources and technology
    c. Policymaking
3) Identification of the scope of improvement in existing technologies
4) Analysis of technological friendliness to society/environment
5) R&D directions and priorities for new emerging/existing technologies

Future Plans

The present paper has focused on the development of a framework for technology assessment. Future work or the subsequent parts of the working series on TAF will cover the below-mentioned aspects:

- Methodology for TAF implementation
    - A stepwise approach to TAF functioning will be discussed in detail
- Assessment for Solar Photovoltaic technologies
    - The TAF will be used to assess the performance of various solar PV technologies
- Identification of implementation challenges w.r.t the TAF
- The way forward and recommendations.

References

Hou, J., Lu, Q., & Han, Y. (2008). A Strategic Framework for Technology Evaluation. *International Conference on Information Management, Innovation Management and Industrial Engineering.* Taipei, Taiwan: IEEE.

Daim, T. U., & Intarode, N. (2009). A framework for technology assessment: Case of a Thai building material manufacturer. *Energy for Sustainable Development*, 280-286.

Ghosh, S., & Bhowmick, B. (2014). Technological uncertainty: exploring factors in Indian start-ups. *IEEE Global Humanitarian Technology Conference (GHTC 2014).* San Jose, CA, USA: IEEE.

GII & WIPO. (2020). *India ranks 48th among the 131 economies featured in the GII 2020.* Retrieved from https://www.wipo.int/edocs/pubdocs/en/wipo_pub_gii_2020/in.pdf

GoI. (2020, December 4). *Science, Technology, and Innovation Policy.* Retrieved from https://dst.gov.in/sites/default/files/STIP_Doc_1.4_Dec2020.pdf

IEA. (2016, June). *The Clean Energy Technology Assessment Methodology.* Retrieved from https://www.iea.org/reports/the-clean-energy-technology-assessment-methodology

IRENA. (2014). *Evaluating renewable energy Policy: A review of criteria and indicators for assessment.* IRENA. Retrieved from https://www.imperial.ac.uk/media/imperial-college/research-centres-and-groups/icept/Evaluating_RE_Policy.pdf

Katsoulakos, N. M., Misthos, L.-M., Doulos, I., & Kotsios, V. (2016). Environment and Development. *Environment and Development*, 499-569.

Li-bo, Z., & Tao, Y. (2015). The Evaluation and Selection of Renewable Energy Technologies in China. *Elsevier*, 2554-2557.

Maddox, E. N., Boozer, R. W., & Forte, M. (2014). The technological impact analysis: a research-based exercise to heighten learners' technological sensitivity. *Developments in Business Simulation and Experiential Learning*.

Siksnelyte-Butkiene , I., Zavadskas, E. K., & Streimikiene , D. (2020). Multi-Criteria Decision-Making (MCDM) for the Assessment of Renewable Energy Technologies in a Household: A Review. *Energies*.

Vera Solutions. (2019, OCtober 17). *10 Criteria To Evaluate When Choosing A New Technology*. Retrieved from https://www.verasolutions.org/10-criteria-to-evaluate-when-choosing-a-new-technology/?locale=en

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