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Research Paper

Glimpses of the Future: Technology Forecasting as a Catalyst for Nations on the Rise

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Introduction

Developing nations today live in a world shaped by accelerating technological change and shifting global economic structures. In such a rapidly evolving global order developing nations find themselves under unique pressures—their societies are not static—they face shifting demographic profiles emergent health challenges & disease burdens, climate vulnerabilities, rising aspirations and accelerating digital transformations. What was sufficient infrastructure or industrial capacity a decade ago might now be redundant or obsolete. Progressive societies need to evolve rapidly to keep pace with new demands on infrastructure, skills, and institutions. And thus, to remain relevant and equitable, such countries need to think ahead. They need to anticipate not only *what* is but also *what could* be.

We live in an era where knowledge and ideas increasingly drive value. Many developing countries are striving to become knowledge economies—economies in which human capital, innovation and information flow matter far more than raw materials or unskilled labour. A knowledge economy is characterized by continuous learning, high levels of R&D, strong intellectual property regimes and digital connectivity that enable the creation, transfer, adaptation, and diffusion of innovation.

But, only a handful of nations today can aptly be called full-fledged knowledge economies. Countries such as Sweden, Finland, Denmark, Switzerland, Singapore and Israel lead global indices of innovation, high-value services, and research intensity. Their capacity to transform research into commercial value, attract best talents and sustain high technology ecosystems gives them outsized influence in defining standards, platforms, and supply chains. The gap between these leaders and most other developing countries is not just one of sheer scale—but of vision, institutional structure, innovation ecosystem, foresight, and adaptability.

The global scenario

Some economies illustrate how strategic attention to knowledge, R&D, and innovation can transform national prospects. China, in around four decades, has revolutionized from a largely agrarian low-value industrial base into a global manufacturing and R&D powerhouse. Recent IMF analysis and forecasts have continued to put China among the faster-growing major economies in the mid-2020s. Hong Kong, with its compact, services-heavy economy and open trade position rebounded through the early 2020s from pandemic shocks and recorded renewed positive GDP growth in recent years—illustrating how flexible well-integrated urban economies can recover and leverage connectivity. Taiwan, on the other hand, demonstrates an equally impressive model. A small but intensely technology-focused economy whose comparative strength lies in high-value-added manufacturing (notably semiconductors) and very high R&D intensity. Taiwan's investments in research and engineering capabilities have produced outsized export and productivity returns helping it retain strategic industrial niches globally.

More broadly, global patterns of R&D investment underline the payoff of sustained technological focus. Across the OECD and major non-OECD players gross domestic expenditure on R&D (GERD) has continued to grow in the first half of the 2020s. China's share of global R&D rose strongly and business sector R&D expanded in many other advanced economies. While small innovation-dense countries (for example, Israel, South Korea and some Nordic nations) show very high R&D-to-GDP ratios these investments are strongly correlated with higher value-added exports, faster productivity gains and the capacity to generate and capture new market segments—the very attributes that distinguish knowledge economies from commodity-centric or low-value manufacturing systems.

Charting the path ahead

In this fast-changing world, short-term reactive policy-making or purely incremental upgrades can leave countries locked into outdated pathways. Instead, deliberate anticipation—a structured effort to scan, project and assess technological futures—becomes a strategic necessity. For most developing economies, that gap needs to be bridged not incrementally but strategically. They need to identify trajectories of technological change early, align public investments and policies accordingly, and monitor their progress with regular course realignments and corrections. In short, they need a practice of technology forecasting and assessment embedded into their development planning that is both challenging and indispensable if they are to avoid lock-in to outdated paths, circumvent being perpetually on the fringe of waves of innovation and to ensure that their domestic resource allocations, including, human, financial and regulatory, are not wasted on dead ends.

For many developing countries, the lesson is clear but not simple, ambition alone is insufficient. It often isn't enough to spend more! States need to choose wisely where to build capacity, when to catalyze private investment and how to shape institutions and skill systems so that R&D and innovation sustainably translate into tangible social and economic returns. This is the intended purpose of Technology Forecasting and Assessment—to reduce fog from the future and turn scarce public resources into sustained competitive advantage.

Defining Technology Forecasting (TF) and Technology Assessment (TA) & the imperative need

Technology Forecasting (TF) is the systematic practice of anticipating future technological trajectories their maturation

timelines, and, the social, economic and institutional conditions that can determine whether those technologies create value locally. Forecasts are not crystal balls, rather, they are disciplined constructions of possible futures grounded in evidence—historical trends, patent and publication signals, performance curves, expert elicitation, scenario development, and quantitative models. As with any forecast, the goal is not perfect prediction but informed anticipation, to illuminate possible futures, help guide strategy, and reduce the element of surprise. Since technology evolves not in a vacuum but amidst interplay with institutions, markets, regulations and societal acceptance therefore, effective forecasting has to be always interdisciplinary. Effective TF should account for uncertainties, multiple competing paths, disruptive shifts, and bottlenecks in adoption.

Technology Assessment (TA) examines the likely impacts of a technology—environmental, social, regulatory and distributional—and identifies barriers to adoption and scaling. When coupled, TF and TA allow decision-makers to see not only which technologies may matter, but how, when and under what conditions they can be embedded in a national development path. Upon effective amalgamation, forecasting and assessment exercises help decision-makers see not just what might come, but what should come given local goals and tradeoffs.

For many developing economies, the stakes are unusually high. They often confront three interrelated challenges—constrained resources, fast-changing external environments, and, a strong mismatch between aspirations and capacity. In such contexts, naive or reac-tive planning might possibly yield large misallocations—or even worse, strategic lock-in to suboptimal technologies. Wrong technological pathway characteristically entrenches inefficiencies for decades.

By contrast, embedding foresight allows more deliberate and resilient development. Well-timed, well-targeted foresight can direct investments into sectors with high spillovers (for example, electrification plus distributed renewable generation that enables industry, services, and rural livelihoods), uncover adoption barriers (skills, standards, supply chains) and create institutional mechanisms when new windows of opportunity open. Forecasting also helps in aligning disparate actors—ministries, universities, industry and financial institutions—around a shared narrative, thereby, reducing fragmentation in innovation ecosystems that often afflicts and distresses developing countries.

Delving further into the need for Technology Forecasting

- **Prioritization:** Technology forecasting helps prioritize sectors and capabilities. A country cannot invest in everything, so, which areas are most likely to yield competitive advantage or resilience in the coming decades? Which emerging fields align with national strengths or needs (e.g., in agriculture, water, energy, health, materials)? A well-structured forecasting exercise helps select candidates that deserve focused public investment, R&D, incentives, infrastructure, and skill-building.
- **Shaping trajectories:** Forecasts help governments and institutions anticipate disruptions and transitions. For instance, a country heavily reliant on fossil-fuel energy should anticipate the shift to decarbonization technologies (renewables, energy storage, carbon capture etc.). Developing nations face more risk in being late entrants into such transitions. Forecasting enables path management—not just reacting to disruptions, but shaping trajectories via policy nudges, standards, and institutional support.
- **Setting the cradle:** Foresight exercises can reveal adoption barriers, institutional gaps, and sociotechnical challenges. Suppose a promising technology is forecast to mature globally within 10–12 years; a developing country may need to build regulatory capacity, supply chains, intellectual property regimes, skills, public acceptance, or standards to be ready. In other words, forecasting is not just about which technologies may come, but how and when and for how long they can be locally embedded.
- **Avoiding reinvention of the wheel:** From a funding and risk-management angle, public R&D, infrastructure investments, subsidies, incentives, and regulations often involve long payback times. Forecasting helps mitigate the risk of backing obsolete paths. In broader terms, forecasting is a hedge against technological surprises.
- **Building bridges and effective coordination:** Technology forecasts foster strategic alignment and coordination across ministries, research institutions, industry, and educational bodies. In many developing economies, fragmentation in innovation ecosystems is a structural weakness. A shared vision informed by foresight can help align otherwise siloed actors.

The fruits (outcomes) of Technology Forecasting

A rigorous foresight and assessment exercise has the capability to deliver multiple types of useful insights.

Such insights turn technology foresight from an academic exercise into a navigational tool for public strategy, industrial policy, and institutional design.

Learning from the World—Global experiences in Technology Foresight

Across the globe many nations—both advanced and emerging—have undertaken structured Technology Forecasting and Assessment exercises to align science, innovation, and national development. These initiatives reveal how foresight, when coupled with policy commitment and institutional continuity, can yield remarkable dividends. From the United Kingdom's participatory foresight panels to China's long-term strategic technology roadmaps and from Singapore's agile innovation frameworks to Finland's ecosystem-based foresight culture, each experience offers valuable insights. Together, they affirm a universal truth—that progress is rarely accidental—rather, it is the result of nations consciously envisioning their technological futures and investing with purpose, patience, and imagination.

United Kingdom: National foresight at scale first became widely visible in the 1990s with the United Kingdom's Technology Foresight programme. Launched in the early 1990s and run in successive rounds, UK Foresight convened large multidisciplinary panels to map promising technology areas, produce roadmaps and link research priorities to industrial strengths. The exercise

Indicator	Outcomes
Technology roadmaps & timelines	Which technologies might become via-ble (or obsolete) by which year; what intermediate milestones to watch.
Technology clusters or ecosystems	Identifying sets of related domains that may coevolve (e.g. sensors + IoT + AI in agriculture).
Bottlenecks & enablers	Infrastructure, regulation, human capital, standards, supply chain, adoption limits.
Scenario variants	Alternative pathways.
Strategic options & pivot points	Where policy or investment interventions could shift the trajectory.
Gap analysis and capacity building	What institutional, regulatory or skill gaps must be filled to realize particular trajectories.
Risk or contingency assessment	Early warning of possible dead ends, failure modes, lock-ins, or disruptive substitution.
Benchmarking and global context	Compares domestic trajectories with global trends, enabling informed positioning.

did not attempt to "predict" any single winners, rather, it identified areas where public intervention, coordination and translation mechanisms could possibly create leverage—and it explicitly fed into research council priorities and collaborative funding instruments. Evaluations and impact studies reflected measurable downstream effects: reallocation of some public R&D funds toward Foresight-identified priorities, creation of networks and consortia, establishment of numerous follow-on applied research institutes, and, improved dialogue between government, industry and academia. The programme created a shared narrative and improved horizon-awareness across policy departments.

China: The People's Republic of China offers a contrasting example of foresight embedded in its national strategy. In 2006, the Chinese State Council published the National Medium- and Long-Term Program for Science and Technology Development (2006–2020), a consciously catalytic blueprint that set explicit targets (including raising gross R&D expenditure towards ~2.5% of GDP and increasing the contribution of S&T to growth). The plan combined priority sector lists (energy, materials, biotech, information technology, advanced manufacturing) with concrete policy levers, funding increases, talent programmes and measures to reduce technology import dependence. Tangible outcomes have been phenomenal with China's GERD and business-sector R&D investment rising rapidly in the 2000s–2010s. The country moved up global value chains in electronics, clean energy, and biotech and stateled incentives accelerated domestic capabilities in areas of strategic importance. Intangible gains included stronger national innovation institutions, mission-oriented coordination between ministries and clearer industrial targets. The Chinese case illustrates how coupling national foresight with scaleable finance and institutional reforms can deliver rapid capability building—and why governance design matters to convert investment into productive innovation.

Singapore: Singapore's RIE (Research, Innovation & Enterprise) planning provides a third model: continuous, rolling foresight tightly integrated with budgetary commitments and industrial policy. Successive RIE roadmaps (e.g., RIE2015, RIE2020 and the current RIE2025) identify a small set of national domains (manufacturing & connectivity, health & biomedical, urban solutions, digital economy) and back them with multi-year funding envelopes and institutional actors. The hallmark here is discipline: foresight led to explicit funding commitments (RIE2025 targets ~S$25 billion and ≈1% of GDP over 2021–25), public-private consortia, and mission projects that derisk early adoption for industry. The economic returns are visible in Singapore's persistent attractiveness for high-value manufacturing and biomedical investment, cluster formation, and continually rising productivity in targeted sectors. The intangible return is a tight, agile policy-research loop that allows priorities to be revised without losing implementation momentum. Singapore shows how coupling foresight with sustained. Predictable investment and industry engagement can make a small economy technologically punch above its weight.

Finland: The Finnish experience—a unique mix of decentralized foresight activities and national initiatives such as Finnsight and TEKES-led programmes—highlights both strengths and limits of foresight. Finland historically combined broad foresight exercises with strong public funding agencies (Tekes, integrated into Business Finland in 2018) and close researcher-industry linkages; outputs included targeted funding instruments, cluster support, and an emphasis on upgrading human capital and networks. Tangible outcomes included internationally competitive ICT and clean-tech capabilities and a reputation for strong public-private cooperation. But the Finnish story also carries a cautionary lesson: foresight and funding do not guarantee market success when global technological disruptions or platform shift rapidly (the disruption of Finnish mobile handset leadership is a classic example). The learning is that foresight should be iterative, embedded in learning institutions, and coupled with policies that foster continual adaptation (not just one-time roadmaps). Finland's mixed record underscores that national foresight is most effective when it becomes a continuous capability—a habit of policy—rather than a single report.

The case of India—TIFAC and Technology Vision 2020

India, too, carried out an impressive, exhaustive, valuable and well-documented national foresight exercise demonstrating a compelling example of how a developing country attempted to institutionalize technology forecasting in its planning apparatus. In the mid-1990s, the Technology Information, Forecasting and Assessment Council (TIFAC)—an autonomous body under India's Department

of Science & Technology (DST)—launched a pioneering exercise known as Technology Vision 2020 under the leadership of then-TIFAC Chair Bharat Ratna Dr. A. P. J. Abdul Kalam.

The exercise enlisted hundreds of experts across academia, industry, and government. It was a sincere attempt to imagine the sector-specific technologies India would need by 2020, and the institutional, regulatory, and human capabilities required to support them for creating an enabling ecosystem. The Vision produced a suite of documents covering multiple sectors, right from agro-food processing, chemicals, waterways & road transportation, engineering & electronics to cross-cutting enablers like biotechnology, telecommunications and strategic industries. Much more than a mere list of technologies, the exercise produced roadmaps, driving-force analyses and recommendations on capacity building, standards, and institutional mechanisms.

Over the subsequent decades, many of the forecasts or priorities set in Vision 2020 shaped funding programs, public-private consortia, and institutional initiatives. For exam-ple, TIFAC's later activities around Home Grown Technology (HGT) schemes, technology cluster development. Foresight updates, and innovation programs reflect continuity from the original vision. By 2020, the document was celebrated as a foundational guide for India's scientific and technology ecosystem. Critics and observers note that while not all predictions came true, the exercise's lasting value lay in orienting institutional attention, creating networks of technology experts, surfacing latent capacity gaps, and offering a shared narrative of where India should aim technologically.

Critically, the TIFAC experience exemplified two practical lessons for other developing countries. First, foresight should be broad and participatory viz. it should draw on domain experts but also include implementers and users to surface realistic adoption constraints. Second, foresight is most valuable when it is connected to implementation levers like, funding instruments, standard-setting, skill development and public procurement, so that identified priorities can be translated into measurable progress rather than remaining aspirational lists.

The *Yagya* of undertaking technology-forecasting and assessment

When we think of technology forecasting it is alluring to imagine a set of rigid steps or models that can somehow predict the future with mathematical precision. Yet, in reality, the art of forecasting is more like a continuous conversation—between data and imagination, between what is possible and what is desirable, and, between the intrinsic capabilities and constraints of an economy. For many developing countries, especially those at a stage of accelerated industrial and digital transformation, such exercises are best viewed not as rituals of prediction, but as frameworks for exploration and preparedness.

Many nations have found it useful to begin with systematic "horizon scanning", an activity that seeks to identify faint but significant signals of change—the kind that rarely make headlines but may shape the markets and societies of tomorrow. Horizon scanning can include careful observation of patent trends, research publications, venture-capital flows, and even social-media debates around emerging technologies. The European Commission's Joint Research Centre (2023) and the OECD's Strategic Intelligence Toolkit (2024) both describe how automated text-mining combined with expert interpretation, can uncover such early signs of technological movement.

Once these signals are gathered, they often need human interpretation. This is where expert consultations, Delphi studies, and participatory foresight workshops become valuable. The strength of such exercises lies not in unanimity but in diversity—in bringing scientists, entrepreneurs, policymakers, and even citizens into a shared dialogue about possible futures. As seen in the UK and Finland, involving multiple voices often yields more balanced and realistic foresight than relying solely on academic or bureaucratic expertise.

From here, many countries move toward scenario building—the imaginative heart of forecasting. Scenarios don't claim to "see" the future; rather, they offer structured stories of how it might unfold under varying assumptions. Singapore's Futures Unit and the Netherlands' Rathenau Institute have shown how scenario planning helps governments and industries test their readiness for disruptive shifts, whether in energy systems, automation, or healthcare. Similarly, "backcasting"—working backwards from a desirable future—helps identify what choices should be made today to reach that goal.

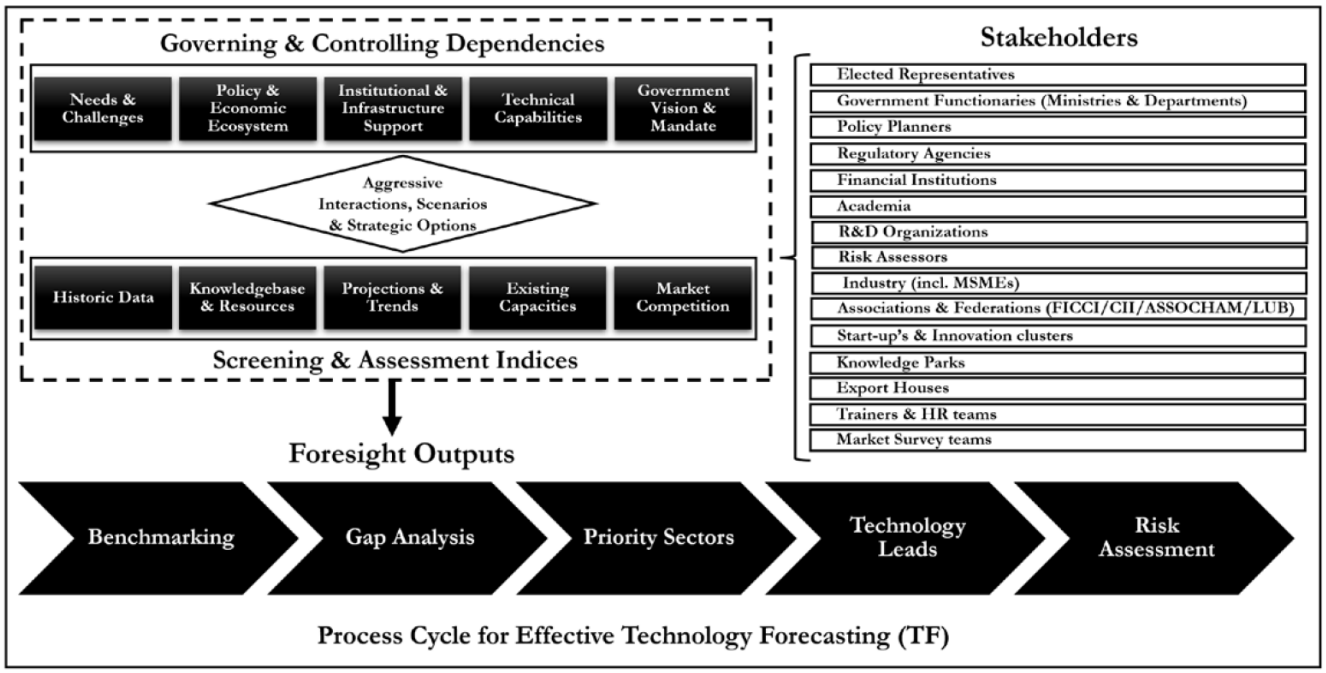
To make these ideas operational, technology roadmaps are often prepared. A roadmap links long-term visions with near-term actions: which capabilities need to be built, which technologies merit local development, and which regulatory or skill gaps should be filled. When such maps are periodically updated and anchored in public R&D or industrial policy, they become powerful navigational tools.

It is equally important to articulate here that developing nations need institutional continuity—not as one-time exercises but permanent foresight cells or observatories that regularly update insights. Some countries have placed such units within science and technology ministries; while others have networked them across universities, industries, and policy thinktanks. The format matters far less than the spirit—foresight should become a habit, not an event. Very aptly, the UNESCO and UNDP often remind their stakeholders that nations that embed anticipation into governance tend to respond better to crises and opportunities alike.

Why do such exercises often stumble or fade away

It is imperative and equally intriguing to ponder on the fact that when the benefits of foresight seem obvious, then why do so many well-intentioned initiatives fade away after a single study or report. The answer probably lies partially in the human nature and partly in institutional realities.

- **Fragmented responsibilities** are a common barrier. In many developing economies, ministries and departments operate in isolation—science in one corner, industry in another, and education somewhere else. Forecasting demands a panoramic view, yet administrative systems are built for narrow tasks. When no single agency owns the outcomes, follow-ups become nobody's priority.
- **Short political cycles** pose another challenge. Foresight is, by nature, a long-horizon investment. Its returns seldom coincide with electoral calendars. A change in leadership



Process Cycle for Effective Technology Forecasting (TF)

can easily sideline a visionary document. The experience of several OECD countries shows that enduring foresight requires bipartisan or crossministerial commitment, not just an individual champion.

- **Data and capacity constraints** also limit the quality of forecasts. Access to reliable data on intellectual property, startups, or emerging R&D themes is still uneven across the Global South. Without these inputs, even the most well-designed exercises risk becoming speculative rather than evidence-based.
- **Lack of followthrough mechanisms** is another critical bottleneck. A foresight study, no matter how insightful, remains a publication unless its recommendations are linked with funding, regulation, and appropriate skill-development programmes. In our own country, for instance, the Technology Vision 2020 exercise under TIFAC led to several thematic reports and sectoral roadmaps, but translating them into actionable programmes required separate institutional effort—a harsh reminder that ideas need instruments.
- **Cultural and psychological barriers** should also not be ignored. Bureaucratic systems are typically risk-averse; they reward compliance more than curiosity. In such an atmosphere, long-term experimentation most often becomes uncertain and, therefore, undesirable. Building a culture that values exploration—where small failures and setbacks are tolerated as part of learning curve—is as crucial as any other formal mechanism.

These constraints are not unique to developing nations, but their impact is deeper where resources are scarce and administrative bandwidth is a limiting factor. The encouraging lesson, however, is that all of them can be mitigated through continuity, openness, and a genuine belief that looking ahead is an investment, not a luxury.

Lessons from the private sector

Interestingly, the private sector has long practiced its own forms of technology forecasting—though under more pragmatic labels such as *strategic planning, R&D road mapping,* or *innovation scouting*. These exercises, though driven by profit, offer valuable lessons for nations seeking to institutionalize foresight.

One of the earliest and most enduring examples comes from **Shell,** whose *Scenario Planning Unit* began in the 1970s. The company did not attempt to predict oil prices but to imagine multiple global futures, right from energy transitions to geopolitical realignments. That flexibility allowed Shell to navigate oil shocks more steadily than many competitors. The moral here was simple: preparedness often matters more than prediction. **Toyota's** philosophy provides another interesting case. For decades, the company has invested in long-term R&D through the Toyota Research Institute and parallel ventures such as Woven by Toyota. Rather than betting everything on one trend, Toyota has pursued parallel technological paths—hybrids, battery-electric vehicles, and hydrogen fuel cells. This multipathway approach reflects a deep foresight: uncertainty becomes an asset when managed deliberately.

Similarly, **IBM's** research laboratories have long treated scientific exploration as a strategic necessity rather than an optional indulgence. Many of the world's computing standards, memory systems, and AI advances trace their roots to IBM's insistence that industrial research must precede industrial revolutions. Giants like **Alphabet (through its X-Moonshot Factory)** and **Siemens (via next47)** demonstrate how even in fast-moving digital landscapes, structured foresight remains essential. Alphabet treats ambitious ideas as "experiments" that may or may not graduate into independent ventures. Siemens, on the other hand, created dedicated innovation arms to explore technologies that did not fit neatly into existing business lines. Both approaches reveal a willingness to explore without immediate payoff—a trait many public systems may perhaps emulate!

The thread that binds these examples is not wealth but vision—a belief that structured imagination, backed by modest but consistent investment, pays dividends over time. If companies can commit to such habits in order to stay relevant and profitable, nations can certainly do so to stay progressive.

Closing reflections—The future belongs to the prepared mind

Technology Forecasting, at its heart, is an act of curiosity and hope. It is not about predicting the future, but about preparing for it intelligently. For developing countries, the task is less about adopting imported models and more about cultivating a national habit of anticipation—to observe patiently, think collectively, and act decisively. The journey may not follow a fixed roadmap, but as history and industry alike suggest, those who invest in fore-sight rarely regret it.

In the final reckoning, Technology Forecasting and Assessment are primarily about cultivating a national temperament—one that values reflection as much as reaction. For developing nations, where priorities shift quickly and resources are always stretched, the courage to pause and think ahead may itself be the rarest form of progress. There will always be those who argue that the future is too uncertain to forecast, or that the pressing needs of the present must take precedence. Both arguments carry truth. Yet, it is equally true that without anticipation, nations drift—reacting to change rather than shaping it. Forecasting does not remove uncertainty; it simply teaches us to walk through it with awareness. History has shown that foresight, when blended with humility, becomes wisdom. The intent is not to prescribe a single path, but to kindle a culture that asks better questions, sooner. Technology foresight, approached in this spirit, is not an academic exercise, rather it is an act of national mindfulness—one that helps societies align their as-pirations with their capabilities.

India and other developing economies stand today at a threshold where their future will be determined not merely by how fast they grow, but by how wisely they choose. And wisdom, as ever, begins with the will to look beyond the present—to imagine, to assess, and to prepare.

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