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# Technology Assessment Framework 2.0: Methodology Note

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Center for Study of Science, Technology and Policy
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# Acknowledgements

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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 the indigenous development of technology and strengthen collaborations with foreign entities for technology sourcing and development. Time averaging of technology impacts has shown improvements in livelihoods, comfort, economy, and health. However, the advent of technology does come with some negative impacts.

Therefore, to achieve its development goals, India needs to identify technologies and products that are sustainable, bring positive socio-economic growth, and adhere to the principles of circularity. Selection considerations must weigh the impact of technologies on the environment and available natural resources. Therefore, to aid the assessment and selection of various technologies, CSTEP has developed the technology assessment framework (TAF) 2.0, which consists of both qualitative and quantitative components.

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

The TAF 2.0 can be useful for making informed decisions pertaining to the adoption and feasibility of technologies 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.

Over the past few decades, India has witnessed significant progress in science and technology across various sectors, such as information technology, aerospace, biotechnology, space exploration, nuclear science, automobile engineering, chemical engineering, electronics, and computer science. The recent years have witnessed a push in digital innovation and the use of artificial intelligence (AI) in agriculture, healthcare, and manufacturing, leading to the Fourth Industrial Revolution or Industry 4.0. Furthermore, investments in research and development in these sectors are expected to increase in the coming years.

However, India continues to depend on some imported products and technologies, e.g. photovoltaics (PVs). In this context, the application of a technology assessment framework (TAF) would guide the selection of appropriate technology and innovation strategy during technology development and adoption.

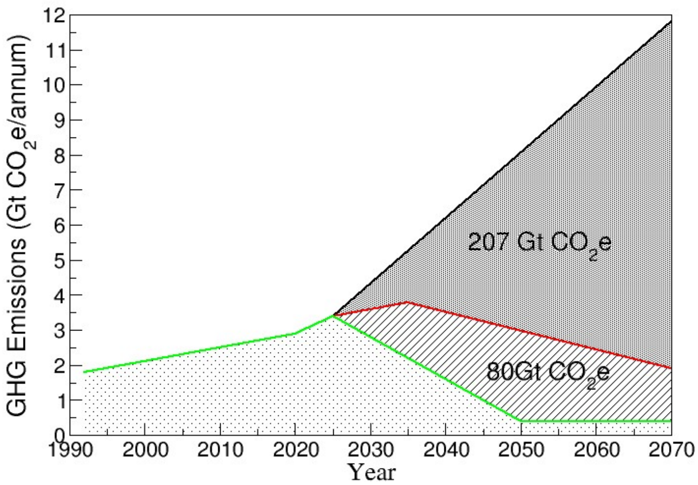


*Figure 1: Greenhouse gas emissions in India (Rajat Gupta, 2022).*

Moreover, India's contribution to greenhouse gases (GHGs) is increasing, with the projected emissions being approximately 207 Gt $CO_2$e by 2070 (Rajat Gupta, 2022). Therefore, the selection and adoption of suitable technology to reduce GHG emissions become imperative.

Furthermore, technology plays a crucial role in economic development, but the application of technology comes with a price. Kuznets curve (Figure 2) explains this effect in a better way.

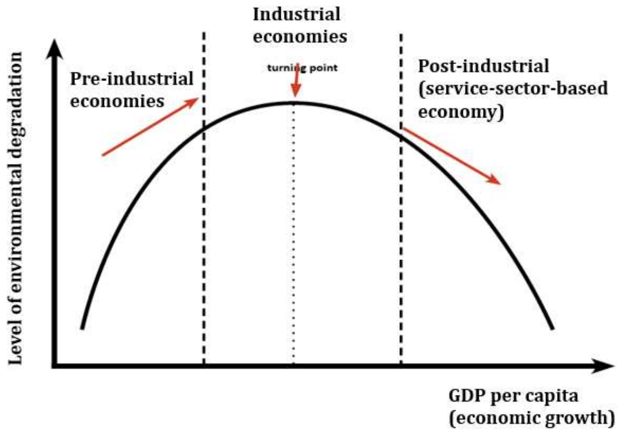


*Figure 2: Environmental Kuznets curve for economic development.*

As seen, the Kuznets curve explains the three phases of industrial development (the pre-industrial phase, industrial age, and post-industrial phase). Environmental degradation worsens with economic growth; however, after the peak growth, the degradation levels decrease. The developed countries have gone through this transition at the cost of the environment. To achieve its development goals, India too will tread the same path unless environment-friendly technologies are chosen. Therefore, it is crucial to identify sustainable technologies, thereby causing less harm to the environment. This will avoid the peak of environmental degradation during economic development (Katsoulakos, Misthos, Doulos, & Kotsios, 2016).

Technology assessment is a type of policy research wherein the short- and long-term consequences of technology adoption, e.g. environmental, social, ethical, legal, and economic consequences, are examined (Banta, 2009). The term ‘technology assessment’ was first used in the 1960s by the United States, with the holistic approach for technology assessment focusing on issues such as environmental pollution, ethics in genetic screening, and implications of supersonic transport.

A TAF is needed for making decisions, prioritising resources for technology development, and evaluating the sustainability of technologies (Figure 3). TAF will provide a systematic and structured approach for evaluating new technologies and their potential impacts. This information can be used by decision-makers, such as government bodies, companies, and investors, to make informed decisions about the adoption and deployment of new technologies.

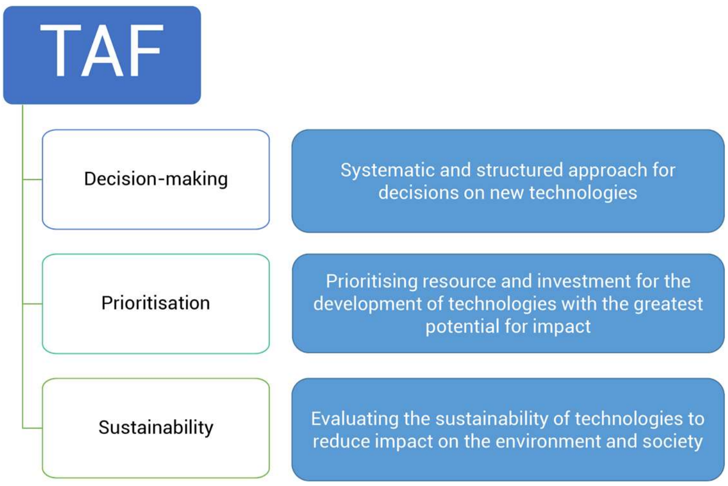


*Figure 3: Infographic showing the importance of TAF.*

Moreover, with the rapid pace of technological change, it can be challenging to determine the most promising technologies that deserve investments. TAF can be useful in prioritising and focusing resources on the technologies with the greatest potential for impact.

Finally, emerging technologies often have unknown or unintended consequences; therefore, it is important to consider their sustainability, including their impact on the environment and society. TAF can help evaluate the long-term sustainability of new technologies and ensure that they are developed and deployed responsibly and sustainably.

### Brief History

Technology assessment was first institutionalised at the Office of Technology Assessment (OTA), the United States in 1972 (Technology Assessment Design Handbook, 2021). However, OTA was defunded in 1995. In 2019, under the aegis of the Government Accountability Office (GAO), the Science, Technology Assessment, and Analytics team was established to provide guidance on technology assessments, strategies for research programmes and policies, and best practices guides for complex technology projects. In a recent study by GAO, AI tools used in healthcare were assessed to provide policy options for maximising benefits and mitigating challenges surrounding the use of such tools, thereby improving patient care (Karen L. Howard, November 30, 2020.). Another study performed a technology assessment for 5G wireless to provide policy options for achieving the expected performance and application of 5G wireless in the United States (Hai Tran, November 24, 2020). In the past, the Ministry of Electronics and Information Technology (MeitY) and National Institute of Epidemiology (NIE) have introduced TAF in India in their respective sectors. While NIE has applied the framework in assessing health technologies, such as those related to medicines and devices, MeitY has done the same to focus on an overall assessment, with 'preference for manual versus computerised systems' as an indicator. The framework by CSTEP might be unique and can be used for assessing technologies in several sectors, including those in the renewable/clean energy/green mobility sector, such as solar and wind energy and electric vehicles.

The current study aims to develop a TAF to examine the suitability and sustainability of both existing and emerging technologies. This framework will provide crucial insights to relevant stakeholders and help them in making informed decisions pertaining to investments in any technology. TAF 2.0 is an upgradation of TAF (Bhupesh Verma, 2021), which provides a systematic, structured, and scientific assessment of technologies of interest.

### Key Features of TAF 2.0

Some of the key features of TAF 2.0 are presented in Figure 4.

**Objectivity**: TAF 2.0 uses objective criteria and systematic methods to evaluate new technologies. Therefore, TAF 2.0 is an impartial Excel-based assessment tool that ensures a transparent and credible evaluation process.

**Multi-criteria Approach**: To evaluate new technologies, TAF 2.0 uses multiple factors, such as technical performance, economic viability, environmental impact, and social impact. This leads to a comprehensive evaluation of new technologies and their potential impact.

**Stakeholder Engagement**: TAF 2.0 engages with multiple stakeholders, including technology developers, government agencies, industry, and civil society organisations. In this process, the perspectives of different stakeholders are taken into account, leading to an inclusive and transparent evaluation process.

**Flexibility**: TAF 2.0 is flexible and adaptable to accommodate new and emerging technologies, as well as changing conditions. The results of such an evaluation process are relevant and useful over time.

**Continuous Improvement**: TAF 2.0 will be continuously reviewed and improved to reflect advances in technology and changes in the broader context of new technologies being developed and deployed, leading to an effective evaluation process.

**Transparency**: TAF 2.0 can provide transparency in the evaluation process, allowing stakeholders to understand the criteria used for assessing new technologies and the reasoning behind decisions. This can increase trust in the decision-making process and reduce the possibility of misunderstandings or conflicts.

**Integrative**: TAF 2.0 can integrate the results of other relevant assessments and evaluations, such as life cycle assessments, risk assessments, and cost-benefit analyses. This ensures a comprehensive evaluation process that takes into account the full range of impacts and considerations associated with new technologies.

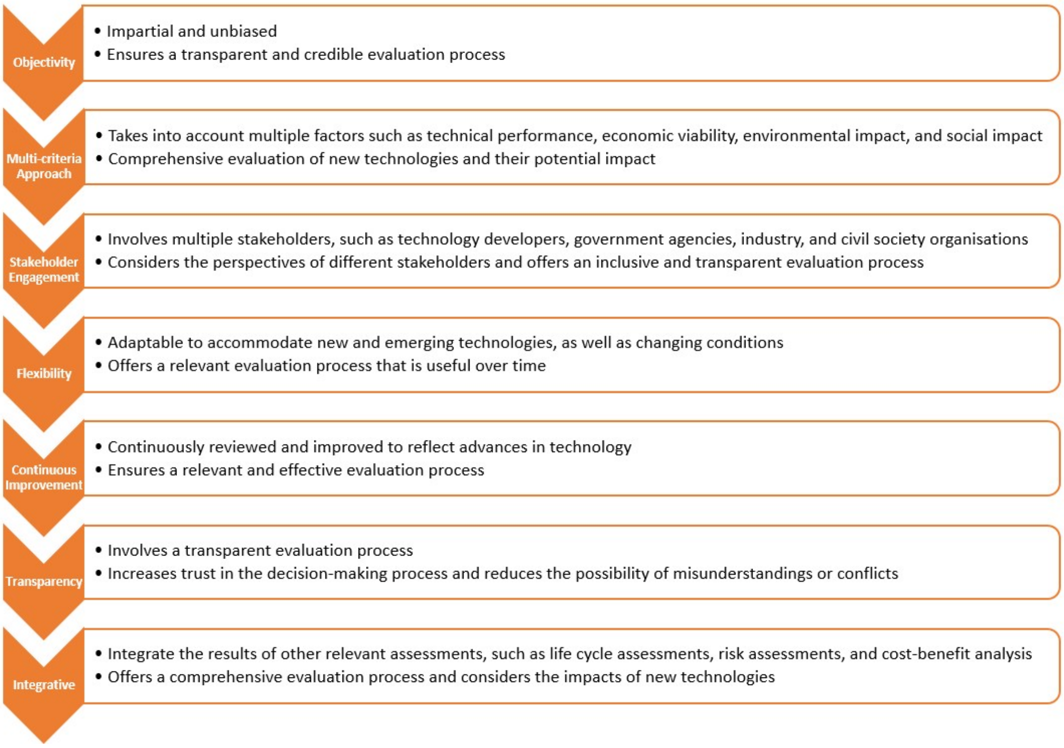


*Figure 4: Infographic showing the key features of TAF 2.0.*

# Methodology

## Criteria for Assessing TAF 2.0

In this section, we propose the usage of key criteria to assess the performance of any technology. Typically, depending on the requirements, around four to six key evaluation criteria are used for such technology assessments (IEA, 2016) (Li-bo & Tao, 2015). Figure 5 provides a schematic representation of various evaluation criteria. Most of the metrics in the assessment are quantitative. In the methodology, each metric is further divided into sub-metrics that are a combination of quantitative and qualitative parameters. The final representation in this figure is based on the number of quantitative/qualitative sub-metrics under each metric.

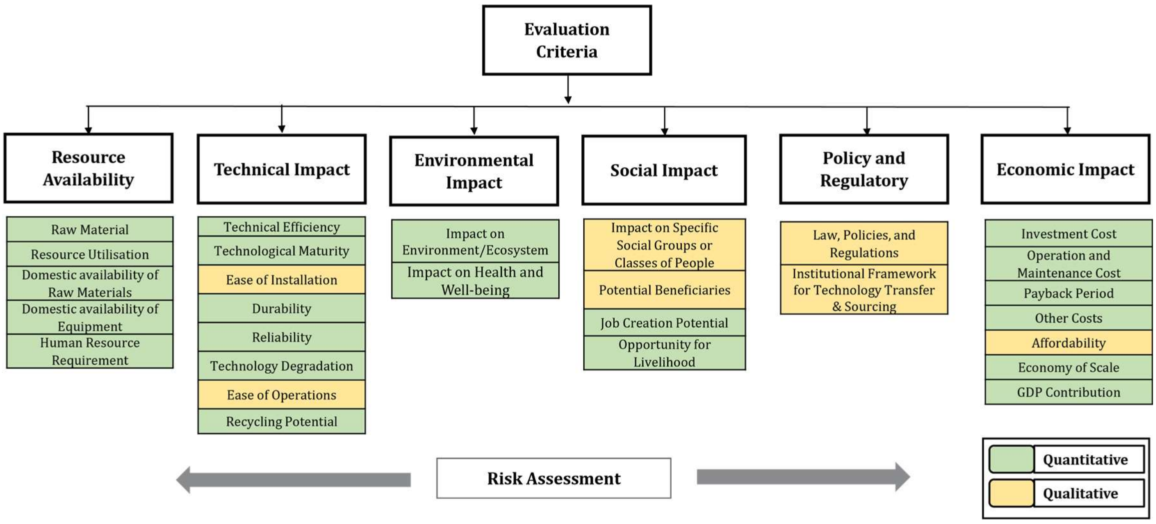


*Figure 5: Evaluation criteria for technology assessment.*

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).

Technical Impact: 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).

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

Social Impact: Assesses the impacts of technology on society/the community, e.g. social awareness and societal benefits (job creation, affordability, health impacts, etc.). The pros and cons of technology deployment in the community are examined (Siksnelyte-Butkiene , Zavadskas, & Streimikiene , 2020).

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).

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

Risk Assessment: Analyses the level of risks associated with a given technology and includes technology risk, financial risk, and risk associated with resource availability/sourcing. (Siksnelyte-Butkiene , Zavadskas, & Streimikiene , 2020). As shown in Figure 5, risk evaluation is performed across all evaluation indicators, as applicable.

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

## Resource Availability

| Metric | Sub-metric | Unit |
|---|---|---|
| **Raw Materials:** Nature of raw materials (processed or unprocessed; critical or easily available) required to construct any technology or project. It includes materials for both upstream and downstream supply chain levels. | Physical availability[1] (reserves or resources) | Quantity (parts per million or ppm/tonnes) |
| | Material availability | Yes/No (abundant/scarce) |
| | Import dependency | Yes/No (name of countries) |
| | Geographical concentration[2] | Percentage (%; distribution across various geographical regions) |
| | Technology for extraction/processing | Available/Unavailable |
| | Applications in other sectors | Yes/No/With customisation |
| | Potential substitutes | Available (to be specified)/Unavailable/ Customisation required |
| **Resource Utilisation (land, water, energy):** Assess the quantity of resource consumption – land, water, and energy for any particular technology –only during operations of a manufacturing facility or a power generating plant. | Land/footprint | Acres/Hectares |
| | Water | Litres (L)/Kilo litres (KL) |
| | Energy input[3] (both thermal and electrical) | Watt-hour per day/kWh per month/Joules |
| **Domestic Availability of Equipment:** Assess the domestic availability of technology or equipment | Availability | Available/Unavailable (if available, provide a list of equipment) |
| | Performance[4] and quality[5] | Percentage (%), |

[1] This could also include the inferred and extractable resources.
[2] Extent to which the reserve base and mine production are concentrated in one or a few countries.
[3] Includes chemicals that might be needed for processing.
[4] Peak performance of the system.
[5] Relative ranking with respect to best available technology.

| Metric | Sub-metric | Unit |
|---|---|---|
| required to construct a manufacturing/power plant. | | 1–3 (1 = very good, 2 = good, 3 = bad) |
| | Domestic share | Percentage (%) addition in the total value chain |
| **Human Resource Requirement:** No. of people required, level of skills required to operate the technology, and training required for the workforce with crucial skills to be able to operate the technology. | Number of people | Number of resources/Units |
| | Skill level required | Skilled/Semi-skilled/Unskilled |
| | Specific training required, training duration | Yes/No; Days/Months |

## Technical Impact

| Metric | Sub-metric | Unit |
|---|---|---|
| **Technical Efficiency:** It represents the performance efficiency of a technology (conversion efficiency, instantaneous efficiency, capacity utilisation/plant load factor, and availability factor[6]). | Ratio of output to total input | Percentage (%) |
| **Technological Maturity:** Assessment of the maturity of new technology by using Technology Readiness Levels (TRLs) at the global level. | TRL | TRL 1–9[7] |
| **Reliability:** To evaluate the ability of a technology to perform in a given period of time without any failure. It is measured by the frequency or impact of failures. | Mean time between failures/Mean time between repairs | Time (hours)[8] |
| **Durability:** The ability of a technology to remain functional in the external environment during its lifetime without failure/damage and unwanted maintenance. | Lifetime performance degradation rate[9] | Time (years of life/hours of use/no. of operational cycles) Percentage (%) |
| **Installation:** How easily the components of the technology can be installed. | Ease of set up[10] | 1–3 (1 = very easy, 2 = easy, 3 = difficult) |
| | Average installation time | Time (days) |

[6] Availability for operations.
[7] 1, Basic research; 2, Technology concept formulation; 3, Experimental proof of concept; 4, Validation in a lab; 5, Tech validated in a relevant environment; 6, Tech demonstration; 7, System prototype demonstration; 8, System completion and qualification; 9, Actual system proven in an operational environment.
[8] Lesser the meantime, the more reliable the technology.
[9] Durability can also be measured in terms of technology degradation, which typically means a decline in the quality and performance of technology over a period of time.
[10] Levels of easiness.

| Metric | Sub-metric | Unit |
|---|---|---|
| | Installation efforts[11] | Person hours |
| | Failures/fault rate | Hours per month/Year |
| | Throughput rate | Total units produced/Time |
| | Safety | Number of accidents or incidents per year or throughout the lifespan of technology |
| **Recycling Potential:** Potential for recycling and reuse. | Recycling technology availability | Available/Unavailable |
| | Material recovery rate[12] | Percentage (%) |
| | Resource requirement | Land (acres), Energy (Wh/kWh), Water (L/KL), manpower (number of skilled, semi-skilled, and unskilled people) |
| | Reusability potential | Percentage (%)[13] |

## Environmental Impact

| Metric | Sub-metric | Unit |
|---|---|---|
| **Impact on Environment/Ecosystem:** Impact of technology on the natural habitat of various living beings. Quantify the impact of local pollutants and greenhouse gas (GHG) emissions/assess the level of GHG emissions throughout the lifespan of a technology (raw material procurement to end of life). | Impact on biodiversity[14] | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Local air quality | Air quality index (0–500) |
| | Aquatic/Marine impact[15] | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Impact on land[16] | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Resource depletion | 1–3 (1 = High, 2 = Medium, 3 = Low) |

[11] Number of persons and their time efforts required.
[12] Ratio of weight of materials sent for processing/weight of products recycled.
[13] Quantity of recycled/recovered material that can be reused.
[14] Impact on living beings (flora and fauna).
[15] Release of industrial waste into local water bodies.
[16] Deforestation, landslides, floods, land pollution, etc.

| Metric | Sub-metric | Unit |
|---|---|---|
| | $CO_2$/GHG or $NO_x$ and $SO_x$ emissions (scope 1, scope 2, scope 3)[17] | kg $CO_2$ e per unit/ppm |
| | Avoided $CO_2$ emission in comparison with coal as a benchmark | Metric tonnes |
| **Impact on Health and Well-being:** Ability to minimise negative health impacts. | Noise pollution/sound levels | Decibels[18] |
| | Quality of air and water | Air quality index (AQI) and total dissolved solvents (TDS) |
| | Waste management | Mechanism exists or not |

## Social Impact

| Metric | Sub-metric | Unit |
|---|---|---|
| **Impact on Specific Social Groups or Classes of People:** Aspects such as the conversion of agricultural land to construct a power plant or physical displacement of habitation due to project construction. | Land acquisition – Conversion of agricultural land | Yes/No/Partially |
| | Physical displacement of local habitat | Yes/No/Partially |
| | Loss of livelihood | Yes/No/Partially |
| | Disruption of economic activities | Yes/No/Partially |
| | Land acquisition – Compensation | Early/Late/Adequate/Inadequate/No compensation |
| **Number of Potential Beneficiaries:** Number of people/members benefitting from the technology/project. | Direct and indirect beneficiaries[19] | Number of persons |
| **Job Creation Potential:** Includes quantity and quality of jobs created. | Number of direct, indirect, and induced jobs[20] | Number of jobs |

[17] Scope 1: Direct emissions from any technology/source; Scope 2: Indirect emissions; Scope 3: All indirect emissions from various other activities at the source.

[18] A noise level above 65 dB is considered noise pollution.

[19] Direct beneficiary-closely linked to the technology/project whereas indirect are secondary beneficiaries (not directly linked to the project).

[20] Generated by employees (by local spending on goods and services).

<table>
<tr><td></td><td>Job security</td><td>Job security index[21]</td></tr>
<tr><td rowspan="6">Opportunity for Livelihood: Potential to improve the standard of living of citizens by providing access to essential services.</td><td>Income levels</td><td>Per capita income (INR)</td></tr>
<tr><td>Employment opportunities</td><td>Percentage/Number of employees</td></tr>
<tr><td>Women empowerment/ gender equality</td><td>Yes/No/Partially</td></tr>
<tr><td>Business opportunity for locals</td><td>Yes/No/Partially</td></tr>
<tr><td>Cost of goods and services</td><td>Per capita expenditure (INR)</td></tr>
</table>

## Policy and Regulatory Framework

<table>
<tr><th>Metric</th><th>Sub-metric</th><th>Unit</th></tr>
<tr><td rowspan="7">Policies, Laws, and Regulations: A policy outlines what a country aims to achieve and the methods and principles it will use to achieve them.<br>Laws and regulations set out standards, procedures, and principles with legal implications.<br>1. Policy Instruments: Includes policy support, regulations, and standards to promote any technology. Following are the details:<br>• Command and Control (Regulation and Standards): Sets the standards and legal boundaries for any technology.<br>• Quantity Instruments: A market-based mechanism to target absolute quantity for any particular technology/deployment of technology and to decide the price.<br>• Price Instruments: A market-based mechanism that creates a favourable price regime for a particular technology and lets the market determine the quantity.<br>2. Innovation Governance: Government's intervention in supporting research and development and innovation for new technologies.</td><td>Policy targets or regulations for monitoring and control</td><td>National-/State-level, short-term/long-term, no specific targets</td></tr>
<tr><td>Quality control, standards, guidelines, prohibition, quota, ban, etc. (Direct[22] and indirect support[23])</td><td>Exists (Yes/No)<br>If yes, mention adequacy on a scale of 1–3</td></tr>
<tr><td>Environmental taxes and charges</td><td>INR/unit</td></tr>
<tr><td>Fiscal incentives (Capital subsidy, investment tax credits, production tax credits, production-linked incentives/feed-in-tariff—preferential tax, purchase obligation, power purchase agreement, etc.)</td><td>INR/unit, % of capex subsidy,<br>PLI scheme – available/unavailable</td></tr>
<tr><td>Support for technological innovation</td><td rowspan="3">Budget allocated (Yes/No) – INR</td></tr>
<tr><td>R&D support</td></tr>
<tr><td>Technology upgradation funds</td></tr>
</table>

[21] Measuring an individual's cognitive appraisal of the future or his/her job with respect to the perceived level of stability and continuance of this job. The higher the index, the higher would be the security level.
[22]Direct support: Supporting a particular technology by removing economic barriers, to increase the demand.
[23]Indirect support: Supporting a particular technology by imposing restrictions on others.

| Metric | Sub-metric | Unit |
|---|---|---|
| **Intuitional Framework for Technology Transfer and Sourcing:** Assess the ease in technology transfer/sourcing from global tech providers. | Geographical distance[24] | Physical distance (in kilometre) |
| | Technical excellence[25] | 1–3 (1 = very good, 2 = good, 3 = bad) |
| | Regulatory issues[26] | 1–3 (1 = simple, 2 = complex, 3 = highly complex) |
| | Trade restrictions/barriers[27] | Exists or not; if yes, mention adequacy on a scale of 1–3 (1 = high level, 2 = moderate level, 3 = low level) |
| | Geopolitical issues | Geopolitical risk index |
| | Intellectual property rights (IPR) protection | Strong/Weak[28] |
| | Engineering risks[29] | 1–3 (1 = high level, 2 = moderate level, 3 = low level) |

[24] Farther the partners/sourcing countries, the more difficult would be the process.
[25] If the partner is known for technical excellence, the risk of failure/breakdown would be lower.
[26] Countries follow different standards, laws, regulations, and business practices.
[27] Embargo, exchange control, import quota, protective tariffs, etc.
[28] Strong IP protection can make access to technology more problematic and vice versa.
[29] Technical risks (material specifications, design, and complexity of the system) should be low.

## Economic Impact

| Metric | Sub-metric | Unit |
|---|---|---|
| **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 |
| **Operations and Maintenance (O&M) Cost:** Costs associated with O&M 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[30] cost | INR/unit |
| **Payback Period**<br>• **Return on Investment:** Annual return as a percentage of the capital cost. | Investment returns/profitability rate | Percentage (%)[31] |
| • **Internal Rate of Return:** Rate of return that the investment is expected to yield. | Investment returns/profitability rate | Percentage (%)[32] |
| • **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[33] |
| **Affordability** | Cost of goods and services | Per capita expenditure (INR) Yes/No/Partial |
| **Other costs** | Price/processing cost of raw materials | INR/unit |
| | Training Cost[34] | INR/employee |
| | Cost[35] of sourcing | Unit cost |
| | Insurance for employee | INR/employee |
| **Economy of Scale** | Decrease in cost per unit output enables an increase in scale | Cost/unit<br>or<br>Reached/Not reached |
| **Gross Domestic Product (GDP) contribution** | Gross domestic product[36] | Percentage (%) |

[30] Sales and general expenses.
[31] Calculated as annual cash outflow/initial investment.
[32] Rate at which the net present value of a project = 0. It signifies a no profit or loss state for the project/investment.
[33] Positive – profitability; negative – loss; zero – no profit, no loss state for the project/investment.
[34] Resource training, need to train the workforce with crucial skills to be able to operate the technology.
[35] Cost of sourcing (planning, transportation, and implementation costs).
[36] Standard measure of the value added and created through the production of goods and services in a country during a certain period.

## Risk Assessment

| Metric | Sub-metric | Unit |
|---|---|---|
| **Technology Risk:** Assess the potential for losses due to technology failure. | Supply chain risk | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Change in technologies/technology upgradation/technology obsolescence | |
| | Competing emerging technologies (cost competitiveness, efficiency, etc.) | |
| | Policy and regulatory changes, etc. | |
| **Financial Risk:** Involves various financial risks[37] associated with any technology or project. | Investment | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Operational costs | |
| | Payback period, return on investment | |
| | Project financing | |
| | Regulatory/legislative changes | |
| | Market risk[38] | |
| | Political risk and uncertainty | |
| **Resource Risk:** Assess the potential risk associated with key resource availability. | Raw material availability | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | 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 | |
| **Policy and Regulatory Framework:** Assess the effect of change in policy, laws, and | Policy targets | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Change in policy, regulations, and laws | |

[37] Possibility of losing money/investment in any technology/project.
[38] Fluctuation in prices of market instruments (foreign exchange, interest rate, etc.).

| Metric | Sub-metric | Unit |
|---|---|---|
| regulations on technology/projects. | Change in price and quantity of instruments | |
| **Social Risk:** Potential loss to society on the adoption of any technology/project/service. | Long-term impact on a community/habitat | 1–3 (1 = High, 2 = Medium, 3 = Low) |
| | Impact on employment | |
| | Impact on quality of life, affordability, and health | |
| **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) |

# Interdependencies of Metrics

We have mapped the interdependencies (qualitatively) of the metrics under the six evaluation criteria as shown in Figure 6 (red, blue, and green lines indicate high, medium, and low interdependencies, respectively). For example, raw materials have policy and regulatory framework, environmental, and economic interdependencies, and land acquisition has economic interdependencies. These interdependencies need to be taken care of while performing the technology assessment.


*Figure 6: Interdependency mapping of metrics. (a) Resource, policy and regulatory, environmental, and economic interdependencies; (b) resource, technical, and economic interdependencies; (c) social, environmental, and economic interdependencies, and (d) resource and social interdependencies*

## Applications of TAF 2.0

The following are the applications of this framework:

- It can be used to assess both emerging and mature technologies in various sectors, such as energy, water, health care, digital transformation, and biotechnology.
- 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, the assessment of solar technologies or a comparative analysis of all renewable technologies.
- It can be used for identifying blue-sky, emerging, and disruptive technologies.
- It can evaluate and select the right technology on the basis of the country's demography, which will be useful in meeting renewable energy technology requirements.
- It can accelerate the transition from conventional to renewable energy sources by providing crucial information for technology development.
- It can help identify the right human resource for technology development.

The TAF is relative in nature. Typically, any technology assessment is benchmarked against well-established technologies.

## Beneficiaries of TAF 2.0

TAF 2.0 can benefit the industry, policymakers, academicians, and others in making informed short-/long-term decisions pertaining to the applications and feasibility of any technology. A proper assessment would assist in identifying investment opportunities for entrepreneurs, as well as in providing future research direction for researchers and technology insights for decision-makers. TAF 2.0 will allow an assessment of India's knowledge pool (research groups, start-ups, etc.) and proprietary know-how (adjacent technology development exercises). Traditional knowledge and IPRs (patents) regarding the technology/product should also be assessed. This can potentially drive the intensity and focus of policymakers towards designing enablers (funding, vocational training, and education) for the area. Advanced planning regarding the development of mission-critical IP and a skilled task force drives self-sufficiency.

## Guidelines for Using TAF 2.0

TAF 2.0 is applied to assess any technology, and data collection is an essential part of technology assessment. Collection and quality checks of data can be time-consuming and costly. Therefore, framing the appropriate research questions and designing the project before applying it to TAF is advisable. It will help users to collect, handle, and analyse data in a more sufficient, appropriate, and relevant way, thereby reducing the time and cost associated with the process.

## Outcomes of TAF 2.0

The following outcomes are expected from this analysis:

1) For policymakers:
   - To provide key insights into the optimal utilisation of resources and capital.
   - To facilitate strategic planning for resources and technology.
   - To assist in policymaking.
   - To select suitable technology for implementation.

- To highlight potential long-/medium-/short-term effects of technology.
- To address social and environmental questions that may arise due to the deployment of technology.
- To analyse technological friendliness to society/environment.
- To explore the positive or disruptive effects of emerging technologies.

2) For researchers:
   - To provide R&D directions and priorities for emerging or existing technologies.
   - To shed light on the status, viability, maturity, and public and private use of technology.
   - To identify the scope of improvement in existing technologies.
3) For investors:
   - To help planning of investment for technology development.
   - To provide details, such as risk versus return, of technologies as shown in Figure 7.

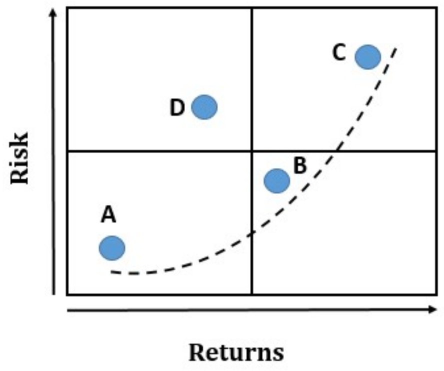


*Figure 7: Risk versus return of technologies. A, B, C, and D, are four different technologies. Technology A is easy to implement but has small returns, whereas technology B can be of interest as significant returns can be expected with moderate investment. Technology C has a high expected value; therefore, it will grow faster but will have high risk. Technology D is unattractive because it will grow faster and offers very low incremental value.*

A typical representation of results from TAF 2.0 is shown in Figure 8.

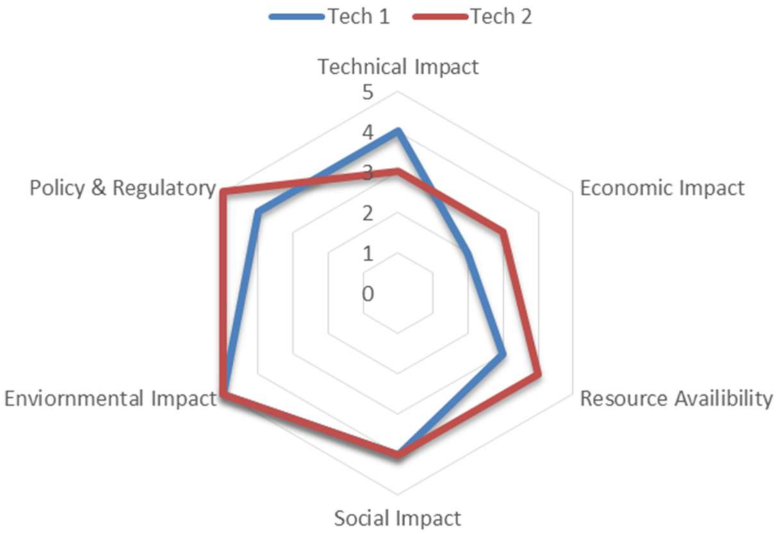


*Figure 8: Typical representation of results from TAF 2.0.*

# Future Plans

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

- Assessment of emerging solar PV and battery technologies.
    - The TAF will be used to assess the performance of various solar PV, battery, and carbon capture, utilisation, and storage technologies.
- Assessment of biomass-gasification-based power generation and its role in round-the-clock power generation in conjunction with solar and wind for standalone micro-grids.
- Implementation of a multi-criteria approach for decision-making to identify suitable technologies.
- Development of a sustainability index to evaluate the sustainability performance of a technology.

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