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Book

Digital dreams, real challenges : key factors driving India's AI ecosystem

Provided in Cooperation with:
Observer Research Foundation (ORF), New Delhi

Reference: Nandi, Anulekha/Yadav, Siddharth (2024). Digital dreams, real challenges : key factors driving India's AI ecosystem. New Delhi, India : ORF, Observer Research Foundation. https://www.orfonline.org/public/uploads/posts/pdf/20240508141138.pdf.

This Version is available at:
http://hdl.handle.net/11159/654448

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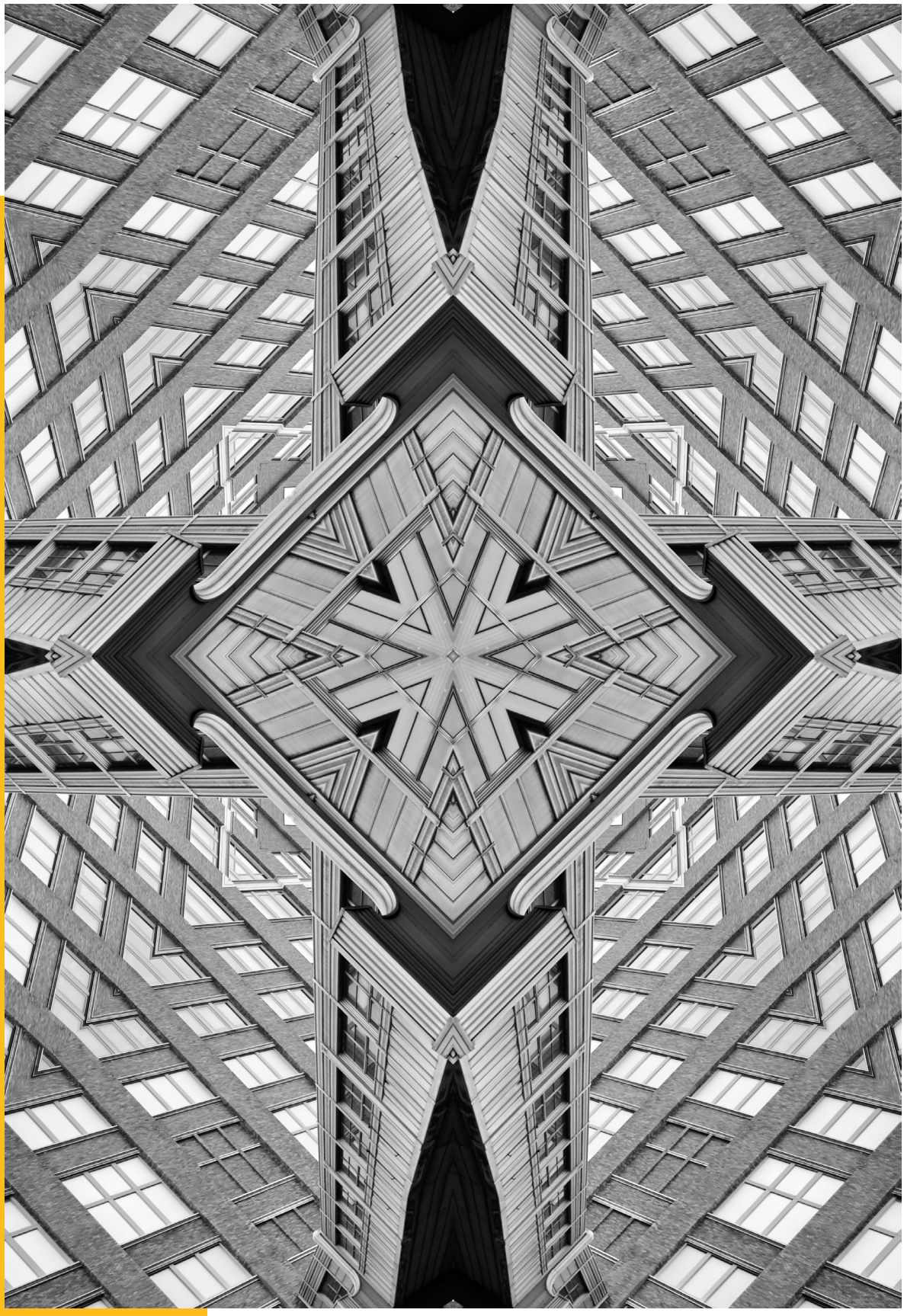

ISSUE NO. 436 MAY 2024

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Digital Dreams, Real Challenges: Key Factors Driving India's AI Ecosystem

Anulekha Nandi and Siddharth Yadav

Abstract

India, like much of the rest of the world, is faced with the twin but opposing conditions of economic potential and social concerns that need to be negotiated to realise the digital dividends from artificial intelligence (AI) and achieve sustainable and balanced growth. AI systems involve layers of technological dependencies that necessitate and enable social and institutional interdependency between stakeholders, enabling conditions, and resources. The stakeholders involved range from governments to businesses and startups that influence and are influenced by conditions such as the regulatory landscape, research, workforce availability, and finance and investment. Still, high-quality data and computational power are critical resources for AI development. This paper attempts to synthesise the diverse conditions that shape the current landscape of India's AI ecosystem. It presents recommendations for India to leverage the existing but untapped potential, collaborate on missing capabilities, and develop its indigenous infrastructures and platforms.

Attribution: Anulekha Nandi and Siddharth Yadav, "Digital Dreams, Real Challenges: Key Factors Driving India's AI Ecosystem," *ORF Occasional Paper No. 436*, May 2024, Observer Research Foundation.

Introduction

In recent years, the rapid pace of developments in the domain of artificial intelligence (AI)—spanning machine learning (ML), cloud computing, neural networks, and large language models (LLMs)—has forced the world to grapple with the disruptive potential of emerging technologies. These have significant ramifications for the economy and society, with the global economy standing to gain US$15.7 trillion by 2030 through the integration of AI technologies in and for business processes, labour augmentation, and product enhancement.[1] Of this US$15.7 trillion projected value, US$6.6 trillion is likely to come from increased productivity and US$9.1 trillion from consumption-side effects.[2] The potential for such economic opportunities has been heightened with the release of generative AI tools such as ChatGPT, Midjourney, and DALL-E. Generative AI is expected to add between US$2.4 trillion and US$4.4 trillion to the global economy by 2030.[3]

However, such economic optimism is often tempered by the looming threat of job displacement, security concerns, and asymmetric wealth generation between high- and low-income countries. AI-related developments are expected to affect 15 percent of the global workforce by 2030,[4] with a 23 percent structured change in the global labour market. This will result in a decline of 83 million jobs and a growth of 69 million jobs,[5] with the fastest growth seen in technology-related roles and the sharpest drop in clerical and secretarial ones. While automation technologies have primarily affected low-skilled workers in the past, the development of generative AI will impact high-skilled 'white-collar' jobs.[6] Economies with a higher proportion of cognitive-based, high-skilled jobs have a higher exposure to AI but are also likely to experience benefits from a greater synergy with AI platforms.[7] This will have a disruptive effect on economies, impacting 60 percent of jobs in advanced economies, 40 percent in emerging markets, and 26 percent in low-income countries.[8]

Further, AI engenders multiple interconnected risks, with the manipulation and distortion of information being the most severe short-term risks confronting societies globally. Misinformation and disinformation enabled by advanced AI capabilities, such as deepfakes, pose significant threats to democracy, stability, and social cohesion. The weaponisation of AI for military use and the criminal use of AI to mount cyberattacks pose longer-term critical risk scenarios.[9] AI technologies used

in military applications typically tend to be dual-use—with both civilian and military applications.[10] The deployment of dual-use technology in the military domain raises significant regulatory concerns.[11] On the one hand, they remain outside the ambit of modes of governance for civilian uses, while on the other, they raise important questions under international law for armed conflict.[12] These involve questions around the ability to delegate decisions of taking lives to machines, the responsibility of harm, particularly in cases of inadvertent casualties, and the ability of AI and autonomous weapons to distinguish between combatants and civilians.

Governments worldwide are faced with the twin but opposing conditions of economic potential and social concerns that need to be negotiated to realise the digital dividends from AI and achieve sustainable and balanced growth. Mirroring global trends, projections for India indicate that AI can add US$1 trillion to the economy by 2035.[13] The adoption of generative AI can add between US$359 billion and US$438 billion in 2029-30 over and above baseline estimates, representing an additional 5.9-7.2 percent of GDP.[14] This would translate to between US$1.2 trillion and US$1.5 trillion cumulated GDP over seven years (2023-24 and 2029-30), leading to an additional compound annual growth rate (CAGR) of 0.9-1.1 percent for the Indian economy.[15] Concurrently, India has also grappled with the adverse consequences of AI-driven transformations. These range from misinformation and disinformation fuelled by deepfakes,[16] to potential job displacement as a result of the restructuring of the labour markets due to automation.[17] Additionally, market concentration occurs as a result of Big Tech firms controlling the AI pipeline (from data to computation in the form of cloud infrastructure).[18] Moreover, cybersecurity concerns stem from AI-driven cyberattacks along with privacy infringements due to data scraping to train AI models,[19] and bias and discrimination due to opacity and lack of transparency.[20] Tech leaders have asked for quick regulations to manage the deep social and economic transformations unleashed by AI.[21] Concurrently, the need to institute mechanisms for fairness, accountability, and transparency is becoming increasingly important.[22] The risks of adverse consequences of AI systems are unfolding within the context of increased industrial concentration and unequal distribution of critical AI resources.[23] This highlights the need to understand the resources, conditions, and actors that drive AI innovation and the guardrails required for their responsible adoption and uptake.

Introduction

This paper synthesises the policy and regulatory conditions, social and technical infrastructural requirements, and concerns around responsibility and safety that shape India's current AI ecosystem. Taking an ecosystem-level approach highlights the simultaneous importance of these diverse factors in balancing AI-driven economic growth and social transformation. The paper identifies key aspects of India's AI ecosystem and the current state of the field. It also presents recommendations on the way forward by contextualising India's approach against the backdrop of the two AI superpowers, the US and China. Finally, it proposes a 'collaborative self-reliance' approach to leverage global market offerings while building national competencies in AI.

India's AI Ecosystem: Key Drivers

The AI ecosystem involves a set of heterogeneous but functionally connected actors and institutions that operate based on a set of available knowledge, resources, and technologies, with complex relationships of interdependency.[24] The evolution of the AI ecosystem is underpinned by the availability of resources in the form of computing power, data management, and processing. These resources support AI production and the development environment in the form of platform technologies such as Azure, Amazon Web Services (AWS), and Google TensorFlow, spanning AI libraries, visualisation tools, and protocols. These then form the platforms that help in AI consumption by experimenting and developing AI use cases that are then deployed in application scenarios and consumer-facing technologies.[25] The concentration of resources among Big Tech companies combined with the need for the responsible deployment of AI systems necessitates enabling conditions. These include responsive policy and regulations, the availability of a skilled workforce, a supportive research and development environment, finance and investments, and trust and security to promote trustworthy deployment and adoption.[26] This highlights the role played by different actors in the ecosystem, such as the government in terms of policy, regulations, and public expenditure outlay, businesses in terms of critical AI resources, academia in terms of research and innovation, and startups for AI-driven solutions and applications.[27]

AI production and consumption are closely linked because training a model involves the use of data to calibrate, leading to positive feedback loops. This increases the demand for computing power, which is provided by cloud computing and chip and microprocessing companies. Further, AI depends on quality data, a vital resource for innovators looking to enter the AI ecosystem. This privileges Big Tech companies that already have access to such a vital resource, highlighting the role of regulations in addressing issues of data access to increase competition.[28] AI enablement and production, characterised by high capital intensity and economies of scale and learning, are controlled mainly by Big Tech, who are primarily concentrated in a single geography (the US). As a result, critical resources for AI development are unequally distributed globally.[29] Big Tech companies have the capability to produce the AI they need for internal and external use. The ready availability of large and varied datasets also

reduces the computational cost of training the model and improving accuracy, resulting in better returns and lower costs of developing AI models.[30]

Given that a few firms have been central to the global AI ecosystem, it is important to understand the multiple drivers across AI development, deployment, and adoption that have implications for fostering an ecosystem of sustainability, collaboration, and self-reliance. This is particularly important for India as it attempts to push AI-led socioeconomic transformations. Understanding an AI ecosystem will involve comprehending the roles and responsibilities among participant actors and the conditions and trends in enablement, production, and deployment. An ecosystem approach highlights the interdependency imperative in scaling unequally distributed AI capabilities. The evolution and growth of AI ecosystems will come to depend on scale and scope, i.e., the cumulative advantages and opportunities of market entry and the ability to grow laterally and innovate in newer application areas.[31] The following are the prevalent trends across key drivers in India's evolving AI ecosystem.

Data availability, access, and management

Data is the foundational component for building AI systems. AI models learn from data and produce outputs based on inferences from such data, which determines eventual implications. The lack of appropriate datasets poses a significant bottleneck for AI development and adoption, highlighting a need for establishing data standards and formats and a governance framework for data collection, access, and management.

Data forms the fundamental component in developing, training, and deploying AI models and applications. Data availability is a significant determinant of what problems an AI system can solve, what kinds of AI systems can be built, and the quality of its output. This is because large amounts of training data are required to train models and improve their accuracy. However, sourcing the required data can be challenging; organisations often need to build their data corpus from scratch, which is time-, resource-, and cost-intensive.[32] This constraints early-stage startups

since venture capital firms rarely invest 'patient capital' to support a company with initial long-term data collection plans.[33] Consequently, startups need to have AI embedded in business models that can generate revenue from the outset. This precludes investment in building foundational models, thereby increasing reliance on existing models that might not fit the local context well.[34]

Data plays a pivotal role across the AI development life-cycle, wherein the data collected is cleaned, organised, and processed for uptake by designated algorithms that then generate outputs. This includes an iterative process of learning from data to train the model. Since the nature of the datasets affects the eventual output, data quality issues such as representativeness, accuracy, completeness, and accessibility have significant socioeconomic and ethical implications on inclusion, equality, and non-discrimination, highlighting the priorities for responsible uses of AI. This is exacerbated by the lack of representation of women and minority identities in the AI development life-cycle.[35] Facial recognition systems have been shown to underperform for darker skin tones,[36] and hiring algorithms discriminate against women and minority identities.[37] Given the potential bias within foundational models on which AI applications tend to be built, there are significant socio-economic implications based on the extent to which AI-led transformation can be implemented in different sectors or industries and the relevance of such solutions in local contexts.

Although India does not suffer from data scarcity, the non-availability of well-annotated, feature-rich local datasets is a bottleneck in AI development and adoption. The available data is spread across different institutional bodies with differing data standards and forms and involves significant collection and pre-processing costs to make them amenable for use.[38] This hinders interoperability among datasets and building solutions at scale. Initiatives such as the Open Government Data Platform are an effort to make government-owned and shareable data easily accessible across different sectors and states.[39] The India Stack's Digital Empowerment and Protection Architecture aims to provide an electronic consent framework for sharing data between individuals and institutions in a secure and standardised manner.[40] The Draft National Data Governance Framework Policy of the Ministry of Electronics and

Information Technology (MeitY) aims to enable access to anonymised data to overcome a data-related bottleneck for AI innovation.[41] The MeitY Expert Working Group has recommended establishing the India Datasets Platform with a federated structure to accommodate data providers from different ministries and departments to facilitate data discovery and value-added services for capacity building for dataset creation and management, while offering platform-as-a-service and architecture-as-a-service along with open metadata standards to ensure consistency and interoperability across diverse datasets. However, this requires the development of a clear governance framework, data standards, and formats, including data security and privacy measures. Concurrently, this involves developing institutional capacity for data governance by establishing a National Data Management Office.[42]

Computing power

Computing infrastructure determines the scale and scope of AI applications that can be built. However, components of such infrastructure, such as chipsets, are in extremely short supply, and reliance on public cloud infrastructure providers tends to be high in the absence of national capacity. This has driven the increased thrust on developing India's compute capacity to scale up AI solutions and drive AI-led transformations.

Computing capacity is a core dependency in building large-scale AI models. Computational power is measured in floating point operations (FLOP), and computing performance is measured in FLOP per second (FLOPs). As deep-learning AI models and generative AI gained ground, so did the demand for high-performance computational resources. This is because an increase in the scale of computing power is key to accuracy and performance in training such models since it can accommodate an increasing number of model parameters. This has led to an increase in the demand for specialised computer chips needed to train large-scale AI models that are shaping public policy and national AI strategies.[43]

Even though the production of chipsets is at capacity, the global demand for high-level AI computing far outstrips the limited sources of supply. Big

India's AI Ecosystem: Key Drivers

Tech companies, cloud computing services, and chip manufacturers are concentrated in the US. Given their critical importance in developing and scaling AI systems and applications, chips have been used as geopolitical tools to maintain supremacy in the global AI economy. For instance, the US has used export restrictions on advanced AI chips to gain a competitive advantage over China.[44] Moreover, while chipsets are needed to develop, run, and train the models, cloud computing infrastructures are required to host them. This increases the reliance on public cloud service providers like AWS, Microsoft Azure, and Google Cloud. The rising cost of cloud computing is a major cause of concern for Indian companies as even the larger ones can only achieve a cost optimisation of about 20 percent while medium and small-scale businesses fall short of their cost-saving goals.[45]

MeitY's Expert Working Group on AI recommended setting up a three-tier compute infrastructure with best-in-class capabilities across five locations with a capacity of 3000 AI petaFLOPs, along with an inference farm and edge computing systems. This also includes AI innovation hubs with a secure distributed data grid nationwide to build collaborations with academia, industry, and startups.[46] The Indian government has approved an outlay of INR 100 billion (US$1.2 billion) to develop the country's sovereign AI capabilities by building computational capacity and offering compute-as-a-service to startups.[47] The India AI programme aims to democratise access to AI infrastructure for domestic players in two ways: by focusing on the institutional development of indigenous compute capacity for the public sector through the AI supercomputing resources of the Centre for Development of Advanced Computing (C-DAC), and through public-private partnerships for creating access to GPU capacity for the private sector, which provide AI compute as a service to startups, researchers, or anyone looking to train a model.[48] Currently, AI4Bharat uses C-DAC Pune's Param Siddhi supercomputer for model training,[49] which ranks 63rd in the world among the top 500 non-distributed computer systems with 5.26 petaFLOPs.[50] C-DAC's AI supercomputer AIRAWAT, with a peak computing capacity of around 13 petaFLOPs, currently ranks 75th in the world.[51] In comparison, among the top supercomputers in the world, the Frontera Dell C6420 at the University of Texas reaches 23.5 petaFLOPs, while the Tianhe-2A at China's National University of Defense Technology, National Supercomputer Center, Guangzhou, reaches 61.4

petaflops,[52] indicating the scaling requirements for Indian supercomputing infrastructures to compete at international levels. While the government has taken initial steps in announcing production-linked incentive schemes to support domestic chip manufacturing, these do not extend to highly advanced GPU chipsets.[53] This highlights the need for sustained efforts to build the necessary industrial infrastrucutre.[54]

Finance and investment

Finance and investment are critical drivers of the AI ecosystem, as they determine advancements in other key drivers such as research, infrastructure, and talent.[55] While India has been climbing the charts in terms of private investment flowing into the country, the role of public investment in supporting key areas of the AI ecosystem development cannot be overlooked.

Between 2013 and 2022, Indian AI companies received US$7.73 billion, the sixth highest in the world in terms of investments in AI.[56] According to the 2023 Stanford AI Index Report, in 2022, over 1900 Indian startups received US$3.24 billion in funding, the country's most significant year of funding. However, there was a significant gulf in AI investment among the top five countries—the US and China received US$47.36 billion and US$13.41 billion, respectively, followed by the UK (US$4.37 billion), Israel (US$3.24 billion), and India (US$3.24 billion).[57] As generative AI gathered momentum, it marked a shift from task-centric AI to data-centric AI, leading to increased competition among businesses to adopt, develop, or deploy generative AI capabilities. There was a 1.5x growth in generative AI startups between 2021 and 2023, with incumbent startups receiving 90 percent of the total investment. In tandem with the funding influx, the Indian generative AI landscape showed a rapid uptick in the application and services spaces across a wide range of industries, spanning design; manufacturing; banking, financial services and insurance; telecommunications; publishing and advertising; legal and compliance; biotechnology and pharmaceuticals; and gaming.[58]

However, despite private investment driving growth in the application and services space, there are limited market-ready AI models. As a result, public investments are a critical driver in expanding and democratising access and adoption beyond immediate economic returns. India currently

lacks foundational AI models because foundational models like LLMs are driven by the logic of economic viability, as a result of which they adopt languages that scale up well on the internet (such as English).[59] For instance, Chat GPT has one trillion parameters built from massive training data sourced from the internet. Indian languages tend to have a comparatively low web presence and do not make the cut for LLMs as they classify as 'low resource languages'. No Indian language currently makes it to the top 10 languages on the internet, highlighting the significant lack of content in local Indian languages.[60] Even though Meta's Vaani project developed many datasets for low-resource languages, it is unviable for these projects to take up languages with a low demographic quotient. This is compounded by the issue of the unviability of cloud-based centralised data management systems for low-population languages.

Bhashini, the AI-driven local language translation platform developed by MeitY, is an example of a public initiative that aims to expand internet access for non-English speaking Indians.[61] However, significant advancements are being made by the AI4Bharat team at IIT Madras in developing an IndicLLM suite, a collection of open-source resources to support Indic LLMs covering 22 languages and 251 billion tokens of pre-training data and 74.8 million instruction response pairs.[62] Sarvam AI's OpenHathi series of work aims to contribute to the ecosystem through open models and datasets for innovation in Indian languages.[63] This work is in partnership with AI4Bharat, which contributes language resources and benchmarks.

Skilled workforce

A skilled workforce is pivotal to driving AI innovation and growth. Technological evolution, digital transformation of industries, and competing concerns of responsibility and safety have led to an increased demand for a diversity of skill sets critical to the development, deployment, and adoption of AI capabilities not just for novel application areas but also for business and process transformation of existing enterprises.

With AI-led transformation across industries and sectors, an estimated 16.2 million workers in India will need to be upskilled or reskilled

as AI transforms the employment landscape and creates newer job requirements.[64] Apart from technology-led businesses, the demand for AI talent from non-tech firms had soared 50 percent in 2023 compared to the previous year, signalling a deepening of AI adoption. The emergence of generative AI has also opened up the need for a broad spectrum of roles, ranging from product managers and annotators to legal professionals, ethics advisors, and content moderators. However, the demand for AI talent far outpaces supply, with an estimated gap of 2,13,000 AI professionals in the country despite India being a coveted hub for AI talent sourcing.[65] India is second only to China in producing Masters level engineering students, twice as many as the US. However, Indian students tend to pursue doctorates in foreign countries, especially the US, limiting the ability to retain and capitalise on training AI talent at scale.

India has the highest relative AI skill penetration across occupations globally, with a score of 3.23, meaning its skill penetration is 3.23 times the global average. India's AI skill levels are also indicated through its participation in open-source AI projects. As of 2022, a significant proportion of the GitHub AI projects were contributed by software developers in India (24.19 percent) followed by the European Union (EU) and the UK (17.3 percent), the US (14 percent), and China (2.40 percent), with the share of the latter three declining over previous years.[66] However, India has the lowest number of GitHub stars (akin to likes on social media) among these countries, with the US scoring the highest. These conflicting trends when it comes to AI-skilled professionals in India indicate an untapped potential and the need for a suitable impetus.

Recognising the need to support the development of a skilled AI workforce in India, MeitY's Expert Working Group recommendations include an AI research-based model curriculum across secondary, post-secondary, and higher education.[67] This includes further support through research fellowships, faculty training for AI, and career path mapping to develop an India-specific AI community. In 2019, India's Central Board of Secondary Education announced AI as an optional subject in its 22,000 schools by partnering with industry providers like Microsoft, Intel, and IBM to develop materials for training, support, and content with non-government organisations assisting with the implementation

and delivery.[68] In recognition of the recommendations of the 2020 National Education Policy to introduce contemporary subjects like AI in the curriculum at relevant stages,[69] the National Council of Education and Training (NCERT) aims to work on developing an introductory course on AI under the National Curriculum Framework for School Education. The All India Council for Technical Education institutions will offer AI as an elective in BTech programmes and also start BTech programmes on AI and Data Science.[70] The Indian government's YuvaAI initiative, the national programme on AI for school students from classes 8-12, aims to sensitise and encourage students to understand and explore the role of AI in socio-economic transformation.[71] The FutureSkills PRIME, a MeitY and NASSCOM initiative, aims to reskill and upskill IT professionals in 10 emerging technology areas, including AI.[72]

Enabling policy and regulatory environment

Creating an enabling policy environment involves creating supporting conditions for innovation, safeguards for adverse consequences, and accounting for existing deficits.

While India possesses a substantial consumer market and talent pool for IT development, it lacks the digital infrastructure for proprietary AI foundational model development.[73] Indian software firms tend to rely heavily on application programming interfaces (or APIs) and external foundational models that may discourage AI adoption by businesses apprehensive of risks like training data extraction.[74] India has been taking a deliberative approach towards regulating AI so as not to hamper the green shoots of innovation that have propelled it as the top 15 AI countries in the world.[75] This has involved a pro-innovation and risk-based stance to regulating AI, establishing a mission-centric approach to develop a precise and cohesive strategy to advance AI capabilities by addressing existing gaps in the ecosystem.

India currently has no specific laws that govern the regulation of AI.[76] India's AI mission is guided by NITI Aayog's foundational National Strategy for Artificial Intelligence,[77] Principles for Responsible AI, and operationalising principles for responsible AI.[78] In 2023, the Digital

Personal Data Protection Act was enacted, which outlined regulations on personal data processing.[79] However, the proposed Digital India Act (DIA) aims to be a future-facing legislation to develop and achieve the national milestone of US$1 trillion economy by 2026.[80] The proposed regulation seeks to take a principled and rules-based approach to keep pace with rapid technological evolution while retaining a competitive advantage. DIA aims to foster innovation through the principle of Open Internet through choice, competition, fair trade practices, online diversity, and ease of doing business and compliance for startups. It also aims to include the definition and regulation of high-risk AI systems by identifying appropriate regulatory models, algorithmic accountability, threat and vulnerability assessment, and AI-based content targeting. The DIA framework aims to encompass the Digital Personal Data Protection Act, National Data Governance Policy, amendments to criminal laws related to cybercrimes, and DIA Rules. Drafting new legislation to keep in step with emerging technologies also aims to leverage existing laws and harmonise their application within the digital domain.

The Data Protection Act and Data Governance Policy aims to provide a regulatory framework for governing personal data while also working on removing bottlenecks of data access for AI development by enabling access to anonymised data. The First Expert Working Group guidance involves recommendations for setting up the institutional framework for implementing the National Data Governance Policy through the National Data Management Office.[81] It also provides recommendations for the India Datasets Platform comprising anonymised datasets for multi-parameter training, India Compute Platform as a public-private partnership for creating substantial GPU capacity, supporting chipset development in conjunction with the semiconductor programme, as well as a design-linked incentive scheme to provide financial incentives and design infrastructure to support domestic startups and micro, small, and medium enterprises.

Moreover, sectoral policies aim to make systemic changes to move towards an AI-led digital transformation. Based on the National Education Policy's recommendation of integrating AI into the education curriculum, the NCERT drafted a National Curriculum Framework for School Education to develop technical skills and capacity for a future-ready workforce.[82] This

will be complemented by on-the-job training and courses on emerging technologies under the Pradhan Mantri Kaushal Vikas Yojana.[83] Further, the Union Budget has included allocations to achieve the objectives of the AI policy. The 2021-22 Budget announced the National Language Translation Mission,[84] leading to the development and deployment of Bhashini, the AI-driven language translation system for the real-time translation of Indian languages to eliminate language barriers to facilitate better access to information and online participation for Indian citizens. The 2023-24 Budget aimed to 'Make AI in India and Make AI Work for India', which included setting up three Centres of Excellence (CoEs) in top institutions across the country and encouraging industry partnerships for research and development in agriculture, health, and sustainable cities. In November 2023, the Indian government invited proposals to set up CoEs with an outlay of INR 9.9 billion (US$118.61 million) or five years (FY 2023-24 to 2027-28),[85] with an allocation of INR 2.55 billion (US$30.5 million) in the 2024-25 Budget.[86] An enabling policy and regulatory environment helps make the necessary push towards public expenditure in computing infrastructure, data availability, and governance standards to facilitate the growth of the AI ecosystem.

Trust, risk, and security management

Trust, risk, and security management initiatives have gained ground due to the risk of adverse consequences stemming from AI systems and the need for compliance driven by regulatory development across jurisdictions.

In recent years, AI policy discussions have emphasised the role of user trust, risk mitigation, and security management as cornerstones of AI ecosystems. The 2023 G20 New Delhi Leaders Declaration and GPAI Ministerial Declaration reinforce the commitments of member states towards developing ethical, explainable, safe AI and responsible AI.[87,88] Risks stemming from AI involve the potential for bias and discrimination through skewed datasets and underrepresentation of women in the AI pipeline.[89] It involves privacy concerns when algorithmic learning comes to depend on personal information and gives rise to ethical dilemmas for contextualised decision-making by AI systems. Additionally, AI-driven cyberattacks and system-security threats remain significant causes

of concern, as does the use of AI-driven autonomous weaponry by non-state actors. Automation-spurred job displacement exacerbates existing socio-economic inequalities, with large-scale job losses reported across the sector.[90]

Another issue in this area is the rise in AI-generated synthetic information, misinformation, and transparency of datasets used by tech companies. The latter half of 2023 saw temporary bans and widespread concerns around adverse consequences of AI in the form of incorrect outputs, bias, deepfakes, and infringement violations. Various industry leaders have called for oversight agencies and the implementation of legal and ethical frameworks, seeking a halt in AI adoption until these issues are addressed.[91] Given the dynamic nature of AI evolution, jurisdictions have increasingly adopted a risk-based approach.

In 2023, the US's Executive Order on AI recommended that American policymakers and federal agencies should focus on eight areas: safety and security, innovation and competition, worker support, AI bias and civil rights, consumer protection, privacy, federal use of AI, and international leadership.[92] The National Institute of Standards and Technology (NIST) has developed the AI Risk Management Framework along with a Trustworthy and Responsible AI Resource Centre to help organisations manage risks associated with AI systems. This framework, to be implemented on a voluntary basis, aims to provide guidance on trustworthy and responsible AI use, emphasising the importance of security, explainability, and accountability. The framework addresses how institutions can frame AI-related risks and outlines four specific functions of governing, mapping, measuring, and managing AI risks.[93]

The EU's AI Act, adopted by the European Parliament in 2024, follows a risk-based approach. Under the Act, the system's obligations are proportionate to the level of risk it poses. It includes four risk categories: 'unacceptable risk', which involves prohibited activities; 'high risk', which involves a set of stringent obligations; 'limited risk', involving transparency obligations; and 'minimal risk', encouraging stakeholders to develop codes of conduct.[94] Following the Bletchley Park AI Safety Summit in November 2023, the UK government released its AI governance consultation outcome

in February 2024, recommending five cross-sectoral principles: safety, security and robustness; appropriate transparency and explainability; fairness; accountability; and governance, contemptibility and redress.[95]

India's MeitY had initially issued an advisory directing Big Tech companies to seek permission before launching 'under-tested' or 'unreliable' AI platforms in the country. However, this requirement was eventually dropped, but firms were told to label AI-generated content appropriately to inform users of the potential unreliability of the output.[96] The advisory also contains provisions for including metadata or identifiers to ensure traceability in the event of its misuse.

These diverse approaches to regulation underscore the global challenge of harmonising AI governance as nations strive to balance innovation with the need for oversight and ethical considerations. They also highlight the need for international collaboration to address the complexities of AI regulation and its impact on society.

Following concerns around AI risks accompanied by regulatory development across jurisdictions, trust, risk, and security management (TRiSM) has become one of the key emerging strategic trends driving adoption. TRiSM principles have been incorporated by the US's NIST, the World Economic Forum's guidelines on responsible AI, and by companies such as Microsoft, Google, Tesla, and Meta.[97] TRiSM programmes help build governance modalities and foster trust in the system. Aspects of a TRiSM programme include explainability or model monitoring, model ops, AI application security, and privacy.[98] By 2026, AI models from organisations that operationalise TRiSM programmes could see a 50 percent uptake in terms of adoption, business performance, and user acceptance. The global TRiSM market was valued at US$1.7 billion in 2022, with a projected rise of CAGR 16.2 percent between 2023 and 2032, rising to US$7.4 billion.[99] TRiSM programmes will help organisations swiftly respond to and comply with regulatory developments. AI models and apps require constant monitoring; as a result, specialised risk management processes need to be built into AI model operations. These controls will need to be applied continuously through the lifecycle, starting from model and application development, testing and deployment, and ongoing operations.[100]

Strategic alliances and partnerships

Strategic alliances and partnerships help to leverage mutual capacities to develop AI solutions, computational infrastructure, and skills and knowledge resources to build and adapt quickly within a rapidly evolving landscape while working on building indigenous capabilities.

The ubiquity of digital technologies means their development spans multiple national borders and involves geopolitical considerations. The focus on AI has been at the forefront of many strategic alliances. For instance, cooperation and partnership on critical and emerging technologies remain key agenda items for the Quadrilateral Security Dialogue (comprising India, the US, Japan, and Australia).[101] The US and India have expanded strategic technology partnerships and defence industrial cooperation through the initiative on critical and emerging technologies.[102] The US-India Artificial Intelligence Initiative highlights the importance of AI cooperation in critical areas with the need to scale up the science and technology relationship between the two countries.[103] In 2018, the UAE's Ministry of AI and Invest India inked a memorandum of understanding (MoU) to encourage investments in AI startups, research activities, and partnerships with the private sector.[104] The Comprehensive Economic Partnership Agreement signed between the UAE and India in 2022 further reiterated commitment towards a key partnership on AI as a strategic sector.[105] Similarly, Australia, Germany, and Japan have bilateral commitments identifying AI as a focal area for strategic cooperation.[106] India and Bangladesh have also agreed to expand strategic ties on AI, cybersecurity, and startups.[107] AI is also a part of EU-India strategic partnerships for 'A Roadmap to 2025' to promote technical and regulatory cooperation and sharing of knowledge and expertise.[108] This was reaffirmed in the India-EU Joint Statement following the first meeting of the Trade and Technology Council to coordinate bilateral cooperation on responsible AI through the GPAI.[109]

Notably, strategic partnerships are not limited to the government-to-government level, with many governments partnering with private

companies, particularly Big Tech. For instance, following the India-US joint declaration, MeitY signed a MoU with IBM to advance and accelerate innovation in AI by developing the national AI Innovation Platform to foster ecosystem growth by focusing on AI skilling and integrating foundational and generative AI capabilities. This would involve access to IBM's Watsonx platform to develop and train models across different application areas.[110] Meta has signed an MoU with IndiaAI under the aegis of MeitY to make Meta's open-source AI model available for use by the Indian AI ecosystem, leveraging Meta's AI research on low-resource language models and open data sets for low-resource languages.[111] India's Bhashini was developed through multistakeholder partnerships between the government, private sector, and academia. The Bhasini project had initial funding from EkStep Foundation and currently uses Microsoft's Azure platform. Tarento Technologies, Thoughtworks, and AI4Bharat are currently developing the code. AI4Bharat also contributed towards datasets and model development along with IIT Bombay, IIT Madras, IIT Hyderabad, and C-DAC.[112]

Apart from public-private partnerships, key partnerships among private companies have also been expanding the scope of ecosystem boundaries to develop AI computational capacity. In September 2023, the US chipmaker Nvidia and India's Jio Platforms announced a collaboration to develop India's foundation LLM trained on multiple Indian languages.[113] In September 2023, Infosys and Microsoft entered into a partnership to leverage mutual AI capabilities in the form of Infosys Topaz, Azure OpenAI services, and Azure Cognitive Services to develop integrated AI-enabled solutions to enhance enterprise functions across multiple industries.[114] In 2017, Airtel entered into a partnership with Amdocs, a software and service provider, to augment its initial relationship from billing to deeper innovation across business processes by deploying ML and AI to pre-empt and self-heal operational issues, introduce smartbots in digital channels, and quickly launch and activate new services to enhance customer experience. In March 2023, PwC India announced a partnership with Singapore-based Actyv.ai to drive the adoption of embedded finance in supply chain ecosystems for their clients.[115] These initiatives highlight the role of multiple actors spanning bilateral and multilateral agreements, public-private partnerships, and commercial tie-ups.

Research and development

Research and development helps shape the frontiers of innovation in AI, determining domestic and geopolitical competitive advantage while also commercialising such innovation as intellectual property for future revenue streams and valuations.

India has a significant stake in the global AI ecosystem because of a strong talent pipeline. India is the fourth-largest producer of AI-relevant scholarly papers., Between 2010 and 2021, China contributed the largest share of AI publications (39.78 percent), followed by the 'rest of the world' (22.70 percent), the EU and the UK (15.05 percent), and the US at (10.03 percent).[116] Even though India's contribution stood at 5.56 percent in 2021, it steadily increased from 1.3 percent in 2010.[117] China's share of citations in AI journals has gradually increased since 2010, while that of the EU, the UK, and the US have decreased. India's share rose incrementally to 6.05 percent in 2021. Mirroring similar trends, India's AI conference publications increased to 6.79 percent in 2021.[118] While India produces a significant quantum of AI-related research output, Indian researchers are less likely to collaborate with foreign authors than the top 10 AI-producing countries, undermining the research's impact. Established research fields provide the opportunity to expand the reach, with Indian authors co-authoring papers with those in the US five times more frequently than any other country.[119]

India ranks among the top 10 AI patent-producing countries.[120] According to a 2021 report, the four large categories of AI patents in India are personal devices and computing, business, telecommunications, and life sciences. Among the areas of traditional strength, these four categories comprise 70 percent of India's patent applications. While the Indian patent system has evolved in the last two decades,[121] and Indian companies have seen the benefit of protecting their innovations with patents, there is still a long way to go to catch up with China and the US, which currently lead the way in AI patents.[122] India had approximately 300 resident patent applications per US$100 billion of GDP compared to 5,738 in China and the US's 1,253.[123] This is compounded by legal and institutional challenges in the patent filing process intersected by higher cost, uncertain timelines, lack of expertise in the patent office, and cumbersome filing processes, coupled

with the lack of clarity on documentation, usability of the website, and awareness of patent schemes.[124] Moreover, certain legal provisions within the Patent Act, particularly section 3(k), complicate the issue of computer programmes or algorithms even counting as patentable inventions.[125] According to the section, computer programmes and algorithms per se are not patentable. Consequently, the section is interpreted differently by different controllers at the patent office and the courts.[126] This complicates the application of a uniform standard procedure to grant a patent to Indian computational and analytics inventions.[127] As a result of these challenges, Indian companies often get their patents through a firm in the US, where the entire process can be as short as two months.[128]

Recognising the role of research and development within the AI ecosystem, the establishment of three CoEs in AI at nodal educational institutions was announced, with INR 2.55 billion (US$30.5 million) allocated towards these in the 2024-25 Budget.[129] The CoEs aim to play a crucial role in positioning India in the global AI landscape through foundational and multidisciplinary research and the development and adoption of foundational AI technologies. Similarly, the Indian Institute of Science partnered with the Karnataka government to launch the US$100 million ARTPARK venture fund for AI and robotics startups.[130] However, while companies can file their patents overseas, the financially and procedurally complex nature of patent filing in India means academic inventions often get left behind.[131]

Despite having the highest penetration of AI talent, India lags behind in the global AI race because of the lack of high-quality training data, computing infrastructure, and funding.[132] Currently, Indian foundational models are still in the early stages of development with limited private investor buy-in for generative AI startups. Approximately 80 percent of Indian generative AI startups are not considered market-ready. Furthermore, there are no original India-based hardware manufacturers.[133] However, these are recognised shortcomings within the policy landscape, highlighting an administrative intent to address these issues. The National AI Mission aims to work towards building and supporting the AI ecosystem through a mix of public expenditure and supportive policies. This includes budgetary allocations for the AI mission, building institutional capacity, and supporting research and development.[134] One key aim is to build indigenous computing infrastructure, which the government is implementing through the National Supercomputing Mission, which aims to build high-performance computing infrastructure. The National Semiconductor Mission aims to develop national capacity in hardware components to propel AI innovation at scale.[135] The government's approach to developing the AI compute infrastructure is the same as its semiconductor mission, which is to incentivise private players and develop public sector capabilities through C-DAC.[136] With the potentially transformative use of quantum computers to accelerate AI development and deployment, the National Quantum Mission could lead to future synergies with the AI Mission.[137] Building an AI ecosystem in the country needs to grapple with India-specific issues, wide regional and linguistic diversity, and sector-specific considerations. The nature of the AI ecosystem development and expansion of ecosystem boundaries will depend on how the government, institutions, and firms interact.

Moreover, there is a regional variation in innovation and startup density. For instance, the Greater Bengaluru region has the highest concentration of GenAI startups (45 percent of all major Indian cities), driven by the city's existing startup ecosystem and the extensive presence of industry and domestic angel investors. With 21 percent of startups, the Mumbai and Pune region has a diverse talent pool and a wide presence of institutional investors and venture capital. The Delhi National Capital Region (10

percent startups) has an extensive presence of knowledge-based advisory industries, and provides an impetus to startups innovating for those categories while also having premier educational institutions and recent college graduates. Hyderabad has leading innovation infrastructure, and Chennai is the software-as-a-service hub with research and development labs of global capability centres.[138] This highlights a need to foster access, support, and resource distribution to democratise innovation opportunities to achieve deeper regional penetration while supporting the existing ecosystem.

India has allocated INR 100 billion (US$1.2 billion) to its AI mission.[139] In comparison, the US government departments allocated US$1.7 billion for non-defence AI research and development, with government contract spending on AI increasing from US$2.7 billion in 2017 to US$3.3 billion in 2022.[140] In 2022, the private sector invested US$47.4 billion in the US, roughly 3.5 times the amount invested in the next highest country, China (US$13.4 billion), and over 14 times what was invested in India (US$3.24 billion).[141] China's public investment in AI research and development was in the range of a few billion dollars in 2018, based on provisional open-source estimates,[142] with reports indicating China's AI market will exceed US$26.69 billion in 2026, accounting for about 8.9 percent of global investment. AI spending will lead AI investment growth with a five-year CAGR of 24.3 percent in China and is expected to exceed US$2.51 billion in 2026.[143]

As India works towards laying the foundations for its AI ecosystem, these comparative figures bring into perspective the financial outlay and public investment required to build and sustain national AI capabilities. Chinese central government support through its five-year strategic plans and support of AI research clusters through universities and enterprises quickly translated to AI dividends. This approach contrasted with the US, wherein the Big Tech companies drove AI-related research investments.[144] A government push helped in greater downstream adoption of AI; 87-89 percent of companies in China are looking towards AI adoption driven by demand from customers and suppliers, compared to 61-72 percent of companies in the US and 63-69 percent in the EU.[145] In China, large technologies companies were driven by the government to

establish AI libraries and platforms to enhance ecosystem linkages and allow small and medium enterprises to access technology at a lower cost. The Chinese government got established technology giants like Alibaba, Tencent, SenseTine, and iFlyTek to lead in developing specific AI capabilities. It formed a task force comprising 15 member companies that exported capabilities through collaborations on open data, algorithms, models, and applications for smaller companies and startups that helped China to develop both foundational AI capabilities and push for sectoral transformation.[146] This is in contrast to the US, wherein AI-led transformations have primarily been led by established and fast-growing technology companies that are vertically specialised and propelled by significant venture capital funding.[147]

India has taken a different approach than China's tightly controlled government-led model and the US's laissez-faire venture capital-funded hyper-growth model. While both approaches have yielded enormous technology-driven economic dividends for the two countries, they have also highlighted the potential for market disruption through overvaluation and layoffs or limiting the generative potential of AI innovation through directed state action. India has taken a deliberative approach to understand and implement the necessary supportive strategies to develop and grow its ecosystem by balancing the necessities of developing indigenous AI capabilities while also creating an enabling environment for innovation through strategic partnerships between and among different groups of stakeholders. This highlights an approach of collaborative self-reliance to leverage existing capabilities while developing indigenous ones. While this approach spans different policies within the AI domain with long-term planning, it must be extended to leverage the existing but untapped potential, collaborate on missing capabilities, and develop its indigenous infrastructures and platforms. This would involve:

- ***Establishing interoperability and data standards in government data***: One of the primary issues is small, siloed, and distributed datasets that are not amenable to multiparametre algorithmic training. This highlights the need for uniform interoperability and data standards across all data generated by the government. With big companies having economies of scale regarding this critical component, this

would help democratise innovation for startups and small and medium firms by enabling access to data to solve extant socioeconomic problems.

- ***Outlining a roadmap for transitioning to indigenous capabilities***: Big Tech companies control most of the critical infrastructure required to build AI models. India is currently looking to develop its AI enablement and product infrastructure through public-private partnerships and design-linked incentive schemes. The development and deployment of Bhashini showed the intent to transition to indigenous technologies. While the government aims to support innovation through collaboration, given the economies of scale enjoyed by technology companies, it would be beneficial to develop a roadmap for developing and transitioning to indigenous capabilities to identify timelines and milestones to not only reduce dependence but also lower barriers of access and entry for AI innovation and development.

- ***Identifying strategic areas of public investment***: India currently needs indigenous foundational models, AI infrastructural enablers, and AI production platforms. While AI has figured prominently in successive budgets, future public expenditure should identify areas of strategic intervention to acquire, develop, and build public AI capabilities. This would involve supporting domestic startups and hardware providers in developing foundational capabilities that do not make the cut for venture capital funding. Insights from the experience of ChatGPT and its evolving organisation composition from a non-profit to a capped-profit company with billions of dollars of investment from Big Tech firms indicate the time, resource, and organisational investment required to build such capabilities, which can be anchored through the proposed CoEs.[148]

- ***Supporting the open source community:*** India has the highest share of contributors to AI projects on GitHub, coupled with high skills penetration and a large graduate cohort. Supporting the open source community will help leverage the country's existing human resource capabilities to drive AI momentum while also decentring the locus of power and dependency on Big Tech companies.

- ***Fostering research and development environment and talent retention:*** To take a leadership position on the world stage, India will need to develop its AI research and development capabilities. In addition, it will need to build capacities for the skill and talent demand required for AI-led transformations. Beyond technical and computational skills, these include regulatory talent, skilling of patent officers, and legal talent to translate value propositions of complex innovations. Apart from the proposed CoEs, which can potentially become the hubs for cutting-edge research, India will need to create a research and development environment that encourages talent to remain in the country through attractive postgraduate research support and research facilities, intellectual property (IP) support and advisory, and streamlining IP application and processes.

- ***Establishing TRiSM standards:*** TRiSM approaches help to operationalise AI safety and responsibility principles within business processes. MeitY's revised advisory highlights the regulatory intent to develop guardrails for evolving AI systems. Establishing AI TRiSM standards will help ease compliance and promote trust in AI systems. It will also help companies streamline AI development and operations.

Conclusion

India is currently laying the groundwork for developing AI capabilities to become one of the leading countries for AI. Its current deliberative approach, driven by expert group recommendations, will help enhance AI capabilities in the country through an appreciation of the need to develop capabilities and institutional capacities for its key drivers. India stands to gain through collaboration to leverage existing and mutual capabilities in its journey towards self-reliance. This can work to democratise innovation while developing and expanding indigenous capabilities.

This paper provides an overview of the emerging AI ecosystem in India to identify its constituent elements and principal drivers. Taking a holistic ecosystem-level approach offers insight into the state of the field in the form of current trends and policy and regulatory developments. This required attention on different aspects of the AI ecosystem as a whole, precluding a deeper engagement with the constituent elements or individual policies and legislations. There is scope for future research to assess the potential of the guidelines, legislations, and aspects in leading transformative changes or their contrasts. A challenge in writing about a rapidly evolving field like AI is how quickly technical and regulatory developments can become outdated. As a result, the examples cited are aimed to indicative and illustrative as opposed to exhaustive. Taking an ecosystem-level approach to outline the conditions, actors, and resources required to expand ecosystem boundaries and, thereby, national AI capabilities helps to understand how dynamic challenges and opportunities in each of these segments stand to be negotiated within and across diverse ecosystem elements.

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