Technology upgrading in the UN Global Pilot Programme on STI for SDGs Roadmaps countries: Serbia, Ukraine, Ghana, Kenya, Ethiopia, and India

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Key Messages

- Frontier The study investigates detailed patterns of technology upgrading of the six countries participating in the UN Global Pilot Program (GPP) on Science, Technology and Innovation (STI) for Sustainable Development Goals (SDGs) Roadmaps: Serbia, Ukraine, Ghana, Kenya, Ethiopia, and India.
- We conduct comparative analysis among the GPP-6 economies and in relation to their respective income groups across all three dimensions of our analytical framework:

  a) intensity of technology upgrading (production, R&D and technology capabilities);

  b) structural upgrading or breadth of technology upgrading (broadly defined 'infrastructure,' knowledge diversification, firm organisational capabilities, digitalisation and 'greening' of economy)

  c) technology and knowledge exchange (technology flows, FDI, export complexity)
- All GPP-6 score *above the average* of their respective income group in terms of intensity of technology upgrading
- Compared to their income peers, GPP-6 economies are significantly *more advanced regarding structural upgrading (breadth) than in intensity of technology upgrading*.
- The relatively weaker position on intensity than regarding breadth of technology upgrading reflects *the cumulative nature of technology capability which takes time to build* , and weaker capacity of the GPP-6 to grow based on technology absorption and generation.
- Although GPP-6 are ranking relatively high compared to their peers in terms of breadth of technology upgrading, *four out of six GPP economies have experienced structural stagnation in the 2002-19 period*.
- There is *polarisation in terms of technology and knowledge exchange*, with three countries improving and three falling behind. GPP-6 ranked relatively the lowest regarding index of knowledge and technology exchange. This reflects their *limited capacity to import, absorb and adapt foreign technologies*.
- GPP-6 levels of *digitalisation correlate highly to their income levels*. However, they have *advanced very differently* in digitalising their economies and society. This will have significant effects on the opportunities for medium- and long-term growth
- Today there is not technology related and innovation activity that can take place unrelated to digital connectivity. In that respect, *prioritising digitalisation is essential* due to its pervasive effects on all innovation processes in the economy and society.
- All six economies show a *negative relationship between income levels and the levels of greening*, and they all show *a worsening in greening performance*. To achieve sustainable development, it is essential to delink economic growth and technology upgrading from increased environmental, energy and material intensity.
- The GPP-6 pursuing technology upgrading along the existing trajectories will not lead to sustainable development. A further technology upgrading requires *structural transformation in all its dimensions, especially including digitalisation and greening*.
- The *uneven paths of technology upgrading* are reflected in very different improvements in different sub-indexes of technology upgrading which reflect their *developmental constraints and large-scale coordination failures*.
- *Policy should not be concerned only with one dimension of technology upgrading*. Improving the intensity of technology upgrading while falling behind in terms of structural upgrading indicates that these improvements will be short-lived without a more profound structural transformation of countries' innovation systems. Also, improving technology and knowledge exchange activities is essential, especially as a driver of structural upgrading of innovation activities.

- The analytical framework of technology upgrading suggests that *the scope of innovation policy is now much broader*. This raises the challenge of how to address the policy areas that cross different parts of innovation systems.
- It is essential that innovation policy has *balanced and broader view on technology upgrading* which cannot be reduced to one of three components but would have to be focused equally on three components – production, R&D and technology capability and it is equally essential to enhance complementarities between three types of capabilities.
- It is essential to recognise that each country's innovation system is unique. A successful policy needs to understand the country's *technology upgrading profile and the direction of its structural transformation*.

Introduction

Science, Technology and Innovation (STI) roadmaps are the mechanism proposed by the UN IATT and designed to assist the achievement of the Sustainable Development Goals (SDGs). The objectives of the roadmaps are 'to build a long-term vision of the desired future, explore innovation and technological pathways and possible scenarios, support policy design, planning and implementation processes'[1].

This *analytical policy brief* is produced as the background policy-oriented analysis to facilitate the work toward roadmaps. It applies an alternative technology upgrading framework to monitor paths of 'catching up' and 'falling behind' in technology upgrading, developed for broadly defined middle-income economies (see Radosevic and Yoruk, 2015; 2016; 2018; Radosevic, D. Yoruk and E. Yoruk, 2019). Here the framework is applied to six of the UN Global Pilot Programme (GPP henceforth) on STI for SDGs Roadmaps Countries, namely, Serbia, Ukraine, Ghana, Kenya, Ethiopia and India[2].

The analytical policy brief conceptualises technology upgrading as a **three-dimensional process** composed of three components: a) **intensity of technology upgrading** depicted through three types of capabilities – production, R&D, and technology capabilities, b) structural upgrading or **breadth of technology upgrading**, which includes broadly defined 'infrastructure,' knowledge diversification, firms' organisational capabilities, 'digitalisation' and 'greening' of economy, and c) **technology and knowledge exchange** as reflected in six indicators which aim to capture the interaction with the global economy through technology flows, FDI and complexity of products and industries (for details see Box 1). The indicators draw upon a comprehensive 2002-2019 database of 164 economies (most recent data available at the time of the analysis).

The choice of indicators is driven by their global availability. In particular, we pay attention to two structural components of technology upgrading – digitalisation and 'greening' of economies - and their relationship to technology upgrading as whole. We consider technology upgrading a useful analytical framework for detecting the broadly defined middle-income economies' long-term growth potential.

The following section (2) depicts the variety of the six GPP countries' technology upgrading positions and changes in their relative positions over the 2002-2019 period, including changes compared to their respective income groups. Section 3 explores patterns of technology upgrading from the perspective of their profiles of technology upgrading, i.e. how the countries score in relative terms in the different dimensions. Section 4 explores the role of 'digitalisation' and 'greening' as critical structural transformation processes and their relationships to other components of technology upgrading. Finally, section 5 summarises the results and draws policy implications of the study.

Six global pilot programme (GPP) economies in technology upgrading perspective: Levels and changes in 2002-2019 period

First, we benchmark each country against a relevant income level group. Four out of six Global Pilot Programme economies belong to **lower-middle-income economies (LMI)** (**Ghana, India, Kenya and Ukraine**). **Ethiopia is a low-income economy** (LI) and **Serbia is upper-middle-income** economy (UMI). These economies do not grow based on frontier Science and Technology (S&T) activities but mainly are importers of technology. Their growth model is based

[1]https://sustainabledevelopment.un.org/partnership/?p=33852

[2] The analytical policy brief is a data-driven mapping and analysis exercise, which builds upon an extensive patterns' identification of technology upgrading in Serbia, Ukraine, Ghana, Kenya, Ethiopia, and India. Also, we benchmark these countries against their "peers" in terms of levels of development measured by income per capita. This approach enables in-depth quantitative analysis of the profiles and patterns of technology upgrading of each of the GPP-6 economies. Ideally, the analysis of this type should be supplemented by the analysis of the institutional and policy context of each of the GPP-6 economies.

on absorption and adaptation capabilities, and especially on production capabilities. R&D capabilities are important but mainly from an absorptive function perspective, not as the input for generating frontier innovation. These economies can also be defined as 'catching up' economies. These economies are characterised by a gradual increase of their technology capabilities but also by structural upgrading in terms of knowledge diversification, infrastructure upgrading, diversification of firms' structure, and digitalisation. As technology importers, the extent of their knowledge exchange is a potentially important determinant of their overall technology upgrading and growth. However, technology openness by itself, without the endogenous process of technology accumulation, is not a direct driver but more moderator in the process of technology upgrading.

Based on these technological and developmental features of the GPP six-country group, the analytical policy brief uses the framework of technology upgrading to discern its patterns and dimensions, which go well beyond narrow R&D and formal S&T system framework. For a full description of the variables and deployed framework, see Box 1.

BOX 1. TECHNOLOGY UPGRADING METHODOLOGY AND INDICATORS

Dimensions and Components of Technology Upgrading

The Index of Technology Upgrading (ITU) is composed of Index A (intensity and types of technology upgrading) and Index B (breadth of technology upgrading).

ITU = Index A + Index B

Index A is composed of three sub-indices: production capabilities, technology capabilities and R&D capabilities, based on 15 variables. Index B comprises five sub-indices: infrastructure, knowledge diversification, firm organisational capabilities, digitalisation and greening. These are based on 23 variables.

The "independent" Index C is composed by five variables and it does not contribute to the Index of Technology Upgrading (ITU) computation.

The weights for each category, their components, and the list of quantitative indicators for each sub-index are presented in the tables below. All indexes and sub-indexes are estimated based on the standardisation of quantitative indicators followed by aggregation of components with equal weights given to each component, which can be written as:

$$I_c = \sum_{j=1}^{J} \sum_{m=1}^{M} w_{jm} \left\{ (X_{jmc} - X_{jm}^{min}) \mid (X_{jm}^{max} - X_{jm}^{min}) \right\}$$

where c indicates country, w is the weight, j and m are indicator and component subscripts, and min and max denote each indicator's minimum and maximum values across countries.

Category (Index)	Component (Sub-index)	Quantitative indicators	Component Weight	Category Weight	Cronbach's Alpha
Index A: Intensity and types of technology upgrading	**1. Production Capability**	1. ISO9001 Certificates pmi (Source: ISO website)	1/3	1/2	0.8437
		2. Trademark Application, residents pmi (Source: WIPO Database)			
		3. Extent of staff training (Source: WEF Global Competitiveness Report Database)			
	2. Technology capability	4. Patents resident applications to national office pmi (Source: WIPO Database)	1/3		
		5. Patent applications to USPTO pmi (Source: WIPO Database)			
		6. Patent applications to EPO pmi (Source: WIPO Database)			
		7. Resident's industrial design count pmi (Source: WIPO Database)			
	3. R&D Capability	8. Business enterprise sector R&D expenditure (as % of GDP) (Source: UNESCO UIS.Stat)	1/3		
		9. R&D expenditure (% of GDP) (Source: World Bank)			

		10 Researchers in R&D per million inhabitants (Source: World Bank)			
		11 Technicians in R&D per million inhabitants (Source: World Bank)			
		12. Scientific and technical journal articles pmi (Source: World Bank)			
		13. Science citations pmi (Source: Scimago Journal & Country Rank)			
		14. Quality of scientific research institutions Q.12.02 (Source: WEF Global Competitiveness Report Database)			
		15. University - industry collaboration in R&D Q.12.04 (Source: WEF Global Competitiveness Report Database)			
Index B: Breadth of technology upgrading: Structural Features	**4. Infrastructure: human capital and physical**	16. Labor force with advanced education (% of total labor force) (Source: World Bank)	1/5	1/2	0.7556
		17.Quality of maths and science education Q.5.04 (Source: WEF Global Competitiveness Report Database)			
		18.Availability of research and training services Q.5.07 (Source: WEF Global Competitiveness Report Database)			
		19.Availability of scientists and engineers Q.12.06 (Source: WEF Global Competitiveness Report Database)			
		20. Logistics performance index- Overall (1=low to 5=high) (Source: World Bank)			
		21.Gross Fixed Investment as % of GDP (Source: World Bank)			
	5. Knowledge diversification	22.Herfindahl-Hirschman Index for total national patent applications (Source: WIPO Database)	1/5		
		23.Herfindahl-Hirschman Index for patent applications to EPO (Source: WIPO Database)			
		24.Herfindahl-Hirschman Index for patent applications to USPTO (Source: WIPO Database)			
	6. Firm organisational capabilities	25.Number of firms in Forbes 2000 pmi (Source: Forbes Global 2000 companies reports)[3]	1/5		
		26.Firm level technology absorption Q.9.02 (Source: WEF Global Competitiveness Report Database)			
		27. Reliance on professional management Q7.07(Source: WEF Global Competitiveness Report Database)			
	7. Digitalisation	28. Fixed broadband Internet subscribers (per 100 people) 29. Secure internet servers (per 1 million people) 30. Mobile Broadband Subscriptions	1/5		
	8. Greening	31. Renewable energy consumption (% of total final energy consumption) 32. CO2 emissions (metric tons per capita) (inverted) 33. Nitrous oxide emissions (% change from 1990) (inverted) 34. Fertilizer consumption (kilograms per hectare of arable land) 35. Total greenhouse gas emissions (% change from 1990) (inverted) 36. Energy intensity level of primary energy (inverted)	1/5		

[3] Observations for all countries were extrapolated using the last available year (2006)

Category (Index)	Component (Sub-index)	Quantitative indicators	Component Weight	Cronbach's Alpha
Index C: Interactions with the Global Economy	**Technology and knowledge exchange**	37. Technology balance of payments (receipts) as % of GDP (Source: World Bank) 38. Technology balance of payments (payments) as % of GDP (Source: World Bank) 39. Share of exports in complex industries in total exports (SITCRev3 5 71-79 87 88) (2002-16 avg) (Source: UN Comtrade database) 40. Foreign direct investment, net outflows (% of GDP) (Source: World Bank) 41. Foreign direct investment, net inflows (% of GDP) (Source: World Bank)	1/5	0.7122

All GPP-6 score **above the average of their respective income group in terms of intensity of technology upgrading** (figure 1). This indicates the "above average" technology potential and ambition to further improve technology upgrading. The leading country is India followed by Serbia and then Ukraine. Compared to their income per capita levels in figure 2, India fares well above its income level, while Ethiopia below, the other four countries are standing close to their income levels.

Figure 1. Index A Intensity of technology upgrading 20194 levels

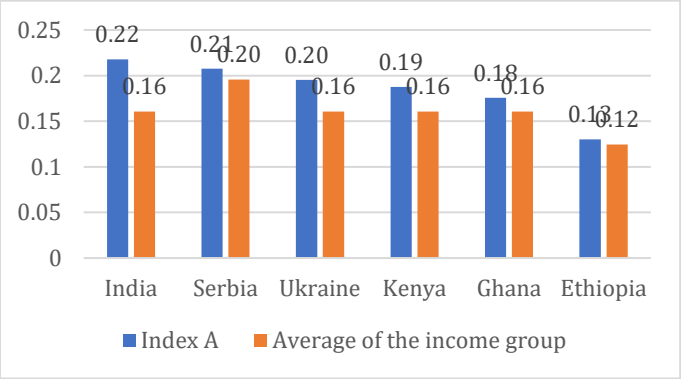
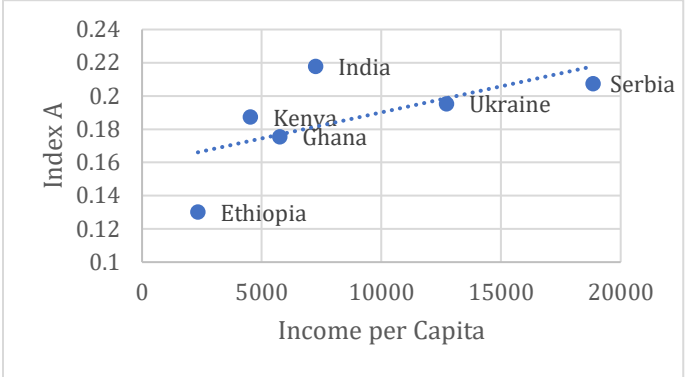


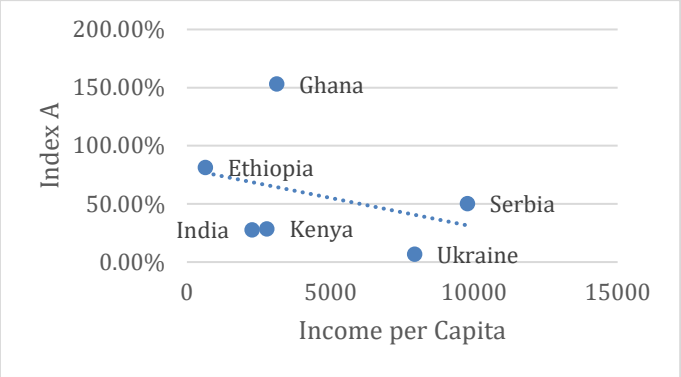
Figure 2. Index A: Intensity of technology upgrading vs. income per capita in 2019



There is an expectation from the academic literature that countries at lower levels of income should upgrade economically and technologically faster due to greater opportunities for imitative technology development (i.e. via convergence or 'catch-up'). Figure 3 suggests that this broad tendency has some relevance but also that there are big differences among the GPP-6. For example, Ghana has improved in terms of intensity of technology upgrading much more than would have been expected while India, Kenya and Ukraine have underperformed.

[4] The last available year is 2019 due to data reporting and quality concerns. Data in 2021 are not available yet and data for 2020 are preliminary and patchy.

Figure 3. Index A Intensity and types of technology upgrading (% change between 2002-2019 vs Income per capita,2002)



Improved breadth of technology upgrading, or structural upgrading, is the second component of the overall index of technology upgrading. In this respect, all GPP-6 (except Ghana) are above the levels or equal to the average of their income group. Also, three frontrunners in terms of intensity of technology upgrading are also ahead in terms of breadth of technology upgrading (figure 4). When compared to their income level, there is a positive relationship with the levels of technology upgrading (figure 5). This fully justifies the inclusion of structural components as essential dimension of technology upgrading. However**, structural upgrading does not seem to proceed in a desirable direction**. A convergence hypothesis is turned completely opposite in the case of the breadth of technology upgrading. Figure 6 shows that **four out of six economies have experienced structural stagnation.** Only Serbia and India have structurally improved, while other countries have fallen behind.

Figure 4. Index B Breadth of technology upgrading 2019 level

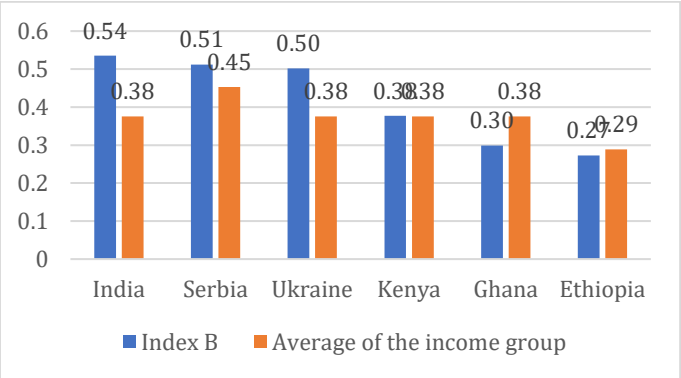


Figure 5. Index B Breadth of technology upgrading vs. Income per capita in 2019

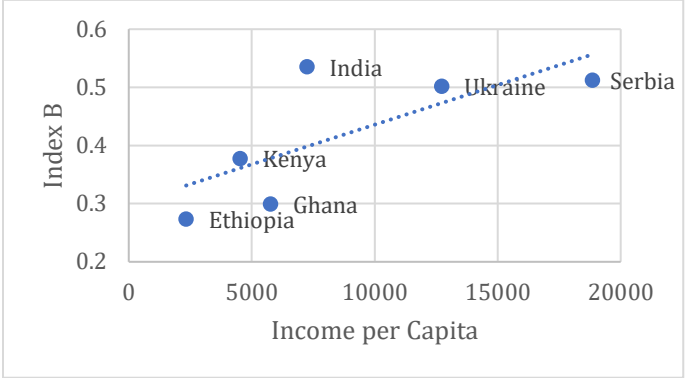
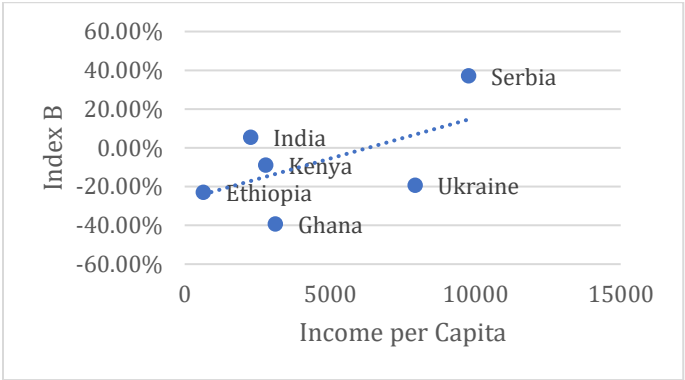
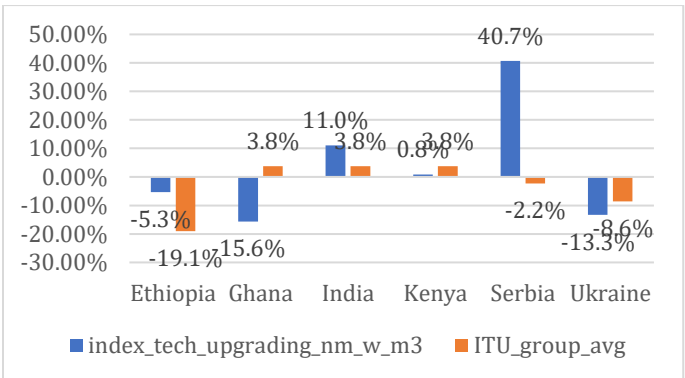


Figure 6. Index B Breadth of technology upgrading % change between 2002-2019 vs Income per capita (2002)



When we combine index A and B into the overall index of technology upgrading, Serbia and India (marginally Kenya) have improved on this index (figure 7). Ukraine, Ethiopia and Ghana have fallen behind. So, **the overall picture is polarisation among GPP-6.** These differences seem to be **driven by country-specific factors** as there are big differences among similar income economies (India, Ukraine, Kenya and Ghana) in terms of changes in overall index TU.

Figure 7. ITU Index of Technology Upgrading (Index A + B) % change between 2002-2019



Technology and knowledge exchange is an essential precondition for technology upgrading. Four out of 6 GPP economies rank in that respect above the average of their income group. Serbia, Ukraine, India and Ethiopia are more engaged in technology and knowledge exchange than their income peers. Ghana and Kenya have lower than expected technology and knowledge exchange compared to their income group (figure 8). The technology and knowledge exchange levels are closely correlated to countries' income levels, but Kenya and Ghana are below expected levels (figure 9). Also, there are no 'latecomer advantages' or more significant opportunities for economies of lower-income levels to engage in technology and knowledge exchange. Instead, we see **polarisation between three countries that have improved in that respect and three that have fallen behind**. Improvers are Serbia, India and Ghana while Ethiopia, Kenya and Ukraine, have fallen behind (figure 10).

Figure 8. Index C Technology and Knowledge exchange 2019 level

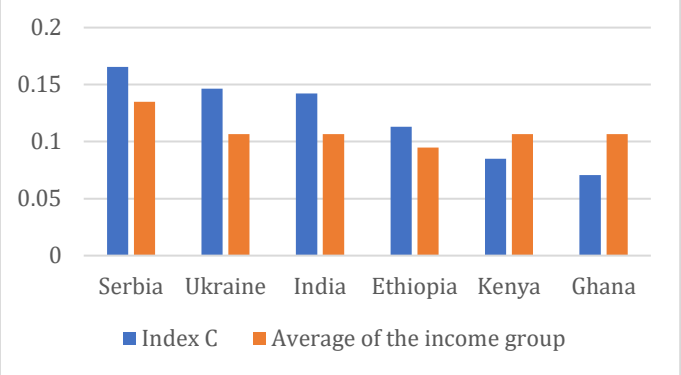


Figure 9. Index C Technology and Knowledge exchange vs Income per capita in 2019

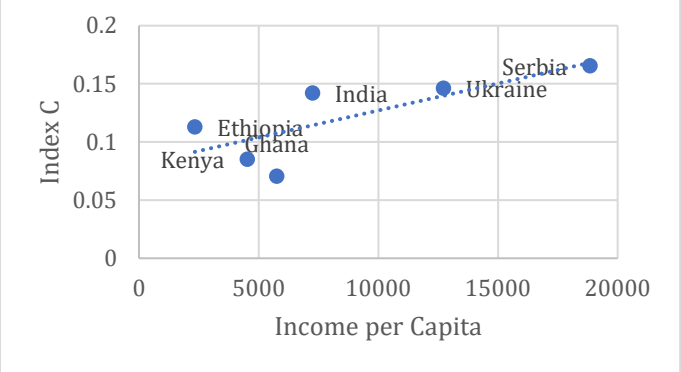
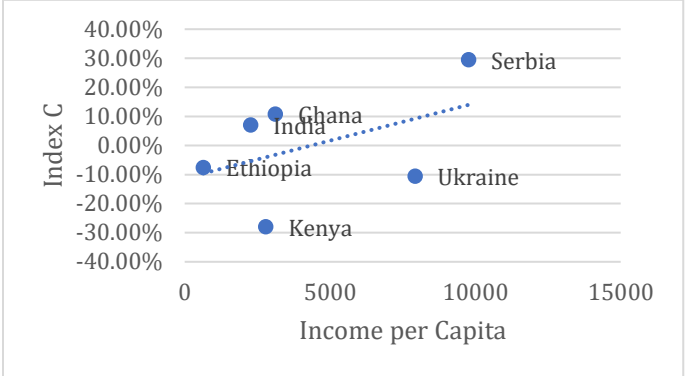


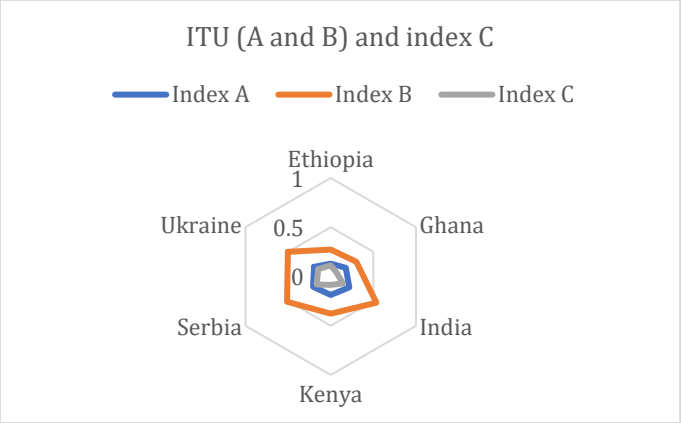
Figure 10. Index C Technology and Knowledge exchange % change between 2002-2019 vs Income per capita (2002)



In summary, all GPP-6 have improved in terms of intensity of technology upgrading but four out of six have fallen behind in terms of breadth or structural upgrading. In terms of **technology and knowledge exchange, there is polarisation**, with three countries improving and three falling behind. These results suggest that policy should not be concerned only with one dimension of technology upgrading. *Improving the intensity of technology upgrading while falling behind in terms of structural upgrading suggests that these improvements will be short-lived in the absence of more profound structural transformation of countries' innovation systems*. Also, improving in technology and knowledge exchange activities is essential, especially as a driver of structural upgrading of innovation activities.

Figure 11 summarises technology upgrading profiles of the GPP-6 on indexes of the intensity of upgrading (index A), structural upgrading (Index B) and on the index of technology and knowledge exchange (index C). GPP-6 economies are significantly more advanced regarding structural upgrading (breadth) than on intensity of technology upgrading and are even less developed regarding index C (knowledge and technology exchange). This may be expected as *the intensity of technology upgrading reflects the cumulative nature of technology capability, which takes time to build and differentiates economies in terms of their capacity to grow based on technology absorption and generation*. They are quite behind regarding knowledge and technology exchange, reflecting a low ability to absorb, adapt, and generate endogenous technology capability. However, although GPP-6 are comparatively doing better regarding the breadth of technology upgrading, there are also differences. India, Serbia and Ukraine are relatively more advanced on the index of the breadth of technology upgrading Index B) compared to *three African economies that have the challenge of both intensity and breadth of technology upgrading*.

Figure 11. Comparative profiles of the GPP-8 on indexes A, B and C



Changes in subcomponents of intensity and breadth of technology upgrading in 2002-19

The patterns of technology upgrading or downgrading evolve differently along different components. In this section, we explore eight subcomponents of index of technology upgrading (ITU): Index 1; Production Capability; Index 2 Technology Capability; Index 3 R&D Capability; Index 4 Infrastructure: human capital and physical and organisational; Index 5 knowledge diversification; Index 6 Firm Organisational Capabilities; Index 7 Digitalisation; and Index 8 Greening.

All GPP-6 economies have improved in production capabilities (figure 12). The biggest "improvers" are Ghana and Ethiopia followed by Serbia. As GPP-6 grew based on technology absorption, this should have been expected and confirms our research on the larger sample of 164 economies (see Bruno et al, 2022). R&D capability is proxy of both technology absorption and technology generation. Also, we capture much broader sets of variables into this index, including subjective assessment of the quality of R&D systems. **Based on this broader notion of R&D capabilities, all countries except Ukraine have improved with Ghana being the biggest improver (figure 13)**. Index of technology capability captures knowledge generation capabilities through four types of patent indicators. **Five out of six GPP countries (except Serbia) have improved in terms of knowledge generation (technology capability) (figure 14)**.

It may be expected that improvement in R&D would lead to at least some improvements in technology capability and vice versa. This is confirmed in four out of six economies that have improved in both R&D and technology capabilities (India, Ghana, Kenya, Etiophia). However, Serbia and Ukraine had changes in R&D and technology capability in opposite directions. Serbia has improved R&D capabilities but has fallen behind in technological capabilities while Ukraine has improved in technology generation but has fallen behind in R&D capabilities. **This shows quite diverging reorientations of R&D systems**. Serbian R&D has improved significantly in its scientific production as evidenced by publications but has fallen behind in its technology orientation. Ukraine system has improved but primarily in terms of patent applications and industrial designs of residents but its R&D base has fallen behind.

Figure 12. Production Capability % change between 2002-2019

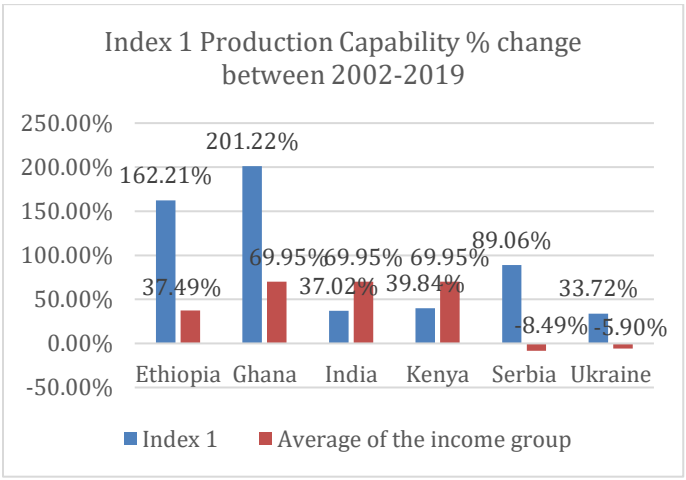


Figure 13. Index 3 R&D Capability % change between 2002-2019

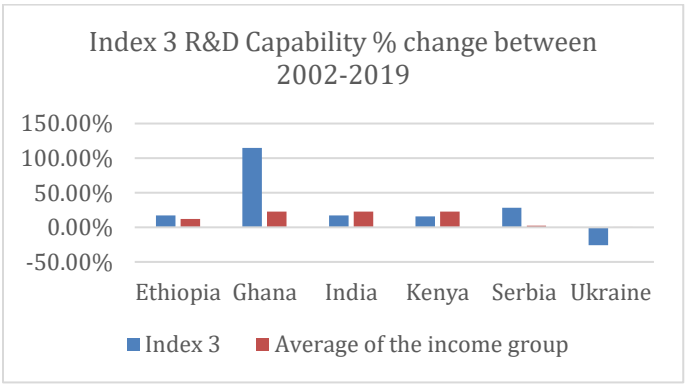


Figure 14. Index 2 Technology Capability % change between 2002-2019

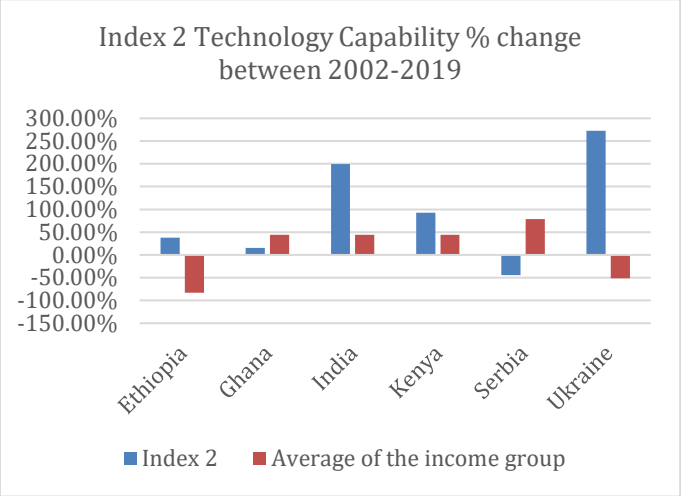
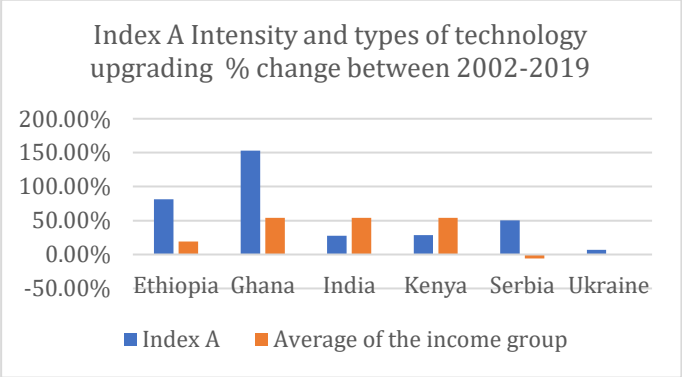


Figure 15. Index A Intensity and types of technology upgrading % change between 2002-2019



The index of intensity of technology upgrading (Index A) is composed of indexes 1, 2 and 3. Figure 15 shows changes in between 2002 and 2019 in this index. Ghana is the biggest improver due to its high growth in Production Capabilities and R&D. Ghana is followed by Ethiopia, which has grown to a lesser extent primarily due to Production Capabilities. India's growth was due to rise in technology Capabilities as is Kenya. Serbia and Ukraine are also improvers but with different drivers. In Ukraine, Index A has improved primarily due to Technology Capability and partly Production Capability despite falling behind in R&D capability. Serbia improvements are due to Production Capability and R&D despite falling Technology Capability.

Growth of African economies reflects an expected path driven by their Absorptive Capabilities. Serbia on the other side, has a path similar to the African economies but it seems that the R&D system is not oriented towards industry as suggested by relative falling behind in patenting activity. India and Ukraine have improved significantly in Technology Capability but it seems that their knowledge generation is not linked to Production Capability, which may limit future technology upgrading.[5]

The evidence suggest that **it is essential that innovation policy has balanced and broader view on technology upgrading which cannot be reduced to one of three components but would have to be focused equally on all three components – production, R&D and technology capability**[6]. Also, it is essential **to enhance complementarities between three types of capabilities**. **R&D and technology capabilities have to be closely linked to stages of technology upgrading in the business economy**. At initial stages, the focus should be placed to absorptive capability, quality, process and product engineering while in advanced stages the focus should be directed to intra-and extra-mural R&D-focused production innovation. This requires balance between supply and demand led R&D policies and close links between science and industry to facilitate R&D excellence but also local relevance of the R&D.

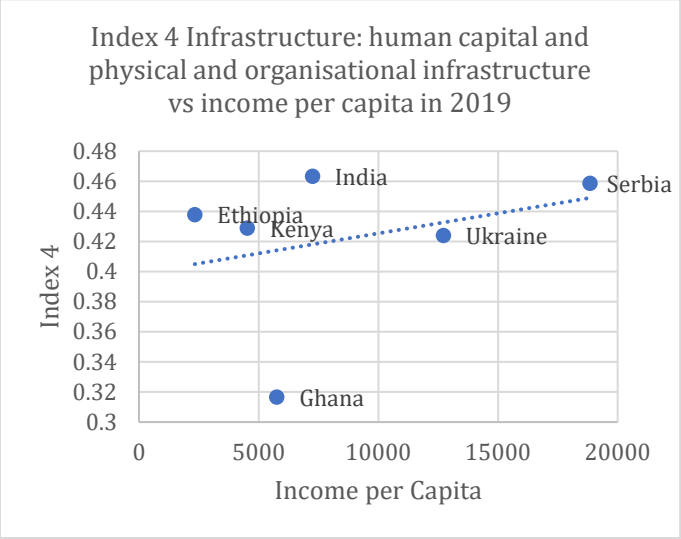
The changes in intensity of production, R&D and technology capabilities at given economic, resource and technology structure will reach its limits in medium term unless complemented by structural upgrading. Technology upgrading is also a process of structural transformation of broadly defined infrastructure, of diversification of knowledge, transformation of firm structure, and of technological transformation through diffusion of digital technologies and 'greening' of production processes, economic and societal activities.

We broadly define infrastructure for technology upgrading as encompassing quality of human resources, quality of education, technical services, logistics and physical investments. Regarding this broadly defined infrastructure differences among GPP-6 are much smaller (except Ghana) compared to other components of the index (see figure 16). For example, although Serbia and Ukraine are above India, Kenya and Ethiopia in terms of income levels they are comparable regarding broadly defined infrastructure for technology upgrading.

Figure 16. Index 4 Infrastructure: human capital and physical and organisational vs income per capita in 2019

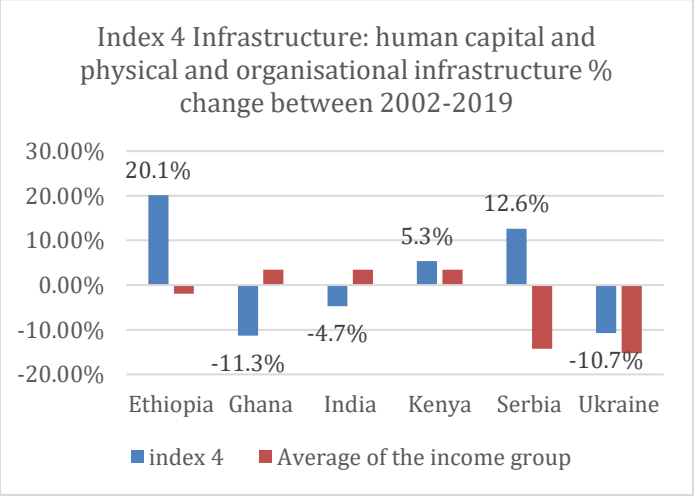
[5] These results corroborate the conclusions of in the upcoming EC JRC publications*: Smart Specialisation in the Western Balkans* and *Smart Specialisation in the Eastern Partnership countries*, where specific relations between Economic, Innovative, Scientific and Technological potential of a number of countries are studied, including Serbia and Ukraine.

[6] Which is consistent with European Union's smart specialisation approach tested in two out of six GPP countries; Serbia and Ukraine



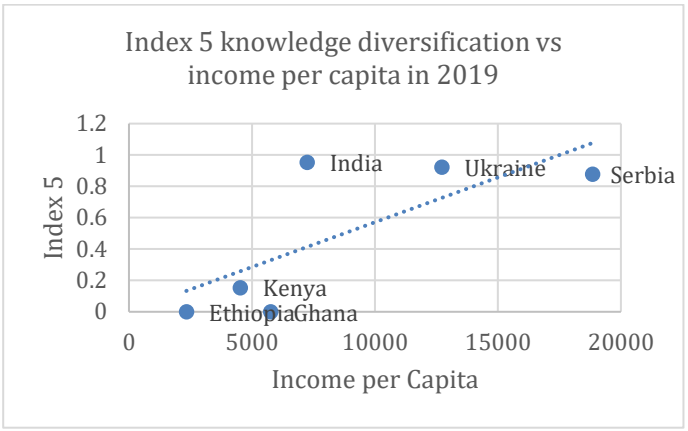
However, in 2002-19 period there has been discernible infrastructure upgrading polarisation among GPP-6 (figure 17). Ethiopia, Serbia and Kenya have improved in relation to their GPP-6 peers but also in relation to their income groups. Ghana, Ukraine and India have fallen relatively behind. This may not hinder their current technology upgrading but will become constraining factor in the medium- and long-term.

Figure 17. Index 4 Infrastructure: human capital and physical and organisational % change between 2002-2019



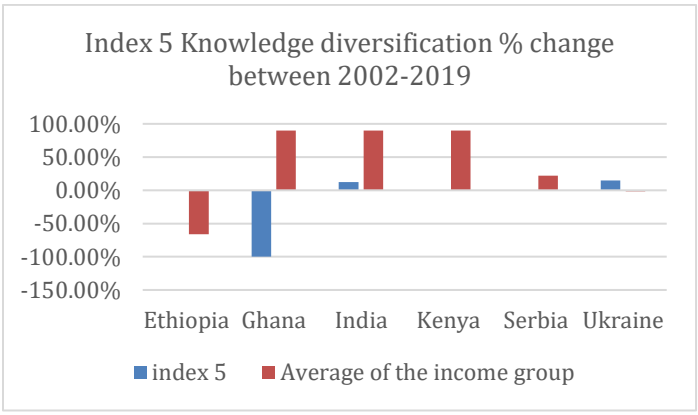
Technology upgrading is a dual process of increasing intensity of production, R&D and technology capability but it is also a process of transformation of knowledge generation activities. As countries upgrade they diversify by entering into new technology areas and mastering increasing complexity of new technologies. In that respect, GPP-6 shows that Serbia, Ukraine and India have significantly more diversified knowledge generation activities when compared to African economies (Ghana, Kenya and Ethiopia) (figure 17). So, knowledge generation base of African economies is much narrower when compared to other three economies, and this may be expected given differences in income levels.

Figure 18. Index 5 knowledge diversification vs income per capita in 2019



Diversification in knowledge generation has been particularly discernible in the lower middle-income group. Unfortunately, data for the 2002-19 period are not fully available for Serbia and Kenya. Still, the picture does not seem to be very encouraging as diversification of knowledge generation activities of individual GPP-6 economies is either below their income group average or not much changed (figure 19). For Ethiopia as the low-income economy the unchanged index of knowledge generation may not be the most relevant at its income level. However, for other economies this may indicate stalemate in diversification into new technological areas.

Figure 19. Index 5 Knowledge diversification % change between 2002-2019



For technology upgrading dynamics, organisational capabilities of local firms are essential. Firms are the organisations that convert technology into products and how they are effective in this process does not depend only on the available R&D and technology capabilities but mainly on capabilities to organise innovation process, which is partly reflected in their size, their control of distribution channels, professional

management and how extensively they train labour force.

When using this composite proxy of firms' organisational capabilities we see they are not correlated to GPP-6 income levels (figure 20). India, Kenya and Ghana have higher firm organisational capabilities (and above what would be expected given their GDP per capita) when compared to Serbia and Ukraine. Ethiopia is well below its African counterparts. In 2002-19 period India, Kenya and Ghana have improved their firms' organisational capabilities well above their income level peers (figure 21). Ukraine and Ethiopia have fallen significantly behind. Serbia is among improvers, but its overall level of firm organisational capabilities is still below its income group average.

From conventional S&T policy perspective, firms' organisational capabilities are outside of the scope of the policy. Yet, firms as organisations that convert technology into products are probably the major actors in the innovation systems. A high level of their organisational capabilities is essential for driving innovation systems to a higher level of dynamism. Developed firms' organisational capabilities are driving firms' internationalisation, access to foreign technologies and their successful absorption. On the other hand, low organisational capabilities of firms are often a sign of low demand for R&D and will result in local technology capabilities available in extramural R&D organisations being unused.

The organisational capabilities are shaped by a variety of policies which do not fall within the remit of narrowly defined S&T policies. They are determined by the corporate governance rules and regulations, by industrial relations, role of owners of capital and their long or short-term investments horizons and interests. In this respect, each of the six GPP economies is unique, and its organisational capabilities and their evolution is the result of country specific institutional and economic processes.

Figure 20. Index 6 Firm Organisational Capabilities vs income per capita in 2019

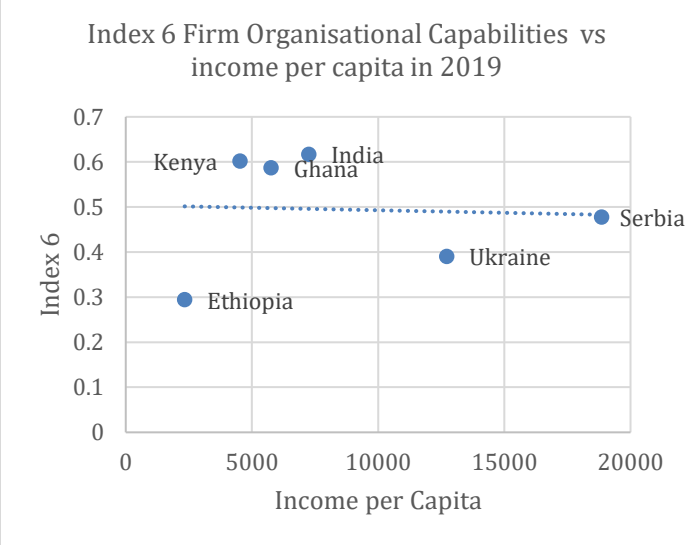
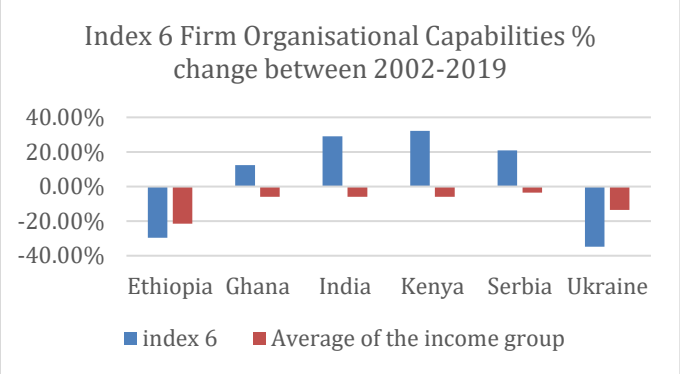


Figure 21. Index 6 Firm Organisational Capabilities % change between 2002-2019



'Digitalisation' is currently dominant transformation process and component of technology upgrading. **Unlike firms' organisational capabilities whose levels are unrelated to the income levels, the levels of digitalisation are even for the small group of only six economies like GPP closely and positively related to the income levels** (see figure 22) . We do not show it in this policy brief but previous research shows that digitalisation is also positively correlated to each of the four indexes that we employ in technology upgrading framework. This confirms that digital technologies are general purpose technologies, and their impact is pervasive across the entire economy and society. Our proxies for digitalisation (due to data availability) reflect basic levels of digitalisation and thus are relevant for low and middle level economies.

As digitalisation closely correlates to levels of income, we can assume that changes in digitalisation may impact prospects for long and medium term growth of the GPP-6. Among GPP-6 Ukraine is the economy that

made the biggest strides in digital connectivity followed by India and Ghana (figure 23). Serbia and Kenya are laggards compared to these economies while Ethiopia has fallen behind well below the fall of its income group. The significance of these trends goes well beyond narrowly perceived digital connectivity. Today there is not technology related and innovation activity that can take place unrelated to digital connectivity. In that respect, prioritising digitalisation is essential due to its pervasive effects on all innovation processes in the economy and society. Digitalisation is especially relevant for opening and exploiting new areas of opportunities in technology upgrading through frugal technologies, low costs innovation and in ensuring global reach and access to knowledge.

Figure 22. Index 7 Digitalisation vs income per capita in 2019

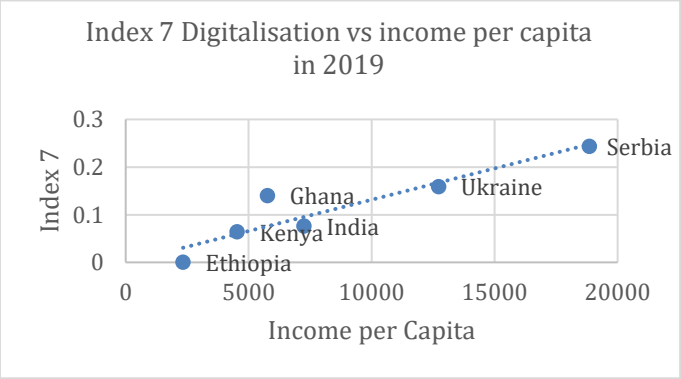
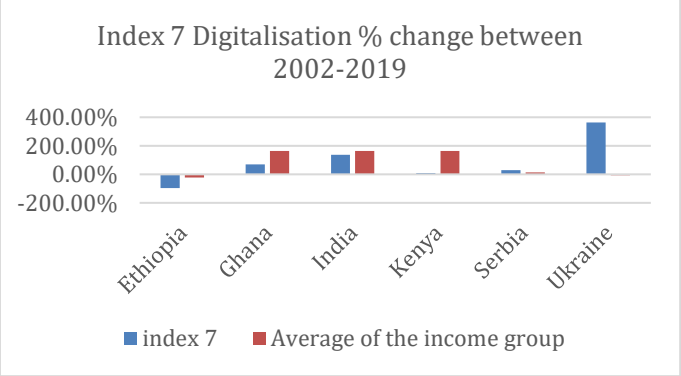


Figure 23. Index 7 Digitalisation % change between 2002-2019



In addition to digitalisation, the current global technological but also social and economic challenge is to reduce environmental pollution and energy and material intensity of the production processes and other economic activities. This challenge is particularly prominent in low- and middle-income economies whose growth in the past has been driven by industrialisation and increased use of material and energy.

Figure 24. Index 8 Greening vs income per capita in 2019

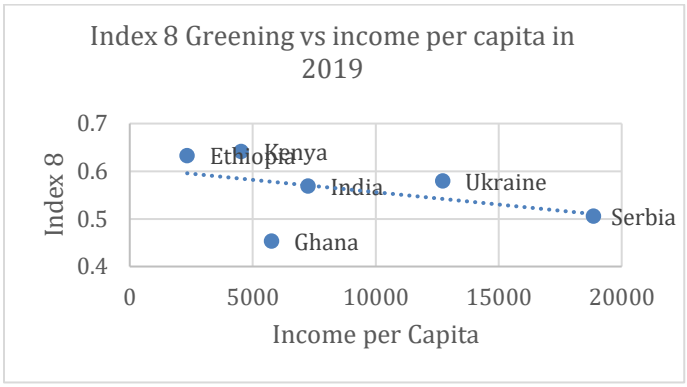
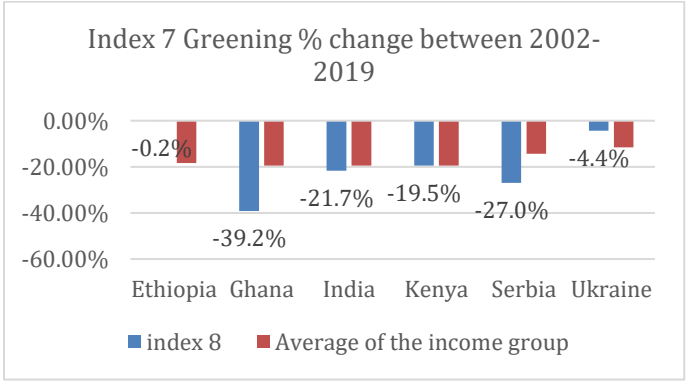


Figure 24 shows as would be expected that less developed GPP-6 economies generate less pollution and use less energy intensive processes or materials. The exception in that respect is Ghana whose levels of pollution and energy/material intensity is much higher (the lower on the scale the higher the pollution) given its income levels. Ukraine and partly Serbia as ex-socialist economies, have more energy and pollution intensive economies but still lower than in the past due to intensive deindustrialisation of their economies during the 1990s and 2000s.

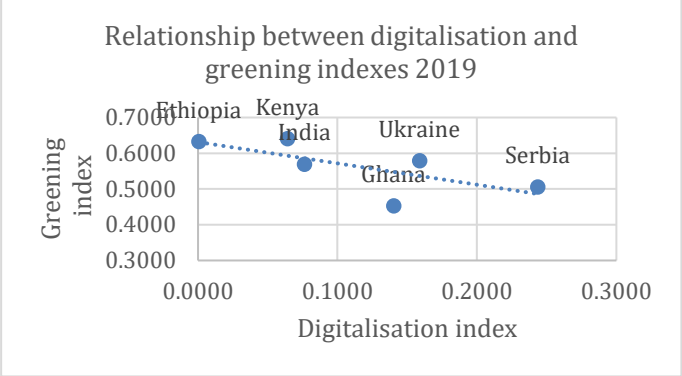
To achieve sustainable development, it is essential to delink economic growth and technology upgrading from increased environmental, energy and material intensity. However, **in 2002-19 period all GPP-6 have increased environmental, energy and material intensity of their economies** (see figure 26). Expressed in percentages greening of the economies has worsened from 0.2% of Ethiopia to 39.2% in Ghana with India, Kenya and Serbia increasing environmental, energy and material intensity of their economies by around 20% in 17 years. These trends are part of global trend where GPP-6 recorded similar or stronger deterioration than their respective income groups (except Ethiopia and Ukraine).

Figure 25. Index 7 Greening % change between 2002-2019



A potential way to link to enhance delinking of economic development from environmental energy and material intensity is to deploy digital technologies through new forms of 'digital greening'. However, figure 26 shows that GPP-6 are still far from 'green digitalisation' as degrees of environmental, energy and material intensity of economies are negatively related to their digital connectivity. This challenge requires solutions that GPP-6 cannot carry on their own but through concerted international technology upgrading and technology transfer activities.

Figure 26. Relationship between digitalisation and greening indexes 2019

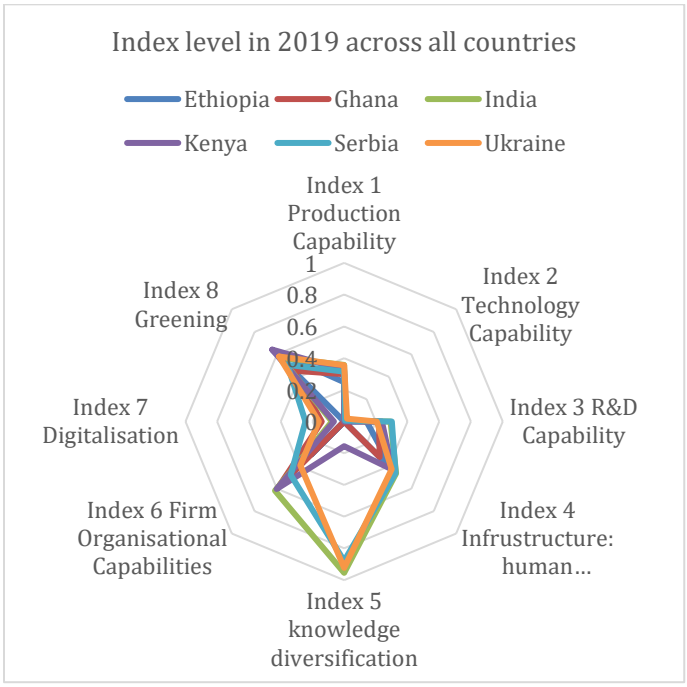


Profiles and changes in profiles of technology upgrading in 2002-19

The analysis above shows a combination of upgrading features shared by some or all GPP6 economies and the patterns that are very strongly country-specific. This section focuses on country-specific patterns of technology upgrading individually and in a comparative context.

Figure 27 shows a radial diagram that synthesises all eight components of indexes A and B for all GPP-6. We observe several common features of the GPP-6 technology upgrading profile. First**, they all perform very low on the index of knowledge generation (index 2) and then on the digitalisation index (7**). Second, they are relatively **better on the index of production capability (1), RD capability (3) and broad infrastructure (4)**. Third, they are **quite polarised regarding diversification of knowledge generation (index 5) and are less polarised on firms' organisational capabilities** (6). Fourth, they perform **the best on the greening index (index 8), though with notable differences among economies**. So, despite country-specific patterns of upgrading, figure 27 shows similarities in levels of technology upgrading, which reflect their income levels.

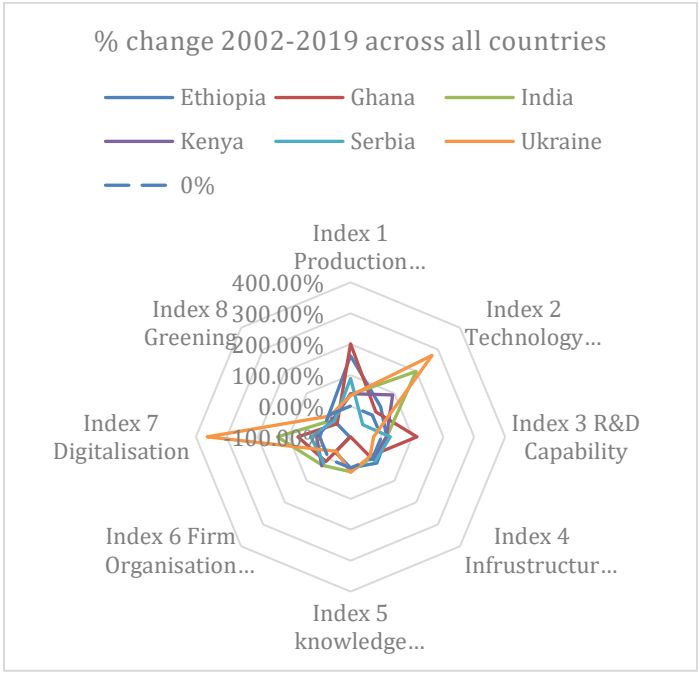
Figure 27. Index level in 2019 across all GPP-6



Note: Index 5 indicates diversification of knowledge generation measured by resident, US and EPO patents. Index 2 measures levels of patenting including industrial designs.

Profile of changes across different sub-indexes in 2002-19 period (figure 28) shows much stronger differentiation of countries. For example, Ukraine has improved significantly on digitalisation (index 7), Ukraine and India on knowledge generation (2), Ghana and Ethiopia have improved on production capability (index 1) and Ghana on R&D capability (index 3). Changes in other sub-indexes (4, 5, 6) are relatively more homogenous.

Figure 28. % Change between the year 2002-2019 across all countries



Annex 1 shows further changes in individual profiles of GPP-6 economies depicted in figure 28 but in relation to the country itself. In particular, Annex 1 shows significant improvement of Ethiopia in production capability, Ghana in production and R&D capability and digitalisation, India in technology capability and digitalisation, Kenya in technology capability, Serbia in production capability, and Ukraine in technology capability and digitalisation.

Annex 2 shows the profile of individual GPP-6 economies on all eight sub-indexes of technology upgrading compared to their respective income group average. The overall picture shows that the *GPP-6 countries follow many indexes profiles of their respective income groups and some country-specific distinctive features*. Serbia, Ukraine and India's technology upgrading profiles follow profiles of their respective income groups. Still, all three show that their knowledge diversification (index 5) is significantly more diversified than their peer groups. In the case of India, this reflects a developed R&D system. In the case of Ukraine and Serbia, their legacy of the socialist R&D system has remained present to some extent, especially when compared to their income peers. India is also distinctively different from its income group regarding the higher development of firms' organisational capabilities. Partly this reflects the internationalisation of Indian business groups. Compared to its income group Ghana underperforms in knowledge diversification and, to some extent, in greening (index 8) while being relatively better in the organisational capabilities of firms. Kenya, similar to Ghana, underperforms in knowledge diversification and is slightly better in the organisational capabilities of firms (index 6). Ethiopia is ranked very closely to its income group average and is somewhat better in the organisational capabilities of firms.

Conclusions and policy implications

Promoting technological upgrading and using it as a mechanism of sustainable economic development and the greening of the economies is the issue that should be central to innovation and development policy today. How to link different dimensions of technology upgrading framework through STI for SDGs roadmaps is a new challenge. Our paper provides some new evidence that can support policy thinking to address these issues.

In summary, our analysis demonstrates that:

1. *All GPP-6 score above the average of their respective income group in terms of intensity of technology upgrading*.

2. Although GPP-6 are ranking relatively high to their peers in terms of breadth of technology upgrading, *four out of six GPP economies have experienced structural stagnation in the 2002-19 period*.

3. There is *polarisation in terms of technology and knowledge exchange*, with three countries improving and three falling behind.

4. *GPP-6 levels of digitalisation correlate highly to their income levels*. However, *they have advanced very differently in digitalising their economies and society*. This will have significant effects on the opportunities for medium- and long-term growth.

5. All six economies show *a negative relationship between income levels and the levels of greening*, and they all show *a worsening in 'greening' performance.*

6. Compared to their income peers, *GPP-6 economies are significantly more advanced regarding structural upgrading (breadth) than in intensity of technology upgrading*. The intensity of technology upgrading reflects the cumulative nature of technology capability, and it reflects their weaker capacity to grow based on technology absorption and generation.

7. *GPP-6 ranked relatively the lowest regarding index C (knowledge and technology exchange*). This reflects their *limited capacity to import, absorb and adapt foreign technologies*.

8. The *uneven paths* of technology upgrading as reflected in very different improvements in different sub-indexes of technology upgrading reflect their *developmental constraints and large-scale coordination failures*.

9. Results suggest that policy *should not be concerned only with one dimension of technology upgrading*. Improving the intensity of technology upgrading while falling behind in terms of structural upgrading indicates that these improvements will be short-lived without a more profound structural transformation of countries' innovation systems. Also, improving technology and knowledge exchange activities is essential, especially as a driver of structural upgrading of innovation activities.

10. The analytical framework of technology upgrading suggests that the scope of innovation policy is now much broader. This raises the challenge of *how to address the policy areas that cross different parts of innovation systems*.

11. It is essential to recognise that each country's innovation system is unique. A successful policy needs to understand the country's technology upgrading profile and the direction of its structural transformation.

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Annex

Annex 1

Figure 1. Ethiopia % Change between the year 2002-2019

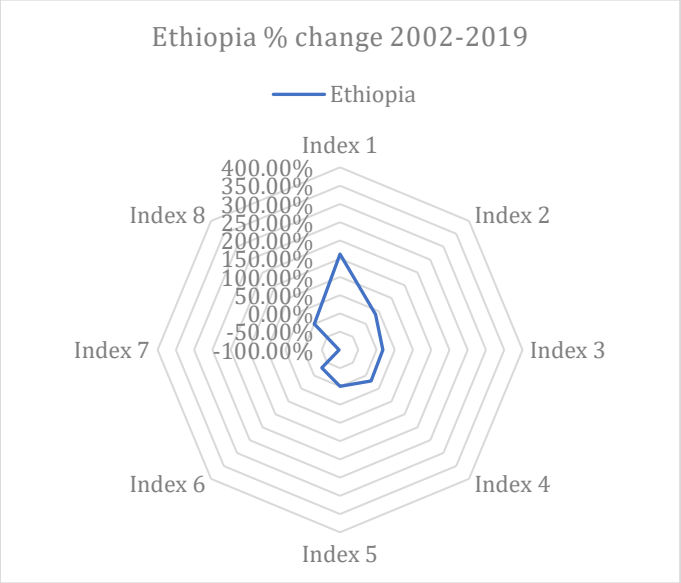


Figure 2. Ghana % Change between the year 2002-2019

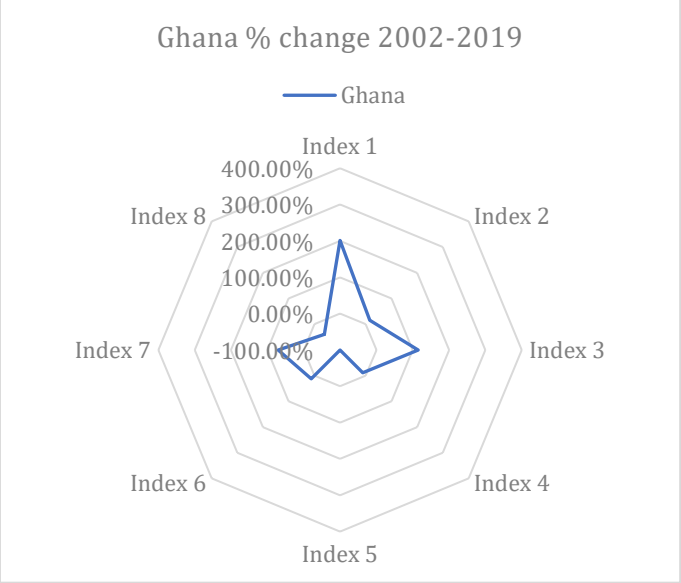


Figure 3. India % Change between the year 2002-2019

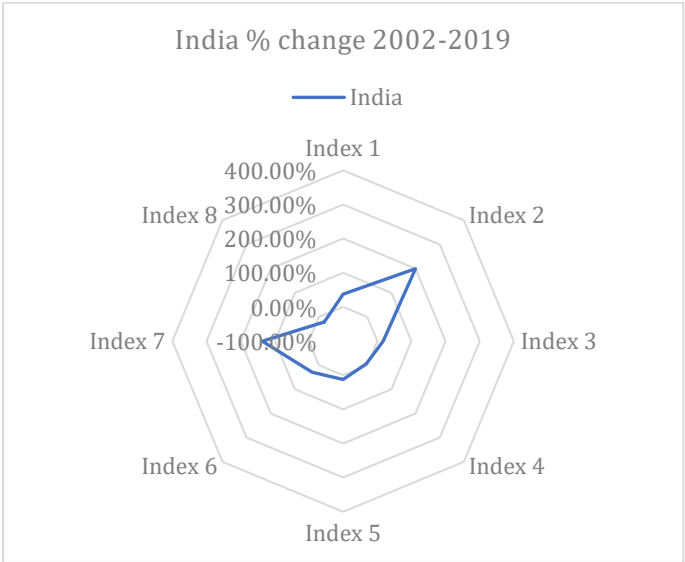


Figure 4. Kenya % Change between the year 2002-2019

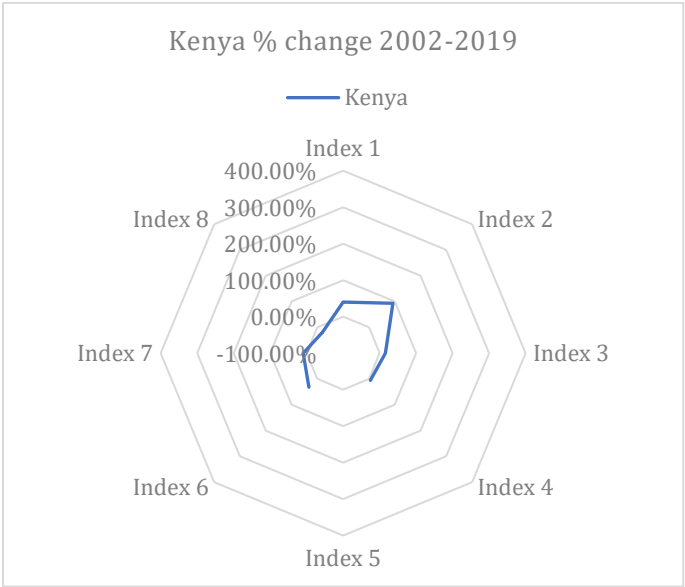


Figure 5. Change between the year 2002-2019

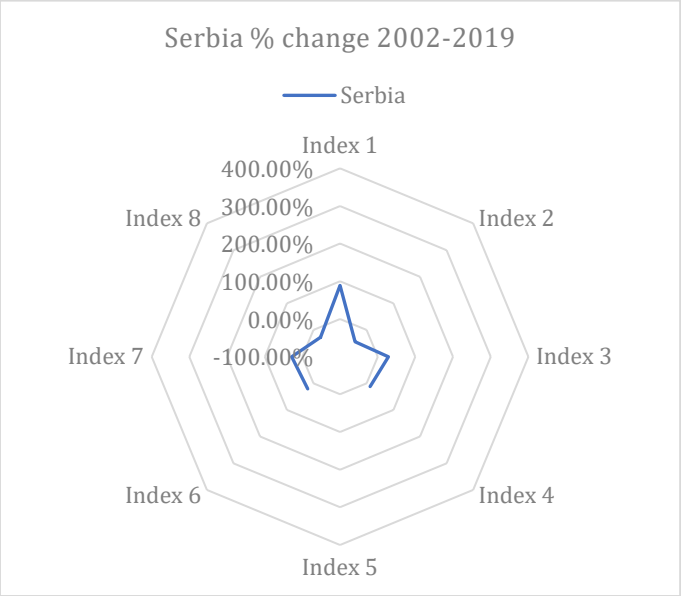
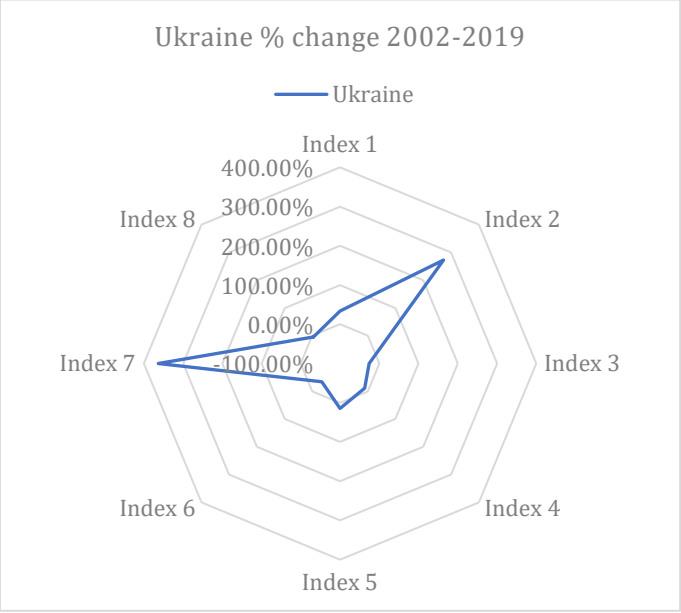
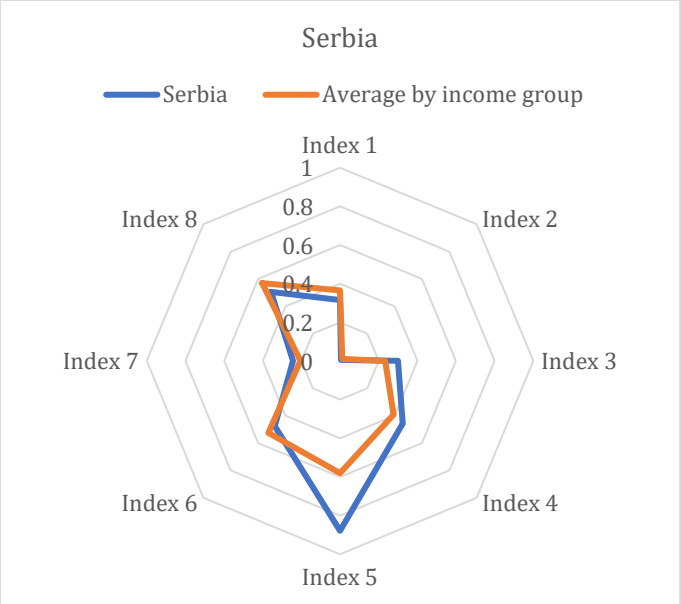


Figure 6. Ukraine % Change between the year 2002-2019



Annex 2

Figure 1



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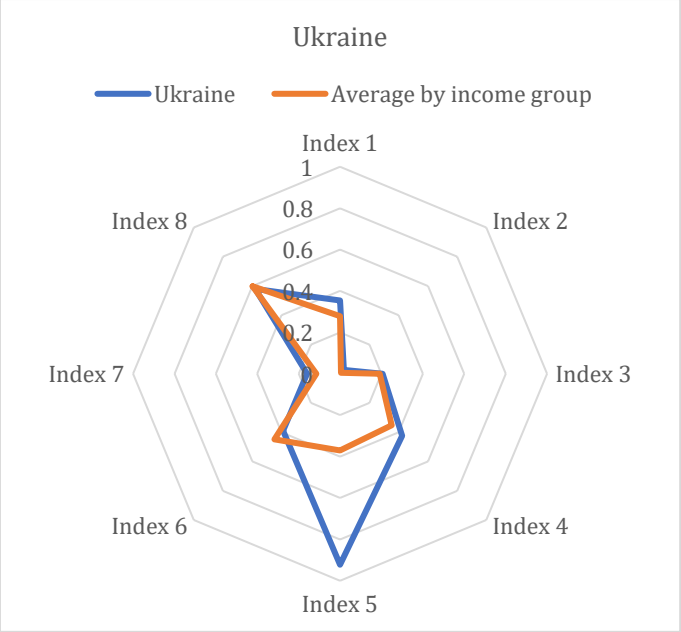

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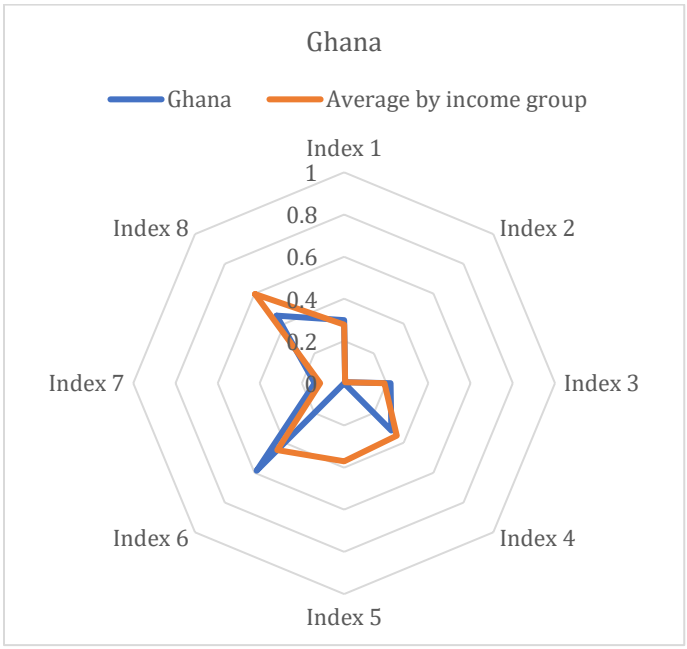

Figure 4

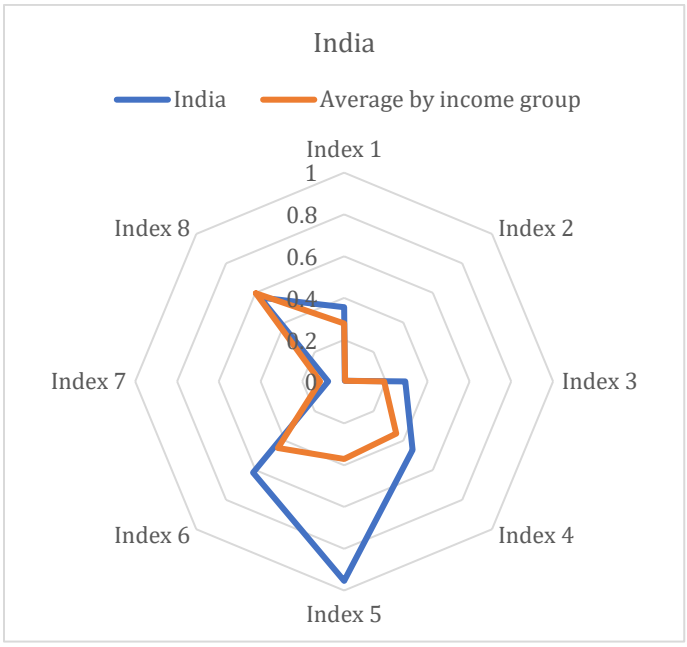

Figure 5

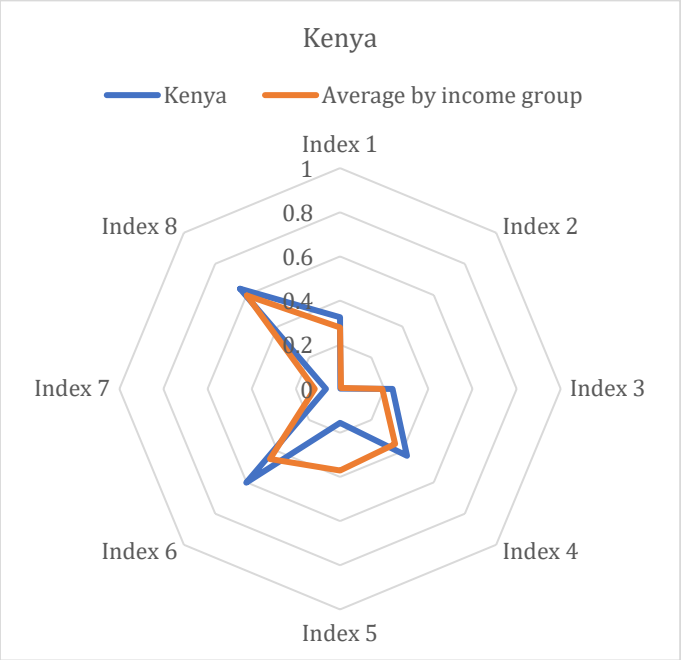

Figure 6