Tortoise

The Global AI Index

Methodology

DECEMBER 2020

The Global AI Index

In 2019, The Global AI Index (GAII) became the first to rank countries based on capacity for artificial intelligence; specifically by measuring levels of investment, innovation and implementation. In the year that has passed, Tortoise has worked to extend the scope of the index and to further analyse the international landscape across the areas of talent, infrastructure, operating environment, research, development, commercial ventures and government strategy.

As a composite index, The GAII draws on a range of sources, measuring the national ecosystems on which the creation and use of artificial intelligence depends. Artificial intelligence, in its still broad and mysterious sense, remains the subject of much public debate, media hysteria and political contention. The publication of national strategies for artificial intelligence has accelerated, with many countries seeking to refresh or amend the approaches that were set out in previous years. In 2020, The Global AI Index is focused on making sense of artificial intelligence in 62 countries around the world.

Special Thanks

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1.0 Methodology Report Overview

This report details the underlying methodology of The Global AI Index, including the reasoning for the structure of the Index, the various techniques behind the data collection, imputation, weighting and scoring.

As a composite indicator, The Global AI Index uses a variety of interrelated measures to define and describe an underlying, multidimensional concept. In the case of The Global AI Index, this concept is 'capacity for artificial intelligence', understood as a combination of connected factors which fall broadly into the categories of innovation, implementation and investment.

This methodology report is intended to serve as a reference point for anyone looking to make sense of the scores, rankings and findings of The Global AI Index, but also to those looking to make sense of the landscape of development and deployment out in the world when it comes to artificial intelligence.

2.0 The structure of The Global AI Index

The Global AI Index is structured around three main pillars: investment, innovation and implementation. The investment pillar contains two sub-pillars: commercial ventures and government strategy. The innovation pillar contains two sub-pillars: research and development. Finally, the implementation pillar contains three sub-pillars: talent, infrastructure and operating environment.

The structure is important consequential for two reasons. Firstly, it helps to define the concept of The Global AI Index and the way that the indicators are grouped together. Secondly, it helps to demonstrate the reasons for which we believe the various parts of The Global AI Index are all contributors to the overall measure of capacity.

The indicators - by which we mean each individual metric in the Index - sit within the sub-pillars which are grouped by associative themes.

Implementation - these metrics reflect the operationalising of artificial intelligence by practitioners in business, government and communities.

Innovation - these metrics reflect technology breakthroughs and advancements in methodology that are indicative of greater capacity for artificial intelligence in the future.

Investment - these metrics reflect financial and procedural commitments to artificial intelligence.

2.1 Why capacity?

At present the availability of information is growing rapidly, and the question as to how to manage and interpret this information is growing more urgent. Composite indicators meet the need to consolidation - through aggregation - a large amount of data into a set of simplified numbers that encompass and reflect the underlying complexity of the information. All indices constructed from composite indicators should be interpreted with caution, and scrutinised carefully before important conclusions are drawn out. In alignment with the OECD 'Handbook on constructing composite indicators'; 'capacity' is the multi-dimensional concept and the underlying model around which the individual indicators of The Global AI Index are compiled.

Capacity - the amount of something that a system can contain or produce - is the organising concept of The Global AI Index. It is an appropriate means of considering the relationship between the different relevant factors that exist within a given nation. Increased capacity, in this case, can be understood as an increased ability to generate and sustain artificial intelligence solutions, now and in the future. The Artificial Intelligence for Development Organisation talk about 'capacity' for exactly this reason; it speaks both to the current organisation of productive factors that contribute to technological development, as well as future potential for generating new innovations in their use, and in the design of the technologies themselves.

At a national level, greater adoption of artificial intelligence means both that; a rising quantity of systems, initiatives and personnel are becoming active in the field, and that the quality of these factors is also improving. In this way, capacity for artificial intelligence expresses both the breadth and depth of adoption - a quantitative aspect - as well as improvements in a given nation's ability to manage and sustain artificial intelligence systems in a productive, safe and fair way - a qualitative aspect.

The Global AI Index is based on the definition of capacity for artificial intelligence as having three major constituent parts, or pillars; investment, innovation and implementation. Within each is the underlying level of interconnectedness and mobility that is not normally constrained by national borders. The three parts, therefore, are taken to represent large domains of activity that can be linked to a national entity. The decision to separate our conceptual understanding of capacity for artificial intelligence, and therefore the structure of The Global AI Index, into these parts was a consequence of lengthy discussion with our expert advisors, as well as extensive consultation of a range of literature and contemporary commentary surrounding artificial intelligence.

2.2 Update for The Global AI Index 2.0

The concept of 'capacity' remains both relevant and informative. The majority of national strategies for artificial intelligence take this as a central organising factor. Specifically, we have seen further discussion of capacity building within government, and in the wider population when it comes to data literacy, digital inclusion and open data.

Our current metrics for the level of education, re-usability of public data and diversity amongst researchers and technicians are a key focus of the index, because they are also a key focus for policy-makers. In the full indicator table (available here) we have reflected this focus in the descriptions and several weightings adjustments within the framework. All changes made to the methodology for this second edition of the Index and rankings

are detailed in this report.

Gross capacity and intensity

Across many of the indicators included in The Global AI Index it was possible to create both a gross, and a proportional score that was relative to population, size of labour force or GDP. An important question as to whether it is reasonable to compare nations of vastly different sizes when considering capacity. Ultimately we have chosen to present the Index as a combined score; featuring both combined, gross and intensity indicators. It is an interesting consideration around which we plan to do more investigation; but we welcome any specific commentary on this point.

We believe it may be interesting to highlight both the gross capacity for artificial intelligence according to our data, as well as the intensity - a measure in which many smaller nations will rise to the top.

2.3 Pillars & Rationale

This section shows the organisation of the sub-pillars and offers a justification for the inclusion of the sub-pillar - and constituent indicators - in The Global AI Index. These justifications reflect our understanding of the interrelated factors that contribute to capacity on a national scale.

We recognise that the fast-changing processes of innovation and implementation in artificial intelligence will require constant re-examination. We have sought to host a lively conversation about the relationship between the pillar and sub-pillars of the Index, and will welcome further commentary of all kinds.

Pillar	Sub-pillar	Rationale
Implementation	Talent	Artificial intelligence is implemented by people. This refers to the everyday practitioners of artificial intelligence who are employed by the public and private sector to apply technology to specific problems. Capacity, therefore, is based substantially on the personnel able to deploy and manage systems.
Implementation	Infrastructure	Reliable infrastructure from basic electricity and internet access, as well as super computing capabilities10 and deep databases are required to sustain and build on artificial intelligence solutions of different kinds. Capacity from infrastructure is vital for the sustained use of artificial intelligence.

Implementation	Operating environment	Technologies thrive when the wider society approve of them. Countries should also focus on developing strong public information initiatives, trust, and recognition in the public sphere. Capacity results from a conducive operating environment.
Innovation	Research	Research and researchers generate new ideas in artificial intelligence. Capacity as a result of research is substantially based upon the level of activity amongst research communities and the extent to which they share and propagate ideas.
Innovation	Development	Innovation is demonstrated by the development of new techniques and advancements - especially in the field of artificial intelligence. Development, in these terms, is the addition of new models, techniques and products to existing fundamental platforms. Patents, and the level of activity on open-source fundamental packages for artificial intelligence are an indicator of capacity through development.
Investment	Commercial ventures	Commercial ventures - businesses that are providing goods and services through the combination of financial and industrial aspects - are responsible for a large proportion of the implementation of artificial intelligence around the world. The scale, funding and volume of these businesses is a contributor to capacity.
Investment	Government strategy	Government strategies - often a collection of publications outlining approaches to digital transformation, innovation and artificial intelligence - are an important aspect of capacity on a national scale, they detail commitments to invest, align interests in research communities and express a macro-level approach to combining useful factors.

2.4 The sub-pillars

Talent

'Artificial intelligence' is a broad discipline, and it has a diversity of associated specialists. The geographical concentration of these specialists, their movements, and the changing supply and demand for them across the field is the focus of the 'Talent' sub-pillar. The purpose of measuring talent is to define the level of capacity offered by human capital within a given nation. This is in order to establish which nations have the deepest pools of specialised labour to operationalise artificial intelligence. Capacity of this kind is needed to develop new machine learning techniques, test said techniques, establish

feedback loops, acquire data and manage end-of-chain products. Practitioners also play a vital role in ensuring that systems using AI are adequately regulated and overseen.

The 'Talent' sub-pillar sits within the 'Implementation' pillar of the Index; this is because it investigates the presence, availability and skill level of practitioners of artificial intelligence technologies who are able to implement, or apply them in business and other institutions. Talent, meaning the appropriately skilled individuals in a given labour force, is a vital part of the ecosystem for developing artificial intelligence in society; it is the human decision makers that govern the processes and institutions that shape technology.

Infrastructure

Infrastructure - the physical and organisational structures that underpin the use of certain technologies and the conducting of certain activities - is an important prerequisite for the adoption of artificial intelligence. All industries require physical infrastructure to ensure that their work can be done effectively and efficiently. The shipping industry requires ports and access to high quality shipping vehicles, retail companies require high streets and roadways for distribution. Artificial intelligence is no different in its requirement for underlying infrastructure.

To focus specifically on what the requirements are: countries need a baseline infrastructure in order to be able to maintain and expand artificial intelligence initiatives. This includes a steady electricity supply and fast broadband speeds in their major cities. It is even better if a country can maintain a high quality standard similar across smaller towns and rural areas. In addition to this, the 'Infrastructure' sub-pillar focuses on supercomputing capacity and networking infrastructure. The 'Infrastructure' sub-pillar sits within the 'Implementation' pillar of the Index; this is because it investigates the present of infrastructure that facilitates the operationalisation of artificial intelligence.

Operating environment

The operational environment stands for political, social, legislative, economic, cultural and natural environmental factors that significantly affect the implementation of any cooperation. A high appetite for artificial intelligence in the community will accelerate the adoption of that technology. Cooperation over the successful implementation of artificial intelligence technologies relies to a certain extent upon the public appetite for such adoption, as well as the prevailing level of understanding of said technologies.

Therefore, businesses and government can contribute to capacity by cultivating and educating the broader population in the merits of artificial intelligence, whilst also listening and acting on their experiences and concerns. On a wider level, there needs to be trusted checks and balances to ensure that institutions, both commercial and governmental, are not abusing opaque methodology to create unfair power structures. The 'Operating Environment' sub-pillar focuses on survey data indicating trust in artificial intelligence, the diversity of practitioners, visa processing and governance of data. It sits as the final part of the 'Implementation' pillar of the Index as it is concerned with facilitating factors.

Research

Research is a major driving factor for innovation in artificial intelligence. The volume and impact of research, as well as the researchers generating it is the focus of the 'Research'

sub-pillar. The purpose of measuring the level of research is to reflect the level of capacity for innovation being generated by professionals focusing on artificial intelligence in a given nation. It considers the number of papers, and the citations, their impact according to the H-Index, as well as attendance at conferences and contributions to IEEE journals. Also considered is the standard of higher education and the number of artificial intelligence societies.

The 'Research' sub-pillar sits within the 'Innovation' pillar of the Index because it is indicative of the advances in understanding and capability that contributes to capacity through new innovations.

Development

Development, like research, is aimed at generating new and useful contributions through innovation. It sits one stage further in the value chain of delivering artificial intelligence solutions; being concerned with the creation of new prototypes and changes to fundamental software. The 'Development' sub-pillar focuses on collaboration on open source artificial intelligence platforms, the ISO Artificial Intelligence Committee status, and several indicators describing the level of patentable innovation.

The 'Development' sub-pillar sits within the 'Innovation' pillar because it is a contributor to capacity through innovative new products and processes. Building on understandings conceived of during research stages, the development of artificial intelligence takes steps towards implementation; highlighting the interconnectedness of the factors measured by The Global AI Index.

Commercial ventures

Businesses have taken a leading role in the development of artificial intelligence, as well as being the major centres of adoption. The increases in productivity, efficiency and reliability that machine learning can provide are all significant enhancements to business performance. However, this is not a universal truth, nor a blanket statement about all business sectors; some are better suited to automation through implementation of artificial intelligence than others. PwC's 'Sizing the Prize' Report provides some considerations of which commercial ventures stand to gain the most in terms of capacity from adopting artificial intelligence systems. The 'Commercial Ventures' sub-pillar is focused on the industrial environment surrounding artificial intelligence in a given country. Ventures themselves, are taken to be risk-bearing businesses nominally focused on artificial intelligence, or artificial intelligence-enabled processes. The sub-pillar analyses the number, scale and funding of such ventures.

Government strategy

Government strategies focused on artificial intelligence are a relatively new phenomenon. The spate of publications since 2016 is indicative of the importance of artificial intelligence to governments as service and security providers. The content, presentation and apparent urgency of these national strategies is the focus of the 'Government strategy' sub-pillar. The purpose of the indicators included in this part of the Index is to establish which nations have committed through outlining spending and targets.

The 'Government strategy' sub-pillar sits within the 'Investment' pillar of the Index; this is to identify strategy approaches as a significant financial and procedural investment into

artificial intelligence. Many aspects of the government strategy documents do speak to other parts of the The Global AI Index framework; but for the purposes of structuring the Index in a coherent way, the investment inherent in the government strategy documents justifies its placement.

3.0 Indicator selection criteria

Relevant

Each of our variable speaks to a contemporary policy area, or ongoing conversation in business. This is to say that they resonate as generally relevant factors when considering the field of artificial intelligence. For example, 'Number of Paper in accepted IEEE Papers on artificial intelligence topics' is a factor that features regularly in contemporary discussion.

Relatable

Many of our variables is selected to be accessible to specialists and non-specialists alike. This accessibility makes the Index more transparent, allowing users to question inclusions and the relationships that they show. The phrasing of each indicator, shown in full in the indicator table in this report, should be clear and understandable.

Sizeable contribution

Finally, our indicators are selected due to the sizeable contribution that they make to the overall level of capacity in a given nation. In this sense, we have aimed to include indicators that are widely referenced and considered on the basis of their significance. For example, the 'Number of Data Scientists' is widely regarded in commentary as not only relevant and relatable as a means of measuring some nations' capacity; but it is also seen as making a significant contribution to that capacity. By contrast, a potential indicator - 'Choice of programming language amongst developers' in a given nation is not included as the indicator would not highlight a significant contribution to capacity, whilst the discussion of Python, C++, Javascript and Scala etc. as alternatives is surely relevant and relatable.

3.1 Quantitative and qualitative variables

The Global AI Index includes most quantitative data i.e. the number of Data Scientists, Artificial intelligence startups or GitHub Stars. For the purposes of scoring these values translated directly into comparable scores. In a small number of cases, qualitative data is included. In these cases e.g. IPSOS "I do not trust artificial intelligence survey" Response data, qualitative data is packaged a quantitative; showing the overall percentage results of the survey.

3.2 Establishing relevance & definitions

Across the full range of national strategies for artificial intelligence published in recent years, the definition of 'artificial intelligence' itself is inconsistent. This is due to a lack of consensus when it comes to identifying the cluster of technological products and methodologies that make up the domain of AI; this inconsistency means that many strategies remain vague, conceptual and cross-sectoral.

The implications for The Global AI Index of this lack of consensus is that we have adopted a keyword approach to identifying entities that are related to artificial intelligence. These keywords were identified in conjunction with our advisors, and were based upon whether they were an indicator which recorded genuine activity in the artificial intelligence domain.
Below is a compilation of the keywords used across the range of analysis we have conducted involving web scraping and searching. This is a part of the methodology that we will endeavour to keep as relevant and up to date as possible in future editions.

Artificial Intelligence	Supervised Learning	Computer Vision	Speech Recognition
Machine Learning	Unsupervised Learning	Image Recognition	Intelligence Systems
Deep Learning	Neural Networks	Facial Recognition	Virtual Assistant
Reinforcement Learning	Natural Language Processing	Face Recognition	Autonomous Vehicle
Predictive Analytics	Robotics	Self-driving	

The lack of a single, clear and agreed definition of 'artificial intelligence' does not prevent us from establishing the relevance of some terms and phrases to the field in general. This is to say that the vague and inconsistent definitions used in the national strategies mostly reflect the difficulties of strictly defining the field, rather finding factors that are closely relevant to it.

The Global AI Index does not propose another such definition; rather it takes a broad and inclusive look at those entities that are clearly of specific relevance to artificial intelligence. In future iterations of the Index we will reconsider the relevant keywords and conduct another series of research and consultations with our experts to refresh the list. In this edition we understand artificial intelligence to be "a discipline focused on building machines that emulate human cognition; helping them to perform tasks and serve purposes through a form of intelligence" and have conducted our research accordingly.

4.0 Geographical scope

The rapid transformation of public and private sector activities by artificial intelligence is a global phenomenon. Whilst the pace of change is faster in some regions than others, The Global AI Index is global in scope. With the aim of including as many nations as possible whilst maintaining the robustness and relevance of the underlying data-set; the second edition of the Index includes 62 countries.

4.1 Nations included in The Global AI Index

Argentina	Hong Kong	Mexico	South Korea
Australia	Hungary	Morocco	Spain
Austria	Iceland	New Zealand	Sri Lanka
Belgium	India	Nigeria	Sweden
Brazil	Indonesia	Norway	Switzerland
Canada	Ireland	Pakistan	Taiwan
China	Israel	Poland	The Netherlands
Czech Republic	Italy	Portugal	Tunisia
Denmark	Japan	Qatar	Turkey
Egypt	Kenya	Russia	United Arab Emirates
Estonia	Lithuania	Saudi Arabia	United Kingdom
Finland	Luxembourg	Singapore	United States of America
France	Malaysia	South Africa	Uruguay
Germany	Malta		
Armenia	Bahrain	Chile	Colombia
Greece	Slovakia	Slovenia	Vietnam

In future editions we hope to expand the geographical scope of The Global AI Index to include more nations; not only will this deepen the comparative relevance of The Global AI Index, but it will also signal that it is not only the global north and OECD nations currently forming the vanguard of development that have a part to play in the rise of artificial intelligence solutions.

We validated the list of nations included in the index in discussion with our expert advisors, as well as through literature review. No one exhaustive study of national artificial intelligence strategies exists, yet beginning with those nations that had published stated initiatives related to artificial intelligence and the digital future provided a basis for listing countries in which the availability of data would be sufficient for ranking.

5.0 Data Sources

The vast majority of sources used for The Global AI Index are publically available and open source; only one of which is proprietary. This was the Crunchbase API, which was drawn on for data in the 'Commercial Ventures' sub-pillar.

A full list of the sources used in the The Global AI Index is available in the indicator table.

5.1 Missing values

Missing values represent approximately 4.5% of the collected data-set for The Global AI Index. There was a limited amount of data available with which to train an imputation model - although this was strongly considered as an option - and as such there are a variety of imputation techniques employed. Each indicator has been individually considered and one of the following strategies applied:

Imputation by zero - used when data is not pre-defined but is the logical or necessary value; e.g, if the number of Kaggle Grandmasters is empty it is most likely because a country has never had one.

Imputation by average value - used when the variable in question is independent of a country's population size or GDP; placing the mean or median value in place of a missing value.

Imputation by last observation carried forward - used when alternative data sources show only values from previous years; in some cases previous values are taken as indicators of a country's current state.

Imputation by model - used in observation of obvious relationships between a country's demographics - population, GDP, employment rates, etc. In some cases it was necessary to build a generalised linear model to predict what value should be used.

Imputation by aggregated k-nearest neighbour search - used in the several cases where a model is inadequate, an average of all countries is not sensible or there are no previous values for an indicator. In these cases it was necessary to implement a k-nearest neighbours algorithm, with k=3, in search of the most similar countries (by region, population, GDP) for a particular observation. When these countries are identified, the imputed value is the median average of those 3 most similar countries.

5.2 Missing values table

Below is a table of the full extent of missing data and corresponding indicators, as well as the sub-pillars in which they sit.

Sub-pillar	Indicator	Number of missing data values	Imputation Strategy
Talent	Share of Enrolments in 'Artificial Intelligence', 'Machine Learning' Courses, gross and per capita	14	Impute by Median
	Number of IT Undergraduates/ pop. (UNESCO)	8	Impute by nearest neighbour search
	Number of SCI Undergraduates/ pop. (UNESCO)	8	Impute by nearest neighbour search
	Number of IT Graduates/pop. (UNESCO)	8	Impute by nearest neighbour search
	Number of SCI Graduates/pop. (UNESCO)	8	Impute by nearest neighbour search
	Number of STEM Graduates/ pop. (UNESCO)	8	Impute by nearest neighbour search
Infrastructure	Average Download Speed	1	Impute by nearest neighbour search
	Proportion of Population using Internet	1	Impute by nearest neighbour
	Cloud adoption of AI professionals (Kaggle Machine Learning & Data Science Survey)	14	Impute by nearest neighbour search
Operating Environment	Gender Diversity of IT Graduates	8	Impute by nearest neighbour search
	Gender Diversity of Science Graduates	8	Impute by nearest neighbour search
	Speed of Visa Processing for Skilled Worked, or Equivalent	8	Impute by maximum

	Dependents Allowed as Part of Visa Processing	8	Impute by 0
	Level of Cloud Adoption amongst 'AI professionals'	14	Impute by median
	Length of residence permitted by visa	7	Impute by median
	OURdata Index Global Score	33	Impute by 0
	Kaspersky Cybersecurity Score	12	Impute by median
Commercial	Average Days taken for approval by patent office	45	Impute by median
	Average Funding to 'AI Startups'	3	Impute by 0
	Average Funding to 'AI Company'	3	Impute by 0
Research	Highest Rank on H-Index	25	Impute by 0
	Number of Researchers	10	Impute by nearest neighbour search

5.3 Normalisation and data processing

To ensure that the data underlying the Index rankings is comparable, it was necessary to normalise each data point to a [0,1] scale. In the processing of this normalisation, it was occasionally necessary to transform the distribution of values i.e. a square root transformation is relevant if the higher end of the values for a particular indicator are having a disproportionate impact on the distribution and therefore the scoring.

This was required as we had a range of different data types including binary, continuous, ordinal and proportion variables.

$$xnew = (x - xmin) / (xmax - xmin)$$

The remaining variables were also normalised to comparable scales, but due to the distribution of the data it was sometimes deemed necessary to transform the values, e.g square/square root transformations, before normalising.

Many of the variables are treated in comparison to other values to ensure relevance and comparability.

5.4 Element AI & The Global AI Talent Report

The Global AI Index now includes a range of metrics gathered as part ofThe Global AI Talent Report. Due to the similarities between the methodological approach taken by Element AI in compiling the Global AI Talent Report, and the techniques used by Tortoise to collect data for the 'Talent' Pillar in the Index, we have developed our partnership by including those figures from the Global AI Talent Report. This affects the following indicator clusters:

Talent	Existing Number of 'Data Scientists', per capita, per working population, and proportion of total.
	Existing Number of 'Machine Learning Engineers', per capita, per working population, and proportion of total.
	Existing Number of 'Artificial Intelligence Engineers', per capita, per working population, and proportion of total.
	Existing Number of 'Data Engineers', per capita, per working population, and proportion of total.

5.5 Currency Adjustments

When dealing with currency values, we have converted all values to USD so that they are comparable. As our values come from various time periods, we endeavour to use an appropriate average for each country.

The majority of our currency information comes through Crunchbase, who have a USD version of all their funding amounts.

5.6 Temporal coverage

The Global AI Index uses the most recent available values when possible. All values carried forward are done so from no earlier than 2016; and a data-collection cut off from 2016 onwards was also enforced.

For the purposes of our analysis, we have also considered the temporal range for a 'Startup Company' to be foundation since 2016.

6.0 Scoring methodology

A country's total score is made up of the weighted normalised sum of its sub-pillar scores. The score for a sub-pillar is then in turn the normalised weighted sum of all the indicators within the sub-pillar. This allows us to compare indicators within a given sub-pillar, such as talent, rather than comparing all individual indicators. By normalising each of the pillars between 0 and 1 we make them comparable, and can account for any importance using the above sub-pillar weightings.

6.1 Weighting methodology

The indicators in The Global AI Index are weighted according to three specific considerations; relevance to artificial intelligence, contribution to artificial intelligence capacity, and data quality.

Weighting for relevance

Each indicator has been considered according to its relevance to the investment, innovation and implementation specific to artificial intelligence. Whilst we maintain that all inclusions in the Index can be justified by this relevance; it is important to reflect in the weightings that some factors are more closely related than others.

Our assessment of relevance is based on the apparent connections between the indicator itself, and the overall change in artificial intelligence capacity. For example, we consider 'Existing Number of 'Data Scientists' to be a highly relevant factor in contributing to capacity - and are therefore heavily weighted in the 'Talent' sub-pillar of the Index. Whereas 'Percentage access to electricity' is considered a less relevant factor, whilst still being clearly connected to capacity. It is, therefore, less heavily weighted in the 'Infrastructure' sub-pillar of the Index.

Weighting for contribution

Each indicator has also been considered according to its contribution to overall capacity through investment, innovation and implementation. Again, we maintain that all inclusions make a contribution towards capacity in some way; but it is important to reflect, also, that some factors contribute more heavily. For example, we consider 'Number of Data Scientists' to be a significant contributor to capacity - and therefore weight this indicator more heavily than others. Whereas 'Question to Answer Ratio on StackOverflow' is an indicator that highlights an important, and relevant factor, but does not represent as great a contribution to capacity.

Weighting for comprehensiveness

Finally, each indicator is considered on the basis of the comprehensiveness of the source data-set from which it is drawn. Some sources are more complete than others - alongside the process of imputation for missing values - it is also necessary to account for the completeness of the data in the weighting system. In the case that data availability is limited we have reduced the relative weight of the indicator. For example, the 'Number of Kaggle Grandmasters' is derived from very comprehensive data-set in which there are no missing values. The degree of confidence that we have in the representativeness of the data means that we can weight this factor more heavily. Whereas, the 'Proportion of the Population as IT Graduates' is derived from a much less comprehensive data-set. The purpose of weighting for comprehensiveness is to ensure that the overall scoring in The Global AI Index is, as far as possible, based upon reliable information; reducing the relative impact of more unreliable data on the rankings.

Pillar	Weighting
Talent	5

Infrastructure	3
Operating Environment	2
Research	5
Development	3
Government strategy	1
Commercial ventures	5

What is the effect of the weightings?

Each layer of the weighting system for The Global AI Index adds to the accuracy, completeness and explanatory value of the comparative rankings. It is intended to account for the fact that contributions to capacity for artificial intelligence take many different forms, and have varying degrees of impact present and future levels.

We recognise, however, that our weightings are based on subjective assumptions, and judgements applied in order to improve the coherence of the data. These subjective judgements affect the composite scoring for each company and therefore their position in the rankings.

Example weighting case

"Existing Number of Data Engineers" is gathered from LinkedIn returns. This means that the level of comprehensiveness is questionable; mostly due to the fact that many data engineers or equivalent may not be listed on LinkedIn or have sufficiently identified themselves as such. The weighting for comprehensiveness is therefore set at a 4. The contribution made by Data Engineers to capacity for artificial intelligence is significant as artificial intelligence is a generic and multidisciplinary domain in many ways and so Data Engineers are able to work in collaboration with practitioners in many different sectors. For these reasons, the weighting for contribution is set a 5. Finally, the title 'Data Engineer' is not specific to artificial intelligence, in that many data engineers work across a range of tasks that do not specifically involve artificial intelligence. As such, the level of relevance is questionable, and the weighting is set at a 3.

Fundamentally driven by human capabilities. Especially in the case of implementation, where practitioners are overcoming procedural challenges that require significant competence and understanding.

7.0 FAQs

Why have we built the Index?

Tortoise are fundamentally committed to data-driven news. We pursue a deep understanding of processes to inform our journalism and our conversation with members. We are also responding to the need amongst governments for a more comprehensive tool for identifying these processes. The Global AI Index is part of our investigation of

artificial intelligence - recognising that it is one of the defining forces shaping our world today.

Why is it an index then? And not just a set of presentations of data?

At Tortoise we believe in the agenda setting power of indices. Not only do they allow for tracking of important processes through carefully selected metrics, but they also invoke repeated comparison. In future editions, and by refining our methodology in open discussion with our members, experts and any other interests we hope to base policy recommendations, stories and observations about artificial intelligence on relevant data. Comparison is key to this, highlighting factors that affect change in some places.

We see this journalistic intent a complementary to a further set of strengths of the index format; following a framework provided in the OECD review "Composite Indicators – A review Michaela Saisana Group of Applied Statistics Joint Research Centre European Commission"22

- To summarise complex or multi-dimensional issues.
- To place countries' performance at the centre of the policy arena.
- To offer a rounded assessment of countries' performance.
- To enable judgments to be made on countries' efficiency.
- To facilitate communication with ordinary citizens.
- To be used for benchmarking countries of best performance.
- To indicate which countries represent the priority for improvement efforts.
- To stimulate the search for better data and better analytical efforts.
- To set local priorities, and to seek out improvements along dimension of performance where gains are most readily secured.

How did you carefully select your metrics?

We selected our metrics through consultation with our expert advisors, who helped us to build an understanding of the development of artificial intelligence-related. Next we conducted a careful investigation of available national strategies; highlighting the common features and deriving a list of indicators from those included in the range of documents.

Why have you presented an index ranking on capacity?

Capacity is the concept we selected as an organisational tool; bringing together the many interconnected factors involved in developing and deploying artificial intelligence. It refers to the amount of artificial intelligence-related factors in a given nation. Capacity is also suitable given that the Index measures a range of inputs, outputs and outcomes - this is because capacity refers both to the present and potential level of development in the future. We considered 'readiness', 'preparedness' and 'agility' as alternatives. Whilst each warrants careful consideration, we believe that all of them focus too explicitly on the future and on prediction of future conditions - preparedness for what? - and so 'capacity' as an expressed description of both current and potential organisation seems a better fit.

How does it make sense to measure the level of capacity within a given nation when many of the factors involved are highly mobile and transnational?

As with many other indices that measure national performance, The Global AI Index

does so with the consideration that factors are mobile. Many factors are linked to national environments through systems of taxation, regulation, language and governance. These boundaries are permeable, in a globalised economy, but we believe that the 'state of the nation' on artificial intelligence is a salient topic.

How have you kept this specific and relevant? Why not just include everything?

It is framed in a way so that it can become a useful platform. Observing changes and learning will yield better insight, which is why we wanted to open up the conversation. Our advisors have offered criticism and comment on the relevance of the factors included in The Global AI Index.This is something that we will continue to take advice, and welcome comment on.

Where are the ethical considerations in this index?

The conversation surrounding regulation and ethical concerns in the use of artificial intellgience has matured in some ways since The Global AI Index was last published. But in many ways it has remained stagnant. For examples, the current indicators of 'Presence of Right to Explanation' and the level of Privacy and Data Legislation in a given country have not moved significantly. Tortoise are engaged in a broad conversation through our Networks, ThinkIns an other dialogue about the implementation and measurement of 'ethical AI'. The reality is that these conversation must go further. The Global AI Index is concerned, as described, with 'capacity'. Tortoise are determined to investigate what is defining the relationship between ethics and artificial intelligence in future.

How are you distinguishing between practitioners and researchers?

It has been difficult to perfectly define the differences between the various types of personnel considered in the Index. This is because people move, reskill, learn and adapt over time. In this sense, the distinction between practitioners and researchers - perhaps the most meaningful in the Index - is imperfect. Some individuals will show up in various metrics across the full range multiple times. For example, a single person may make commits to open source Artificial Intelligence platforms on GitHub, take part in a Kaggle competition as well as being a PhD holding graduate working for a company with a large valuation that is intensively using artificial intelligence. This essentially means that they are contributing to capacity across several different pathways and legitimately represent both categories of talent and researcher. For the purposes of constructing our measurement of the multi-dimensional concept - capacity - we have enforced some strict definitions on the otherwise blurred distinction between practitioners and researchers.

Don't the weightings of the Index define the rankings, making this a subjective exercise?

The weightings set by Tortoise Intelligence have an effect on the proportional impact of each indicator on the total score, and therefore the rankings. We have endeavoured to include weightings that reflect not only our own biases, but also the consensus of the academic and business community on issues of importance. Our weighting methodology is described in more detail in this report; and we welcome any comments or recommendations. We have also conducted a sensitivity analysis to determine the impact of the weights on the overall rank pairings, finding them to account for only a small variation in the rankings.

Methodological Changes as of December 2020

'Number of Researchers' indicator was gathered as 'Researchers per Million of population'.

Tertiary education data on the number of graduates from UNESCO is no longer available.

ISP Review for indicator 'Proportion of Population using Internet' changed to World Bank.

'infra_broadband' source is Cable.co.uk. infra_broadband is given as a average cost of a fixed-line broadband package (Per month in USD) i.e. infra_broadbandcost_income = (infra_broadbandcost/World Bank average annual income)*100

Removed 'Percentage from training coming from online course' from Kaggle.

Added Coursera Indicators of Enrolment Rank; in four versions, ML, AI, and both per capita. Relevance: (4), Contribution: (3), Reliability: (4).

Added Coursera Indicators Relevance: (4) Contribution: (3) Reliability: (4).

2019 OURData Index Global Score added: removed Open Data Barometer Rank Indicators.

Removed 'Open Data Barometer Leaders', 'Open Data Leaders Score 2018', and 'Open Data Score (2016)'

The 'Cloud Adoption of AI professionals' indicator is calculated via the following method: Respondents of the Kaggle ML and DS Survey who say they use at least one cloud service are given a point. The number of participants who use cloud computing in one country is then divided by the total number of participants in that country and multiplied by 100.

5G score changed from categorisation (0, 1, 2, 3) to raw numbers of 5G networks in each country

Relevance dropped for Averaged indicators from Guide2Research from 4 to 1, so that the new weights are as follows:
'Number of AI Articles': Relevance (5) Contribution (3) Reliability (1)
'Average Number of Paper Citations': Relevance (5) Contribution (5) Reliability (1)

Reduced the Relevance (from 5 to 3) weight of:
- Python Package Downloads
- Python Package Downloads per population
- Proportion of Python Package Downloads
- R Package Downloads
- R Package Downloads per population
- Proportion of R Package Downloads
- Adjusted weightings for the following:

Number of Kaggle Grandmasters Relevance (4) Contribution (2) Reliability (4)
Number of Kaggle Grandmasters per capita Relevance (4) Contribution (2) Reliability (4)
Proportion of Total Kaggle Grandmasters Relevance (4) Contribution (3) Reliability (4)
Female Diversity of AI users Relevance (5) Contribution (5) Reliability (3)
Cloud Adoption of AI professionals Relevance (4) Contribution (3) Reliability (2)

UNESCO source change to Science, Technology and Innovation : Researchers by sex, per million inhabitants, per thousand labour force, per thousand total employment (FTE and HC)

Changed Number of Years since Release of AI Strategy Report to Number of 'Months'

Removed Indicator: Percentage of AI Training coming from Online Courses

Removed Indicator: All Data Scientist Wage-related values.

Dependency allowed as part of Visa Application reduced from Relevance (3), Contribution (5), Reliability (3) to Relevance (3), Contribution (2), Reliability (3)