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RESEARCH EFFICIENCY IN HIGHER EDUCATION: CLUSTERING HIGHER EDUCATION SYSTEMS GLOBALLY

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ABSTRACT

This research aims to identify the research efficiency clusters of higher education systems (HESs) globally by comparing size-independent research inputs and outputs. The research was designed benefitting from two different approaches, correlational research to discover the individual contribution of each research output and the general survey model to define research efficiency clusters of HESs. Including 75 countries' HESs, the data were collected from the database of the UNESCO Institute for Statistics, PATSTAT of European Patent Office, and the Web of Science Core Collection records for a designated time period in terms of "per researcher rates" in each HES; 2015 for Research & Development spending, 2018 for articles and patent applications, and 2018-2019 for initially received citations. Through this dataset, regression analysis was first performed to re-calculate the research performance scores of HESs by the individual contribution of each output (patent applications, articles, and citations) eliminating the multicollinearity connections among these variables; then, cluster analysis was carried out to categorise countries in terms of the research efficiency ratios of their HES. The analysis showed four clusters of research efficiency ratios: only one country in the highest group, three in the higher group, 32 in the middle group, and 39 in the lower group. Discussing various policies and practices from HESs displaying the top research efficiency ratio in the analysis, this research presents recommendations to further improve research performance by the potential contribution of each national and international factor in the global research structure.

Keywords: *Higher Education Systems, Research Inputs, Research Outputs, Research Efficiency in Higher Education, Global Clusters of Research Efficiency.*

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[1] SDGs: 1. No Poverty; 2. Zero Hunger; 3. Good Health and Well-Being; 4. Quality Education; 5. Gender Equality; 6. Clean Water and Sanitation; 7. Affordable and Clean Energy; 8. Decent Work and Economic Growth; 9. Industry, Innovation and Infrastructure; 10. Reduced Inequalities; 11. Sustainable Cities and Communities; 12. Responsible Consumption and Production; 13. Climate Action; 14. Life below Water; 15. Life on Land; 16. Peace, Justice and Strong Institutions; 17. Partnership for the Goals (https://sdgs.un.org/goals)

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1. INTRODUCTION

Starting in 2015 but aiming for 2030, Sustainable Development Goals (SDGs) of the United Nations have provided well-established strategies to enhance welfare and living standards in modern, knowledge-based societies. While all of the 17 SDGs[1] are directly or indirectly related to research efforts all around the world (Nakamura et al., 2019), governments naturally prioritise Research & Development (R&D) investments to support the socio-economic development of their countries (Salvia et al., 2019). As an essential part of the entrepreneurship and innovation ecosystem in each country, higher education institutions (HEIs) are typically the main beneficiaries of R&D funds (Castro et al., 2019; Fetters et al., 2010). Herein, observing the Gross Expenditure on R&D (GERD) utilized by HEIs in different countries (UNESCO, n.d.), research efficiency is an open question for any national higher education system (HES).

Efficiency is technically defined as "[obtaining] the maximum possible improvement in outcome…from a set of resource inputs" (Palmer and Torgerson, 1999: 1136). In keeping with this definition, Guan and Wang (2004), for example, compared research related outputs (publications and citations) and inputs (personnel and finance) to examine the efficiency of knowledge production for 21 projects in China. They concluded that when including the size of research groups (and also "per staff" ratios for research outputs), the bibliometric indicators (articles, citations) present a valid and practical model to assess the research efficiency of academic units. Similarly, Bolli and Somogyi (2011) examined the relationship between third-party funding and university productivity in Switzerland. They found that public funds have a positive influence on increasing the number of master students and scientific publications, while private funds are a significant factor fostering universities' technology transfer efforts rather than their publication performance.

In another study, Schmoch and Schubert (2009) analysed the performance-based funding mechanism in Germany using the survey data of academics from the fields of astrophysics, nanotechnology, economics, and biotechnology. In addition to research inputs (i.e., number of scientists) and outputs (i.e., publications-citations in SCI/SSCI Database), they also counted various factors (e.g., personnel quotas, goal agreements, third-party funds, teaching-research time) to examine the research performance of academics. Interestingly, they revealed that the amount of third-party funding negatively affects researchers' efficiency, "especially if the level of third-party funds is already very high" (Schmoch and Schubert, 2009: 195). Similarly, Nikonova and Shavaleyeva (2017) claimed that "science cannot develop without the state financial support…[but] increase in the budgetary financing not necessarily means increase in effectiveness of scientific activity" (p. 1618). Further, summarising the

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conclusions of the Audit Chamber of the Russian Federation, they argued that the efficiency level of R&D activities remained insufficient in the period 2012-2016 because of inadequate coordination of disciplinary priorities, operating standards, and regulatory and economic incentives for research development nationwide.

Beyond nationwide efficiency examinations, there are several multinational comparisons in the reviewed literature. In one of these studies, Auranen and Nieminen (2010) examined the publication data (from Web of Science) and R&D expenditures (from OECD Statistics) for eight (including big and small) countries. They found that Australia, Denmark, Finland, and the UK spent less than 100,000 US $ (research money) per publication during the period 1981-2006 whereas Germany, Netherlands, Norway, and Sweden spent more than 100,000 US $. In another study, Agasisti and Berbegal-Mirabent (2020: 8) employed a long list of variables (including "per academic staff" ratio for each of the following: third-party funding, undergraduate students, graduate students, publications, and patents granted, as well as budgetary input) to examine the efficiency of HEIs through a comparison of 307 universities from eight European countries. They revealed that against the average efficiency of 0.571 for the whole sample, UK universities have "the highest average scores (0.654), followed by Belgium (0.614), and Sweden (0.592)… [while] universities in Switzerland (0.404), Portugal (0.467), and Germany (0.468) are the less efficient… on average" (Agasisti and Berbegal-Mirabent, 2020: 9).

Dip (2021) also re-ranked the knowledge transfer and research performance of universities from all around the world benefiting from the data of the U-Multirank system for 818 universities from 56 countries. Focusing on seven indicators in two dimensions ("Knowledge and Transfer" and "Research"), Dip (2021) discovered that there were two clusters of universities based on their indicator values and institutional size; he concluded that patents awarded and research publications significantly influence the place of universities in these two groups. Rather than universities, "U21 Ranking of National Higher Education Systems 2020" is a unique study which evaluated HESs at global level in terms of Resources and Environment (as inputs, based on international records and/or surveys), and Connectivity and Output (as outcomes, based on international records and/or surveys) (Williams and Leahy, 2020). While this study benefitted from the records of "R&D Expenditure by tertiary education institutions" and "Total number of research documents produced by HEIs", these data were interestingly divided into the population of a related country to normalise the ratios country-size independently. Using the number of universities in the top-300 of QS World University Rankings, Benito and colleagues (2020) also generated the Excellence/Quality Rankings for 39 countries' HESs and then examined the relationship between their own ranking scores and the Gross Domestic Product per capita, R&D Expenditure, and U21 Ranking scores for the Environment and Connectivity indicators. Their research clearly showed that GDP per capita is the most important factor, even bringing about two divisions for the Excellence/Quality of HESs, as follows: "high GDP per capita" and "low GDP per capita" countries.

As expected, most of the studies given above confirmed the well-known fact that giant R&D investor countries (e.g., USA, China, UK, Germany, France) are largely the forerunner nations in terms of massive scientific production by HEIs. Although some studies observed the population factor for the size-independent normalisation of country data, such studies could not fully reveal the potential impact of "the high amount of funding for the research workforce in HEIs" by relatively small but rich countries (e.g., Australia, Canada, Denmark, Israel, Ireland, Netherlands, Luxembourg, Norway, Sweden, Switzerland (UNESCO, n.d.)). On the other hand, HESs from all around the world display a huge variety in terms of "R&D funding per researcher", independent of their population size, big or small. In fact, including the financial and human resource components together, this variety on "funding level per researcher" allows us to focus directly on the input aspect of the personnel level in HESs, regardless of the size of their researcher population.

For example, there are some countries having relatively small population of researchers in their HEIs but spending large amount of R&D money for these researchers, as in the case of Qatar, employing 1,047 researchers in 2018 against 985.6 million US $ R&D spending by its HES (UNESCO, n.d.). A contrary example from countries displaying lower record by "R&D spending per researcher" in their HES, India spent 4.2 billion US $ R&D money in 2018 for 124,702 researchers in its HEIs (UNESCO, n.d.). In addition to this variety of "R&D spending per researcher" records, as already stated by Guan and Wang (2004), in terms of international patent applications, articles in high-impact journals, and the number of citations in prestigious databases, the ratios per researcher also constitute the size-independent outputs for research efforts at the personnel level in the related HES. As a result, comparing "the output and input ratio per researcher" can provide a fair picture to assess the scientific-technological productivity and impact viewed against the R&D investment by the country's HES.

However, when we consider the "Matthew cumulative effect" through publishing patent-related articles in high-impact journals and then receiving a large number of citations for such articles (Bruni et al., 2020), eliminating multicollinearity between these research outputs is necessary to explore the individual contribution of each output category to the research efficiency of the related HES. Considering the time that elapses to obtain the earliest products following fund payments, it is also important here to assign an appropriate period for the data of "funding records" and "the number of scientific and technological products" later on, as well as the initial impact of these outputs (see details in Methodology). At the end, such research including R&D funding input and scientific outputs free from their mutual connections for a certain period of data can provide opportunities for each country to compare the research efficiency of their workforce in HES with other countries in the same or different efficiency groups. This multinational comparison can also assist higher education authorities as well as university managers to overview science, technology, and higher education policies and practices from HESs displaying high research efficiency. Therefore, the purpose of this study is to examine the research efficiency clusters of HESs from all around the world comparing size-independent input and outputs, based on their non-autocorrelated values through the data of a suitable time space. For this purpose, the research questions are:

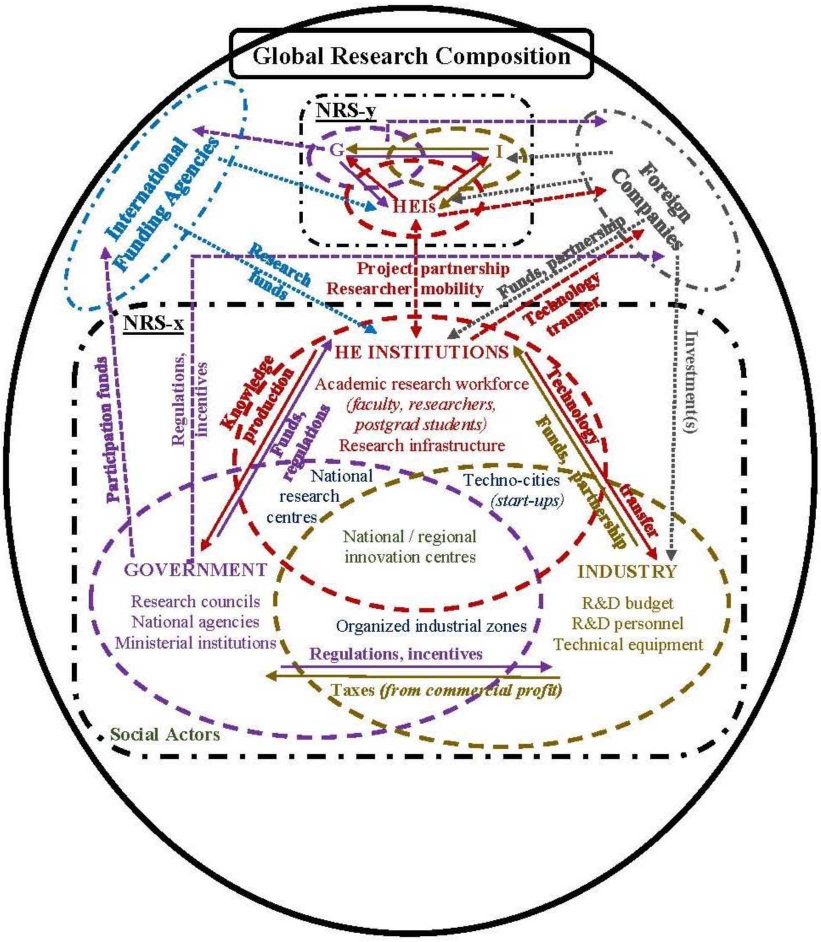
1. Which countries spend the highest and lowest amount of "R&D funding per researcher" in their HES?
2. Which HES displays the best ratio(s) per researcher in terms of patent applications, articles, and citations?
3. What is the percentage value of each research-related output (patent applications, articles, and citations) for HESs?
4. How many clusters are there in terms of the proximity of research efficiency rates for HESs?
5. Which country has the most efficient HES comparing the per researcher ratios of scientific-technological productivity and impact with R&D funding?

2. THEORETICAL APPROACH

HEIs can be seen as the basis of HES in a related country; then, teaching, research, and service activities of academics in these HEIs constitute the products of the related HES. Accordingly, to be able to fully evaluate the efficiency of any HES, we should count the outcomes of academics' teaching, research, and service activities altogether. Without standardised data, however, it is not possible to compare teaching quality indicators or the impact level of service activities in the related HES with others. Nonetheless, looking at research inputs and outputs, there are some standardised data allowing to compare different HESs' research efficiency (Coccia and Rolfo, 2007). Herein, rather than solely generating numerical comparison by HESs, it is more important to discuss the potential factors bringing a higher efficiency for any HES within 'Global Research Composition'. At this point, defining the major components of a research system allow us to consider various relations between these components (Banu, Kumar, Rizvi, Rai, and Rana, 2024; Auranen and Nieminen, 2010).

While the Triple-Helix approach picturised "University-Industry-Government" configuration for research and innovation systems (Etzkowitz and Leydesdorff, 2000), this configuration is criticised by focusing largely on university-industry linkage around research commercialisation activities (Banu, Kumar, Rizvi, Rai, and Rana, 2024; Schneijderberg and Götze, 2022). Nonetheless, considering further Helix structures with civil society (see Galvao et al., 2019), it seems that Helix configurations offer a good start to outline the research-oriented relationship between academia and the other components in the research system (see Figure 1).

Figure 1. Components and Their Relations within the Global Research Structure



Notes: (NRS: National Research System)

As can be seen in Figure 1, in addition to the major components of the helix configuration, international funding agencies and foreign companies are also important parts of the Global Research Composition. Further, as argued by Cai and Etzkowitz (2020), collaboration between each component (HEIs, government, industry) with the same component in other countries enriches the transnational dimension of research systems. Nonetheless, to be able to discuss the efficiency of HES for any country, rather than considering the relations between all components of Global Research Composition, it will be better to focus largely on HEIs as well as their relations with other actors in the research system, both at national and international level. When focusing on the research efficiency of different HESs at the global level, of course, it is not easy task to consider individual HEI examples or various disciplinary cohorts within such an extensive framework given above (see Limitations and Further Research section). Still, observing the research productivity of any national HES, it could be a good way counting joint patent applications (particularly for researchers from STEM areas and industrial organisations) with industry-oriented articles (with collaboratives from academia and industry) and co-authored publications (by Social Science and Humanities researchers and their societal partners) as important parts of knowledge and technology production in a related HES (see Methodology section).

Without doubt, as the body guiding policy regulations, the government of any nation undoubtably plays an important role in the general formation of HES, as well as research priorities for HEIs in their country (Clark, 1983). U21 Rankings, through their survey component on policy environment and financial autonomy, clearly show the influence of governmental policies on the performance of HES in the related country (Naseem, Mahmood, Rauf, and Yen, 2025; Williams and Leahy, 2020). Moreover, as Nikonova and Shavaleyeva (2017) argued, public funds from the government are an essential support for the development of research efforts in HEIs. In addition to direct public funds for HEIs, secondary funds from government-related units (research councils, development agencies, etc.) are another important source for researchers in the higher education sector. Here, being a part of national research centres can provide indirect public support for researchers from the partner HEIs in the related centre (Coccia and Rolfo, 2007). As much as governmental regulations allow, social actors can also become valuable partners for researchers from HEIs, particularly to form co-authored publications on public reforms (i.e., with collaborators from Non-Governmental Organisations (NGOs) (Reddy and Reddy, 2006), policy analysis (i.e., as the part of their roles in Think Tank organisations (McGann, 2009), or even social responsibility projects (i.e., with their partners both from civil society and industry (Asih, Bachtiar, and Utami, 2025; Doh and Guay, 2006).

While HEIs, governmental units, and social actors also develop research collaboration within the national (or regional) innovation centres, industrial institutions can become crucial partners for research production and particularly for technology innovations, as in the case of the local public technology centres in Japan (Fukugawa, 2008). Further, industrial firms can provide funds solely for researchers from HEIs (especially through contract research) or develop a partnership with HEIs bilaterally to produce new technologies (Fetters et al., 2010). It is important to remember here the fact outlined by Bolli and Somogyi (2011), that the funds from industrial firms as well as research cooperation can motivate researchers from HEIs to focus more on practical studies and technology innovations. As exemplified by Ma (2019) for the Chinese case of Tsinghua University, multinational industrial enterprises, mostly through their local organisations and investments, can also contribute to the research and innovation efforts of HESs in a related country. Additionally, international funding agencies (i.e., CRDF Global, European Research Council, Human Frontier Science Program, The African Academy of Sciences, The World Academy of Sciences) provide research funds for researchers from HEIs. While researchers can develop a project partnership with their international colleagues to be able to compete for these prestigious international funds, HEIs mostly seek bilateral agreements with higher education and/or research organisations abroad to generate research-based mobility opportunities for their researchers (Yang, Cai, and Li, 2024; Aldieri et al., 2018).

All in all, rather than individual HEIs' research performance or the productivity of researchers from a particular discipline, as previously mentioned, this study focuses on the comparison of national HESs globally in terms of their research efficiency. Herein, the components of a national research system and their relations with transnational actors together offers a more comprehensive perspective to evaluate the background factors for research productivity in any HES. However, analysing the research investment and production in HEIs independently from the size of the research workforce is also important to equitably compare the research efficiency of HESs from all around the world. All the details for comparing the research efficiency clusters of HESs at the designated time period are presented in the following section.

3. METHODOLOGY

This research was designed as a survey model but benefitted from combining two different approaches of survey research. These are: i) correlational research to discover the individual contribution of each research output, and ii) the general survey model to define research efficiency clusters of HESs at the global level. While correlational research allows researchers to examine the relationship between variables on attitudes, opinions, terms, or scores via the explanatory or predictive approach (Adelson et al., 2018; Tekbıyık, 2014), the general survey approach is used to investigate the descriptive characteristics of existing data (Stapleton, 2018; Özdemir, 2014). In keeping with these definitions, regression analysis was first performed to re-calculate the research performance scores of HESs by the percentage value of each output (patent applications, articles, citations), and then cluster analysis was carried out to categorise countries in terms of the research efficiency ratios of their HES.

3.1. Period for Dataset

Considering the dramatic effects of the Covid-19 pandemic on funding priorities and also the contemporary publications on this health topic, the researcher preferred to restrict the collection of data to the pre-pandemic period (in other words, before 2020). Therefore, the citation impact was assessed through the citation rates in 2019 for each country's HES. Taking the period between publication and impact in the related field into account, the number of articles in 2018 was included in the dataset. It is a well-known fact that most articles (particularly in prestigious journals) receive citations in the same year as the publication date; hence, the citations in the publication year of articles were also included in the research impact data. Then, the researcher labelled these citations in 2018 and 2019 as having "initial citation impact" for articles published in 2018. In addition to citations and articles, the number of patent applications by HEIs in 2018 was also counted as research outputs in the dataset.

When deciding a reasonable time between funding date and the results (at least initial ones) of funded research, the researcher examined research periods for different funds from various countries and international research agencies. For example, in our home country, the most prestigious fund of the national research council has a maximum of three years for a project's duration (see 1001 programme: https://www.tubitak.gov.tr/), or, with the same period, the National Research Foundation of (South) Korea provides support to social science researchers for three years (see Social Sciences Korea programme: https://www.nrf.re.kr/). As another example, while most funding agencies in Germany foresee a six-year period as the maximum for individual research, they generally pay half the funding for the first three years and expect to see the initial outcomes of funded research (in the form of patent preparation, articles, chapters, and/or conference papers) in the same time frame (see Emmy Noether programme: https://www.dfg.de/). Similarly, the European Research Council offers five-year support for its Starting, Consolidator, and Advanced Grants programmes, asking for an interim report in the third year to decide whether they will pay the second half of the grant (see: https://erc.europa.eu/). No doubt, there are still various time frames for research funding in different HESs. Nonetheless, based on all the examples given above, the researcher considered three years as the acceptable time to see the results or initial products of funded research. Therefore, for 2015, both the records of R&D spending by the higher education sector and the number of researchers in HEIs were added to the dataset.

3.2. Data Collection

The data collection process was started with the research input dimension of a HES, including the number of researchers in HEIs and the amount of R&D spending by the higher education sector in 2015. These data for various countries were retrieved from The UNESCO Institute for Statistics (UIS) (UNESCO, n.d.). UIS presents data from 162 countries, but many countries' data are missing on the number of (full-time equivalent (FTE)) researchers and GERD in the higher education sector. Therefore, if there was not enough data to use, countries with missing data were eliminated. After this, 81 countries remained in the dataset. Next, the researcher examined the extreme cases of HESs in terms of 'R&D expenditure per researcher in HEIs'; six more countries were then eliminated (detailed in next section). At the end, the dataset included 75 countries in total (see Appendix).

For the research output dimension of a HES, both the number of articles published in 2018 and the number of citations these articles received in 2018-2019 were retrieved from the Web of Science (WoS) Database. Using https://apps.webofknowledge.com/ interface of WoS, the researcher limited the data about articles published in journals indexed by Science Citation Index Expanded, Social Sciences Citation Index, and Arts & Humanities Citation Index collections. While collecting the data, the search settings for the WoS database was first limited to 2018, and only "ARTICLE" was selected among the options of "Document Type". The researcher then wrote the name of each of the 75 countries one by one in the address section. Here, 2018-19 citation reports were also taken from WoS only for articles published in 2018.

Additionally, the researcher benefitted from the PATSTAT records of the European Patent Office to extract the number of patent applications for the 75 countries in the dataset. Using the "https://data.epo.org/expert-services/index.html" interface of PATSTAT, 2018 was first selected in the "Application Date" section. Secondly, the two-digit country codes of ISO-3166 was used to select each of the 75 countries in the "Applicant / proprietor (Country)" section. Lastly, the patent data was limited for HEIs through the "Applicant / proprietor" section. For this section, the keywords for various types of HEIs (university, institute, college, school) were entered one by one. Here, the researcher searched these keywords in both English and the native language of the related country (benefitting from Google Translate) and even looked for alternative terms in the native language (e.g., Politecnico in Italian, Ecole Polytechnique in French, or Universitat Politècnica in Spanish). In addition, for the keyword "school", each result was checked to see whether the related school was a HEI or not (meaning a K12 – high – school). Further, considering the "institute" keyword, the name of each patent applicant was checked on their website to decide whether the institute is a HEI/research centre or a private company. Here, the patent files applied jointly by a HEI and a private company were counted as a sign of academic-industrial collaboration. Completing the dataset with the number of patent applications by the 75 HESs and entering all data onto MS Excel, the researcher then began analysis of research efficiency.

3.3. Data Analysis

When looking at efficiency ratios for various factors in different issues, 'Data Envelopment Analysis' seems as commonly used non-parametric technique including multiple inputs and multiple outputs together, mostly for a longer time period of data (Martín-Gamboa and Iribarren, 2021; Song et al., 2013; Thanassoulis et al., 2011). On the other hand, considering the continuous nature of our research variables (in terms of their quantity sequence) and having a sole input (research expenditure) for a certain year, the researcher preferred different analysis for our normally distributed data (see: 'iv' below) to calculate the weights of variables and the research efficiency coefficients of national HESs. Thereby, starting with the data of 81 countries, our analysis process included several steps related to basic calculations, regression analysis, and cluster analysis. All processes of the analysis were explained below step by step:

i) The researcher calculated "per researcher in HEIs" values of the patent applications, articles, and (initial) citations, as well as the amount of "R&D spending per researcher in HEIs" for each country's HES.

ii) As suggested for the normality condition of dataset (Tabachnick and Fidell, 2014), the researcher looked over HESs recording extremely high and relatively low "R&D spending per researcher in HEIs". In other words, observing the outlier values for "R&D spending per researcher in HEIs", six countries were eliminated. Dividing the 2015 data of "GERD by higher education" by "researchers in HEIs", while two of these countries (Congo and Qatar) showed over a million US $ spending per researcher, another four (Kuwait, Mali, Uzbekistan, and Vietnam) spent less than 10,000 US $ per researcher in HEIs. In the final dataset of 75 HESs, Table 1 shows countries displaying the highest and lowest "R&D spending per researcher in HEIs".

iii) The researcher calculated the mean of the remaining 75 countries for each of "patent applications", "articles", and "citations" per researcher in HEIs separately. Assigning 100 points to the global mean for each of these three variables, the country scores were assessed to sum up the total "research output score" of each HES.

iv) Following Soh's (2011: 22) example calculating attained weights of university rankings criteria, the researcher performed multiple regression analysis to calculate individual contribution of each research output (eliminating the multicollinearity between patent applications, articles, and initial citations) to the total "research output score" for 75 HESs. Whereas regression analysis is generally employed to predict (at least some variance of) the dependent variable through independent variable(s) (i.e., $A = constant + x\beta_x + y\beta_y + z\beta_z + \ldots$), it was used here to see the individual contributions of the sub-components of the dependent variable (i.e., $A_{total} = constant + A_1\beta_{A1} + A_2\beta_{A2} + A_3\beta_{A3} + \ldots + A_n$) (Uslu, 2020). Nonetheless, at the beginning, the researcher checked pre-conditions for regression analysis on the dataset (Hair et al., 2010), as follows: (1) The total "research output score" as the dependent variable shows normal distribution (Kolmogorov-Smirnov Z=1.326; $p > .05$); (2) Observing Tolerance (> .10) and VIF (< 10) criteria, Collinearity Statistics are at an acceptable level (in other words, no multicollinearity problem – see Table 3); and (3) the Durbin-Watson test (D-W ≈ 2 criterion) evinced no "autocorrelation between error ratios" (another sign for no multicollinearity) (see Table 3). After ensuring these prerequisites, naturally expecting a full-prediction ($R^2=1$) for "total research output scores (as, A_{total})", the researcher calculated the individual weight separately for patent applications (as, A_1), articles (as, A_2), and initial citations (as, A_3). Here, the standardised beta coefficients were extracted to estimate the percentage value of each of our three independent variables without multicollinearity among them (in other words, eliminating the Matthew cumulative effect between our predictors, "patent applications", "articles", and "initial citations" per researcher in HEIs).

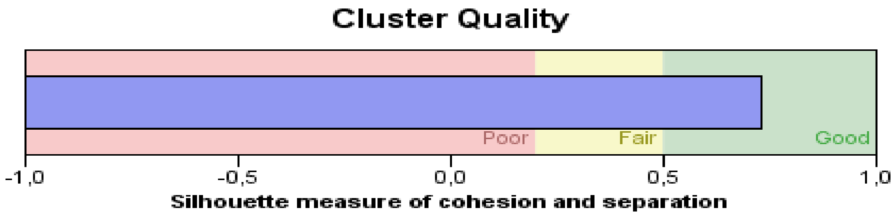
v) Summing up these weighted scores, the final score of (size-independent) research outputs was calculated for HESs in the dataset. Finally, dividing the final "research outputs" score by the "R&D spending per researcher" in HEIs (per thousand US $), the researcher calculated the efficiency ratio of each country.

vi) For the cluster analysis, initially, two pre-conditions were checked. First, enhancing the representative power of the sample by eliminating the outliers (Çokluk et al., 2012), as the researcher explained in "step ii" above. For the second condition, when considering only "*research efficiency ratios*", there was no separate dependent or independent variable(s) to check multicollinearity concerns (Hair et al., 2010). Instead, as a non-hierarchical clustering method not needing to check multicollinearity, K-Means Cluster analysis was employed to categorise the research efficiency ratios of HESs for 75 countries into the pre-determined number of groups. Here, to be able to decide the most suitable number of clusters, the researcher carried out TwoStep Cluster analysis, and this analysis produced a good separation into four clusters on the research efficiency ratios of the sampled countries (see Figure 2).

Figure 2. Twostep Cluster Analysis of Hess by (Size-Independent) Research Efficiency Ratios

Model Summary

Algorithm	TwoStep
Inputs	1
Clusters	4



4. FINDINGS

The findings are presented sequentially to the research questions and country names are given in tables. To respond to the first question, the researcher summarised the lowest and highest R&D spending HESs as well as per researcher ratios in Table 1.

Table 1. R&D Inputs for HESs

Rank	Country	R&D Spending by HES (thousand US $)	Country	Researchers in HES	Country	R&D Spending per Researcher in HES (thousand US $)
1	USA	64,623,000	China	298,728	USA	361.53
2	China	25,798,671	USA	178,751	Oman	291.40
3	Japan	20,694,194	G. Britain	167,463	Mexico	289.13
4	Germany	19,724,843	Japan	137,078	Netherlands	242.83
5	France	13,553,504	Germany	130,148	Sweden	227.17
mean	*Global*	*3,649,965*	*Global*	*28,436*	*Global*	*128.36*
71	Montenegro	17,783	El Salvador	267	India	28.02
72	Cambodia	11,332	Guatemala	215	Pakistan	26.40
73	Moldova	9,827	Cambodia	178	Senegal	20.00
74	Eswatini	8,105	Eswatini	68	Moldova	18.27
75	Lesotho	2,817	Lesotho	32	Bulgaria	17.50

Note 1: For the Australian HES, the mean of 2014 and 2016 were included as the number of researchers in 2015.
Note 2: For the United States HES, the number of researchers in 2015 was calculated, as: GERD by HES / (GERD / researchers)

Table 1 shows a visible difference between the highest and lowest five R&D spending HESs in 2015. Looking at the number of researchers in various HESs in the same year, the giant R&D investor countries have the highest researcher population; similarly, the same applies to the lowest R&D investor countries, with generally the lowest number of researchers in their HES. On the other hand, only the USA keeps its place among the five highest and five lowest R&D spending HESs while most of the 75 countries display a different picture in terms of "R&D spending per researcher" in their HES. When checking the ratios of research production and impact, Table 2 also presents a differentiation between the highest R&D investor HESs and the top performing countries at the level of individual researchers.

Table 2. R&D Outputs for HESs

Rank	Country	Patent Applications per Researcher in HES	Country	Articles per Researcher in HES	Country	Citations per Researcher in HES
1	Luxembourg	.04444444444444440	Cyprus	2.95	USA	17.53
2	Belgium	.01193399469600240	Chile	2.49	Cyprus	15.41
3	USA	.01083630301368940	USA	2.29	Netherlands	13.52
4	Israel	.01011470281543270	Slovenia	2.01	Denmark	12.90
5	France	.00955765994323177	Cambodia	1.96	Switzerland	12.15
mean	*Global*	*.00338112673903431*	*Global*	*1.01*	*Global*	*6.76*
71	Senegal	0	Paraguay	.21	Malaysia	1.14
72	Serbia	0	Malaysia	.21	Eswatini	1.04
73	Sri Lanka	0	Eswatini	.21	Paraguay	.92
74	Sweden	0	Senegal	.06	Un. Arab Em.	.29
75	Ukrain	0	Un. Arab Em.	.06	Senegal	.22

Note: 25 countries had no patent application record for 2018[2]; among these countries, the last five by alphabetic order were stated in the latest rankings.

According to the 2018 data summarised in Table 2, the country displaying the highest patent application ratios in terms of their researchers in HES was Luxembourg. Whereas one-third of the 75 countries did not have any patent application record, it is a remarkable achievement with 945 researchers in total that Luxembourg HEIs applied for 42 (international) patent files in 2018 (UNESCO, n.d.). At the bottom, the HESs with the lowest ratios of "articles per researcher" were about the same as the lowest ratios of "citations per researcher", hence their lesser-known profile in global academia. While assigning 100 points separately to the global mean of each of these three variables, Table 3 presents the regression results for the individual contribution of each variable to countries' size-independent research performance score.

Table 3. Regression Analysis of the Scores of R&D Outputs

Indicator	β	*t*	p	Collinearity		Value
				Tolerance[¥]	VIF[†]	(percentage)[3]
Patent Applications per Researcher	.731	199446.52	.00*	.86	1.17	59.4792514239219
Articles per Researcher	.251	33094.87	.00*	.20	5.03	20.4231082180635
Citations per Researcher	.247	31443.70	.00*	.19	5.36	20.0976403580146
Model Summary	R = 1.00; R^2 = 1.00; $F_{(3-71)}$ = 29029849222.29; p = .00*; D-W[Π] = 1.89					

Notes : * p ≤ .05; [¥] Tolerance > .10; [†] VIF < 10; [Π] D-W ≈ 2

As can be seen in Table 3, by eliminating multicollinearity among the three variables, the highest contribution to the research performance of HESs comes solely from their "patent applications per researcher" ratio (with 59.48% value). The percentage values for articles and citations per researcher are nearly the same (around 20%). Nonetheless, the total percentage of these two (40.52%) is still less than the contribution of "patent applications per researcher" to the research performance of HESs. The research performance score of each country was re-estimated multiplying these percentage values; then,

[2] The patent records for each of these 25 countries was double-checked: for example, considering the autonomous positions with China, all patent records of Chinese HES were visually inspected one by one for Hong Kong and Macau; or, PATSTAT records were checked through the names (both in English and in Swedish) of each of the 39 Swedish universities (Study in Sweden, 2021).

[3] i.e., for patent applications per researcher: [.731 / (.731+.251+.247)] x 100 = 59.4792514239219 %

dividing the total research performance score by the amount of R&D spending per researcher in HEIs, the research efficiency ratio was calculated for the related country. Table 4 displays the clusters of HESs based on their research efficiency ratios.

Table 4. Clusters of HESs by (Size-Independent) Research Efficiency Ratios

Focus	Mean square	d.f.	F	p	Clusters	Distance between cluster centres			
						1	2	3	4
Size-independent research efficiency	13.08	3	346.29	.00*	1-highest (n=1; $\bar{X}$=5.66)	-			
					2-higher (n=3; $\bar{X}$=2.34)	3.32	-		
					3-middle (n=32; $\bar{X}$=.92)	4.74	1.41	-	
					4-lower (n=39; $\bar{X}$=.34)	5.32	2.00	.59	-

Notes: * p ≤ .05

The findings in Table 4 reveal four clusters considering the research efficiency ratios of HESs. Although only one country took a place in the highest efficiency cluster, the ratio of this country is more than double the next cluster, with three countries. While the means of research efficiency ratios in the middle and lower clusters are relatively close, these two clusters include 71 (roughly 95%) of the 75 countries. All these findings clearly show that Luxembourg HES, sitting alone in the highest efficiency cluster, is far above the rest of other countries' HESs in terms of research efficiency (see: Appendix).

5. CONCLUSION, DISCUSSION, AND RECOMMENDATIONS

This study focuses on the research efficiency of HESs, independently of the size of their researcher population. Assigning a particular time period for the research-related data, the weighted contribution of patent applications, articles, and citations were used to calculate the score of "research outputs per researcher" in each HES. The research efficiency ratio of each country was then calculated through the "research outputs" score divided by "R&D spending" per researcher in HEIs.

Looking at the individual contribution of each research output, while article and citation ratios per researcher produce almost the same value (.20), patent applications per researcher display a roughly three times larger (.60) value. This is not a surprising result when we consider both the huge amount of investment in technology-oriented projects and also the intensive scientific work to create end-products with commercial potential. With this reality, many universities around the world have already embraced increasing the number of their patent applications each year as one of the major priorities in their strategic plan (i.e., see the University of Luxembourg: UL, 2018). It is then easy to see the reflection of such a strategy in the related HEI. For example, posters with the motto "First patenting, then publishing" can be seen all around our home institution, even on the walls of the faculty buildings of social sciences, humanities, and arts.

Beyond these institutional strategies and policies, it is also important to query other potential factors to achieve more innovative production in HEIs. Here, not an innovation giant but the global champion of research efficiency clusters, Luxembourg HES presents valuable insights. In the centre of Europe, this small country (with a population of only around 600,000) has neither large tracts of land for agricultural production nor a substantial workforce for heavy production industries. On the other hand, Luxembourg was named as one of five innovation leaders in the European Innovation Scoreboard 2020 (EC, 2020), and this report explained the advantage of hosting many "top R&D spending enterprises" in the country, compared to the European mean. The report also described the higher proportion of the workforce engaged in knowledge-intensive services as a sign of the innovation-oriented ecosystem in Luxembourg. An important detail in the theoretical framework of this research (see Figure 1) is that the government has also employed various policies to attract foreign technology companies to Luxembourg, such as low tax rates, state support for small-medium-enterprises (SMEs), and "strong incentives towards innovation, especially in regards to industrial and technological sectors" (Kavvadia et al., 2018: 3).

With this favourable environment, Luxembourg presents a perfect pitch for HEIs to develop well-established cooperation with technology-oriented industries. This finds a response in the patent applications from the University of Luxembourg (as the main and biggest HEI) in 2018; according to PATSTAT records, nearly half of these applications were partnered with local or international companies. Further, Luxembourg seems to be the most attractive research system in the European Innovation Scoreboard 2020 in which it was described thus: "Luxembourg scores particularly well on Foreign doctorate students, International scientific co-publications" (EC, 2020: 57). This is obvious evidence for another factor in the theoretical framework, that of international collaboration between researchers from Luxembourg with other countries. By means of this highly internationalised structure, Luxembourg HES also achieved obtained a higher score from article and citation rates per researcher compared to the global means of these research output categories (see Appendix).

In another example, a neighbour country strongly influencing the roots of Luxembourg HES, Germany has the highest number of universities (23 of top100) in the European list of Reuters' most innovative universities (Reuters, 2019). However, the European Innovation Scoreboard 2020 reported as follows: "[Although] Germany performs particularly well on Public-private co-publications, R&D expenditure in the business sector and … [yet] Attractive research systems, Human resources… are the weakest innovation dimensions, [and the] lowest indicator scores are on Foreign doctorate students, Population with tertiary education, Lifelong learning…", because they are below the European means for all these indicators (EC, 2020: 46). This shows that even giant R&D investor countries like Germany need to further strength their HES, particularly for attracting international researchers.

Examining the research efficiency ratios for USA and China HESs, as top R&D investor countries in the world, both are just above the global line (see Appendix). While these countries have many companies with an impressive amount of patent records (e.g., Huawei, China, with 5,405 patent applications in 2018, or Qualcomm, USA, with 2,405 applications), a large number of companies from these countries prefer to invest abroad. For example, Ireland, occupying the third position here in the research efficiency list of HESs, already hosts over 700 US Companies, including technology firms such as Mastercard, LinkedIn, and Intercom (ACCI, n.d.). Similarly, Belgium, as another HES found to have a high research efficient ratio in this research, has attracted a remarkable amount of direct foreign investment, particularly from Chinese companies such as Huawei (BCECC, n.d.). In addition, The China Belgium Technology Center is a part of UCLouvain Science Park aiming "to create an ecosystem where collaboration in research and innovation, strategic investment and industrial partnerships between China and [Belgium] becomes reality" (CBTC, n.d.). Such international technology centres possibly make a great contribution to KU Leuven's success in being first in European and seventh in the world list of Reuters' most innovative universities; described thus "[KU Leuven] consistently produced a high volume of patents and papers that influenced researchers across Europe and around the world" (Reuters, 2019a; Reuters, 2019b).

Furthermore, as the HES having the second highest research efficiency ratio in the present study, Slovenia HES presents a different picture displaying the influence of another factor in the theoretical framework. While Slovenia has a public investment record in the R&D sector roughly half of the mean of European countries, the private sector spending for R&D investment is around the European mean (EC, 2020). On the other hand, as described by Čok (2020), "The financial situation of science and technology in Slovenia depends largely on the funds… from the European budget. While Slovenia's performance within… Horizon 2020 is not bad, we are even the best of the EU13 countries in terms of size" (p. 1). This clearly shows the importance of international funds for HESs, as in the case of Slovenia, with an impressive record of 319 successful applications in the Horizon 2020 program and 137 researchers in Marie Curie Actions mobility schemes within the five-year period between 2014 and 2019 (Net4Mobility, n.d.). These R&D funds, mostly coming from the international funding agency (EU funds) and private sector, naturally resulted in a "high [performance] on International scientific co-publications, Public-private co-publications, Innovative SMEs collaborating" (EC, 2020i: 65), therefore increasing Slovenia HES's research efficiency by patent and publication scores and roughly doubling the global means (see Appendix).

In conclusion, going beyond solely investing more money in R&D activities, as already suggested in the triple-helix formation (Etzkowitz and Leydesdorff, 2000), authorities should seek ways to enhance collaboration between university-industry-government in their countries. In this regard, industrial-PhD programmes (Ori, 2013) and industry-university co-fund initiatives (i.e., Industry-academia partnership programme of UK Newton Fund's programme of Industry-Academia Partnerships in which seven countries have collaborated (RAE, n.d.)) are already well-known practices. In addition, to increase research productivity in HEIs, establishing moderator institutions could also be useful to bring academic researchers, industrial partners, and social actors together, as in the case of two Asian innovation leaders (GII, 2020); local public technology centres in Japan (Fukugawa, 2008) and "Innovation Cities" hubs in South Korean cities (Ahn et al., 2021). However, this research revealed that in this globalised world, multinational industrial organisations are crucial actors to strengthen a nation's research and innovation capacity. Therefore, looking at the "Luxembourg" example, governments have to establish various incentives (tax exemptions, land grants, easy firm establishment, etc.) to attract foreign investments to their country. Naturally, this is not an easy, short-term task for any government considering the political stability, financial transparency, population and (particularly well-trained) workforce dimensions of the business environment in a related country (Wilson and Baack, 2012). Nonetheless, HEIs can develop their own initiatives, as KU Leuven did with the China Belgium Technology Center, or another example, copying the "China Torch Program" and then establishing a "Torch Innovation Precinct at UNSW (University of New South Wales)" in Sydney, Australia to "bring together industry, SMEs, entrepreneurs, investors and policy makers from Australia, China and beyond" (Torch at UNSW, n.d.).

According to the results of this study, improving international collaboration is another important factor to enhance the research performance for any HES. As an ambitious example for countries aiming to strengthen the international structure of its higher education and research systems, Germany established the German Academic Exchange Service (DAAD, n.d.) to attract international postgraduate students and researchers and has also employed different scholarship programmes to support short-period research visits by foreign researchers to Germany and long-term research collaboration between German and international researchers (see: https://www.dfg.de/en/index.jsp and https://www.humboldt-foundation.de/en/). In addition, international funds are another source naturally resulting in more visible research products on behalf of the country's HES at global level. To increase success in gaining international funding, in addition to promotional international information-giving day events (i.e., European Research Council (ERC) Info Day) in their country, national authorities can also organise various activities to guide the project applications of researchers from their HEIs. This was carried out in Slovenia by hosting Research Proposal Reading Days to provide opportunities for researchers to learn from their colleagues with previous ERC fund achievements (ERC, 2020). As another interesting practice to increase the chance of their researchers in international fund applications, Türkiye recently initiated a pre-evaluation programme under the Horizon 2020 framework to receive paid evaluation advice from internationally experienced experts for (a limited number of) Turkish applicants to improve their proposals for Marie Curie Fellowships and ERC Grants (Ufuk 2020, n.d.).

6. LIMITATIONS AND FURTHER RESEARCH

At the end of the analysis, this research discussed the structural factors (nationally and internationally) influencing the research efficiency of HESs and presented some political strategies and practical recommendations through the examples from various countries given above. However, the research efficiency ratios, independently of the size of the researcher population in the HESs, were calculated using the data of research inputs and outputs only for the designated time period (funding and research workforce in 2015; articles in 2018 and citations in the following year). On this point, researchers might usefully work with the data of a longer time period to compare the long-term research efficiency ratios of various HESs. Another issue, considering the high percentage value of patent applications (around 60%) for research productivity, suggests that researchers can examine the research efficiency ratios of HESs in terms of various disciplinary perspectives, possibly following the distinctions of Science, Social Sciences, and Arts & Humanities in the Web of Science database. Moreover, considering the time variations for publications in different disciplines to reach the highest number of citations (Glänzel et al., 2014), it would be a good idea to examine the time-period for citation data in each discipline separately. In addition to detailed statistical examination, using qualitative inquiry via various participant groups (higher education managers, administrative staff, academics, students, innovation partners, etc.), it is also necessary to conduct further research to be able to comprehensively understand the influence of policy changes on institutional strategies and organisational formations in HEIs as well as their reflections of the work conditions, research agenda, and publication strategies of academic researchers.

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Appendix. Cluster Lists of HESs by (Size-Independent) Research Efficiency Ratios

(HES of) Country	Cluster	(Size-independent) Research efficiency ratio	(per researcher, weighted score of) Patent Application	Article	Citation	R&D spending per researcher (thousand US $)
Luxembourg	1-highest	5.66	781.85	28.10	27.00	147.98
Slovenia	2-higher	2.92	136.04	40.74	29.57	70.60
Ireland	2-higher	2.07	121.60	14.65	11.92	71.75
Belgium	2-higher	2.02	209.94	23.00	22.41	126.30
Israel	3-middle	1.48	177.93	32.31	26.12	160.02
Bulgaria	3-middle	1.24	.00	11.98	9.64	17.50
Portugal	3-middle	1.21	61.11	12.12	10.89	69.49
France	3-middle	1.21	168.13	18.93	18.21	170.22
South Korea	3-middle	1.15	135.60	30.44	30.28	171.21
Cyprus	3-middle	1.15	33.25	59.99	45.84	121.40
G. Britain	3-middle	1.13	45.17	16.30	16.90	69.08
Spain	3-middle	1.06	60.99	21.58	20.56	97.60
Ukraine	3-middle	1.01	.00	23.46	12.17	35.39
Switzerland	3-middle	.99	154.72	30.62	36.14	222.84
Cambodia	3-middle	.96	.00	39.70	21.59	63.66
India	3-middle	.95	2.96	12.87	10.90	28.02
Italy	3-middle	.95	91.85	28.37	29.03	156.73
Chile	3-middle	.92	52.72	50.51	34.60	149.37
Malta	3-middle	.90	54.29	29.33	22.28	118.20
Austria	3-middle	.88	150.70	24.96	24.59	226.29
Iraq	3-middle	.88	.00	21.58	14.94	41.37
Finland	3-middle	.86	71.86	23.13	20.27	133.28
Iceland	3-middle	.84	39.44	28.55	30.16	116.88
Germany	3-middle	.83	91.10	17.46	17.77	151.56
Czechia	3-middle	.82	77.45	24.87	21.58	150.33
Denmark	3-middle	.82	82.56	25.08	38.39	178.54
USA	3-middle	.80	190.63	46.57	52.14	361.53
China	3-middle	.79	16.84	25.43	26.36	86.36
Global	***mid-line***	***.78***	***59.48***	***20.42***	***20.10***	***128.36***
Poland	3-middle	.77	32.00	14.87	10.00	73.65
Croatia	3-middle	.75	4.96	22.97	13.73	55.54
Australia	3-middle	.75	28.59	19.54	22.02	94.01
New Zealand	3-middle	.72	3.30	13.18	10.44	37.15
Japan	3-middle	.70	84.57	11.96	9.62	150.97
Hungary	3-middle	.70	6.27	27.26	20.09	76.33
Romania	3-middle	.70	.00	24.65	14.85	56.30
Moldova	3-middle	.65	.00	8.08	3.73	18.27
Netherlands	4-lower	.59	66.14	37.27	40.23	242.83
Lithuania	4-lower	.58	40.06	11.27	7.33	100.51
Norway	4-lower	.56	43.27	28.27	25.15	171.66
South Africa	4-lower	.55	22.99	16.53	11.52	92.31
Singapore	4-lower	.55	62.12	16.57	18.79	177.66
Estonia	4-lower	.53	14.47	17.66	18.51	95.84
Sri Lanka	4-lower	.51	.00	35.70	34.78	137.25
Hong Kong	4-lower	.51	.00	20.60	31.55	102.01
Greece	4-lower	.50	4.77	9.78	9.30	47.73
Serbia	4-lower	.48	.00	10.60	6.02	34.34
Montenegro	4-lower	.48	.00	18.92	6.27	52.61
Bosnia- Herz.	4-lower	.45	.00	12.92	5.91	41.64
Un. Arab Em.	4-lower	.44	36.88	1.15	.86	87.42
Colombia	4-lower	.42	11.75	37.78	24.77	177.18
Canada	4-lower	.41	27.20	24.32	23.24	180.34
Pakistan	4-lower	.40	1.09	5.37	3.99	26.40
Lesotho	4-lower	.37	.00	22.84	10.13	88.03
Latvia	4-lower	.37	7.59	8.54	8.14	65.56

Uruguay	4-lower	.37	10.27	14.00	8.17	87.71
Guatemala	4-lower	.36	.00	16.91	16.13	92.79
Russia	4-lower	.35	.57	8.72	4.86	40.25
Mozambique	4-lower	.34	.00	7.76	7.66	45.58
Türkiye	4-lower	.30	26.82	13.90	8.13	162.50
Argentina	4-lower	.30	4.86	9.27	4.90	64.20
Sweden	4-lower	.29	.00	33.04	33.48	227.17
Slovakia	4-lower	.29	12.41	9.68	5.71	97.12
Thailand	4-lower	.25	1.65	8.76	4.58	59.31
Oman	4-lower	.22	.00	38.63	25.25	291.40
Macedonia	4-lower	.18	.00	6.85	5.22	68.17
Costa Rika	4-lower	.16	.00	11.34	10.03	133.18
Malaysia	4-lower	.16	.32	4.19	3.40	50.17
Macao	4-lower	.16	.00	11.93	8.28	128.52
Paraguay	4-lower	.14	.00	4.35	2.74	50.86
Philippines	4-lower	.14	.00	10.35	8.29	137.07
Mexico	4-lower	.12	4.22	20.07	11.23	289.13
El Salvador	4-lower	.11	.00	4.56	4.56	81.97
Egypt	4-lower	.10	.00	7.56	5.55	126.53
Senegal	4-lower	.09	.00	1.19	.65	20.00
Eswatini	4-lower	.06	.00	4.18	3.11	119.19

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