

Engineering and society – prospective remarks, with a focus on Portugal


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Abstract

Engineering researchers and students dedicate most of their working time to the details of the fields they are advancing or studying. Since excessive focus on details may lead to loss of contact with the wider societal context, it is advisable to create opportunities for their exposure to ‘the wider picture’; the topics chosen for this presentation are of transversal interest and expected to provide food-for-thought for those willing to venture outside the strict borders of their discipline.

But first a disclaimer: I am not a professional forecaster neither a crystal ball reader, but just a Mechanical Engineer with a career of 40+ years as a researcher / professor in a field transversal to several disciplines and specialties – fracture and fatigue of materials and structures. As with every other researcher, early in my career I was mainly asked to participate in activities and panels within the boundaries of my own research but, as time went by, the scope of my activities was progressively enlarged, namely with membership of the board of Agência de Inovação - AdI (precursor of the present ANI) and involvement in several EU activities in fields as aeronautics, civil engineering, transportation but also innovation and higher education management.

Awareness of the past and curiosity about the future motivated my growing interest in the interplay between society and engineering – the societal context within which engineering takes place. Although many topics addressed here are general, details reflect the nationality and interests of the writer (Portuguese). The talk at EJIL 2022 briefly touches the following topics: Portugal, macroeconomics, inequality, innovation, skills, education, R&D, sustainability, future, and geopolitics.

Portugal

Lord Kelvin famously wrote that ‘... *when you can measure what you are speaking about, and express it in numbers, you know something about it; but when you cannot express it in numbers, your knowledge is of a meagre and unsatisfactory kind; it may be the beginning of knowledge, but you have scarcely, in your thoughts, advanced to the stage of science, whatever the matter may be.*’ [1]. Even in a personal reflection as the present one, recourse to numbers is of the essence because they allow for comparisons, and these are often required for a proper understanding or evaluation of situations, policies, etc. . Fortunately, cravings for numbers find answers in many databases, as those freely provided by the EU (EUROSTAT), UN agencies, the IMF, the World Bank and OECD. In Portugal a user-friendly source is PORDATA.

The recent economic performance of Portugal is a matter of intense internal political debate. Comparison with countries that joined the EU more recently shows that, using PPP, the Portuguese GDP has been overtaken by *e.g.*, Baltic countries, the Czech Republic and Hungary, Figure 1.

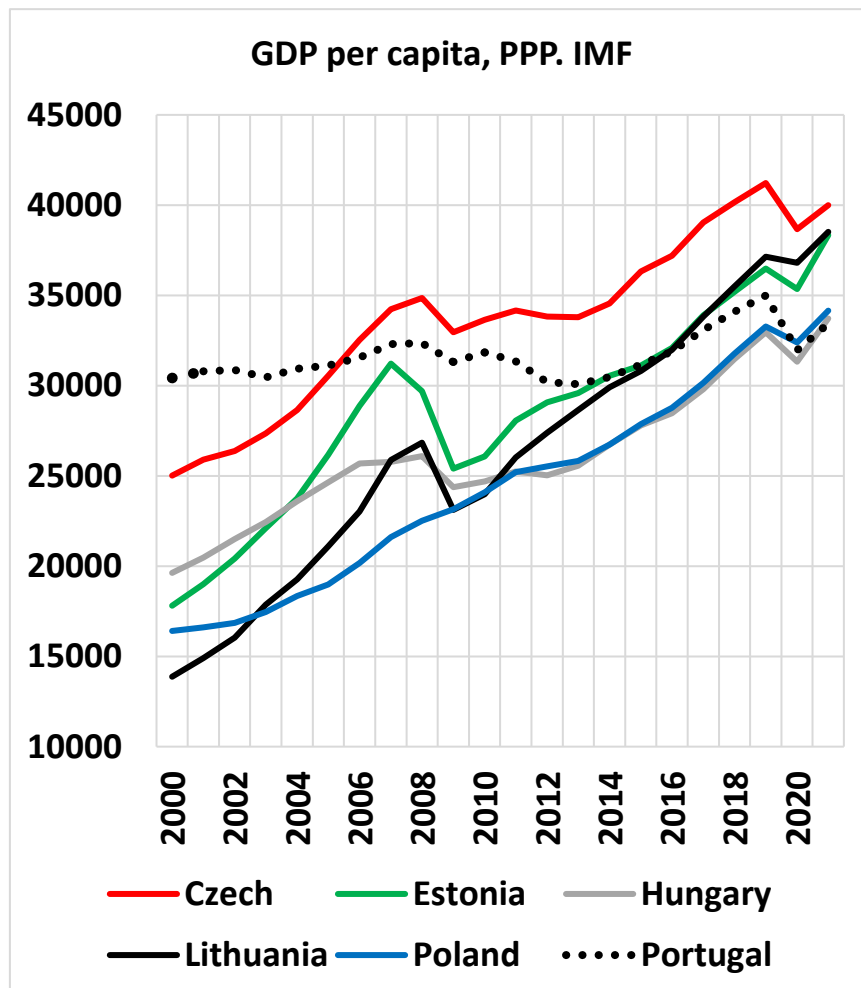


Figure 1: Comparison of GDP per capita, PPP. IMF.

In a possibly simplistic viewpoint, I associate the lackluster performance to the level of education or human capital, knowing that this is just one among several causes. The level of education has an influence on the type of economy – a tourism-based economy requires a certain level of education, as hospitality skills, basic knowledge of English language to interact with most of the visitors, and so on; other types of economy, involving the design and production of sophisticated systems for transport, health, defense, etc. require other skills much more expensive to acquire and deploy.

Educational level in Portugal is increasing steadily but was dramatically below European standards during most of the XX century, with special neglect during the long dictatorship of 1926-1974 (although in its last period progresses were made, namely under the reformist influence of the then Minister for Education José Veiga Simão).

What is the percentage of population with tertiary ¹ education in Portugal? the answer depends strongly on the age group considered. If older people are included, the Portuguese performance is appalling, as already suggested in the previous paragraph, see Figure 2a; but if younger people are considered, the values increase substantially, Figure 2b, illustrating the great effort that has been made since the later part of the twentieth century. Figure 2 also include data for Lithuania – chosen here as an example of a country that benefited from EU membership with fast growth of its economy, made possible – as far as I understand – by the educational level and human capital.

International trade has been promoted by the globalization trends. Recent data for Portugal shows a ratio exports/imports greater than one, a virtuous period ending in 2018 and interrupted by the COVID crisis, Figure 3. A ratio exports/imports below one suggests accumulation of external debt, as it was the case of Portugal for too long.

The ratio total exports/GDP suggests the attractiveness of a country's products and services to other countries. According to the World Bank data ², in Portugal this indicator reached 43.5% in 2019 presenting an increasing trend interrupted by the COVID crisis. Comparison with others e.g. Lithuania with 77.3% or with Poland with 55.4% all in 2019, indicates that progress must be made.

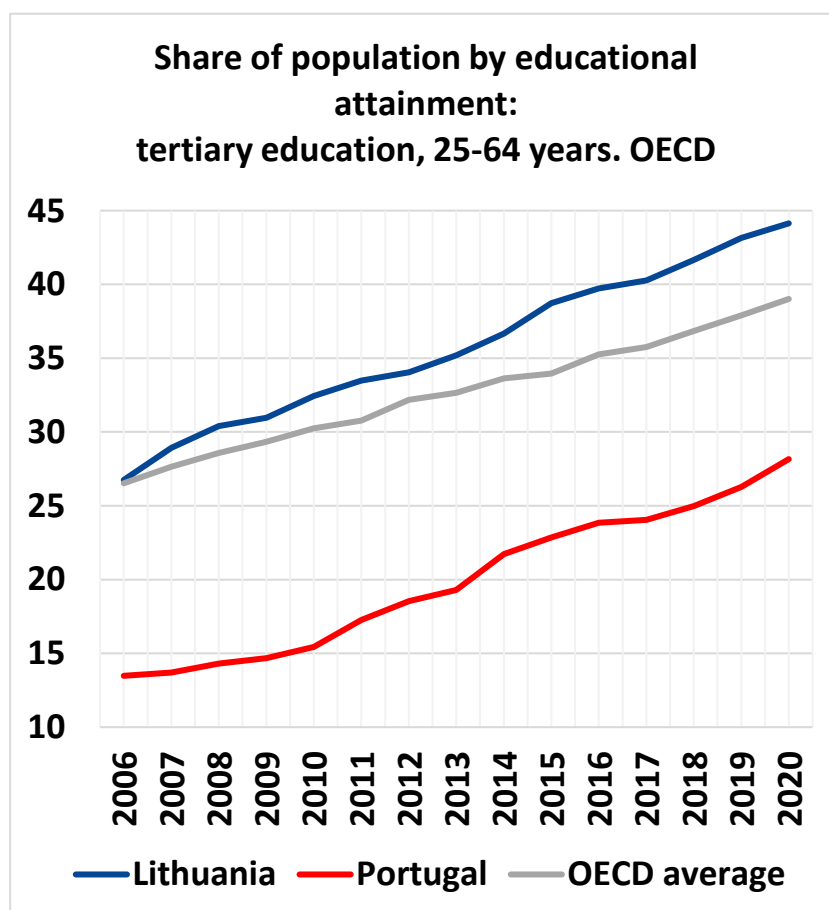


Figure 2a: Share of population by educational attainment: tertiary education, 25-64 years. OECD.

¹ tertiary (or post-secondary) – in Portugal typically degrees awarded by *universidades* or *institutos politécnicos*.

² The World Bank. Exports of goods and services (% of GDP).

<https://data.worldbank.org/indicator/NE.EXP.GNFS.ZS?locations=PT-PL-LT-LI> .

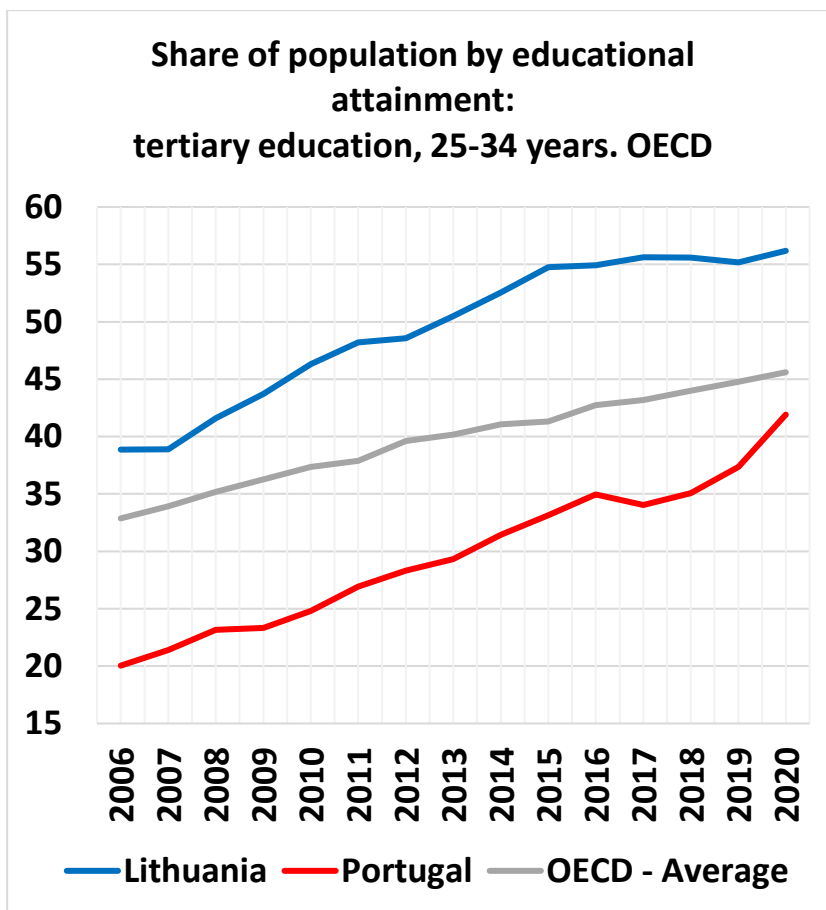


Figure 2b: Share of population by educational attainment: tertiary education, 25-34 years. OECD.

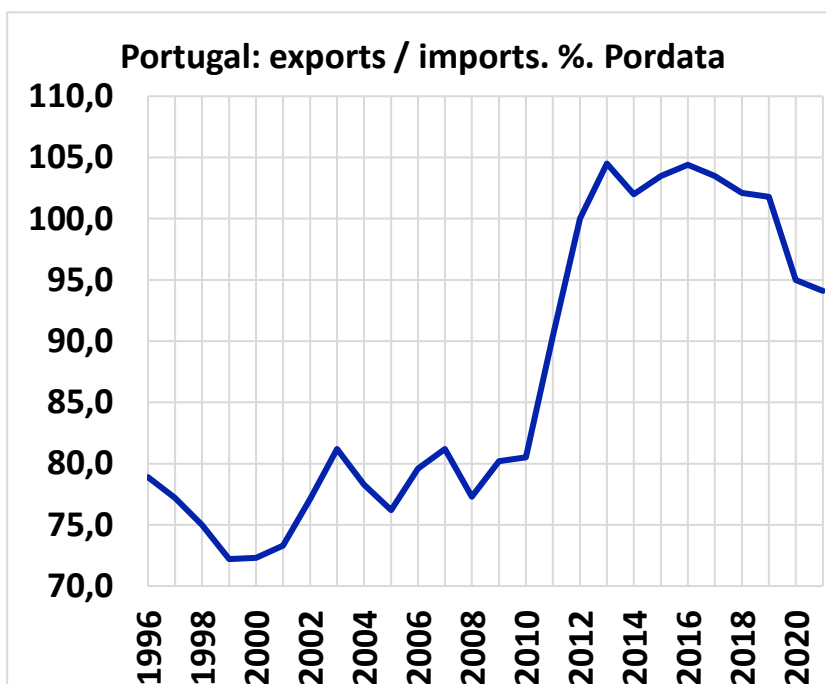


Figure 3: Portugal: ratio exports / imports. %. Pordata.

Since without people there is no future, it is mandatory to be aware of the demographic trends. Decreasing population is predicted for EU countries as Spain, Italy, Germany or Portugal. Adequate immigration policies, particularly those directed to young, educated segments, together with policies promoting increasing birth rate and general economic development that encourages natives to stay are among the tools to fight these trends.

In the case of Portugal, a decrease to approximately 7 million in 2100 is predicted by the Population Division of the UN Department of Economic and Social Affairs in its site 'World Population Prospects 2022' [2], Figure 4. The EU report 'Demographic and human capital scenarios for the 21st century - 2018 assessment for 201 countries' [3] shows three scenarios for the evolution of the population, all of them also predicting a continued decrease of Portuguese population; the medium scenario indicates 10.2 million people in 2020 and 8.28 million in 2060, with a percentage of over 65 years of age of 22,8% and 33.3% respectively.

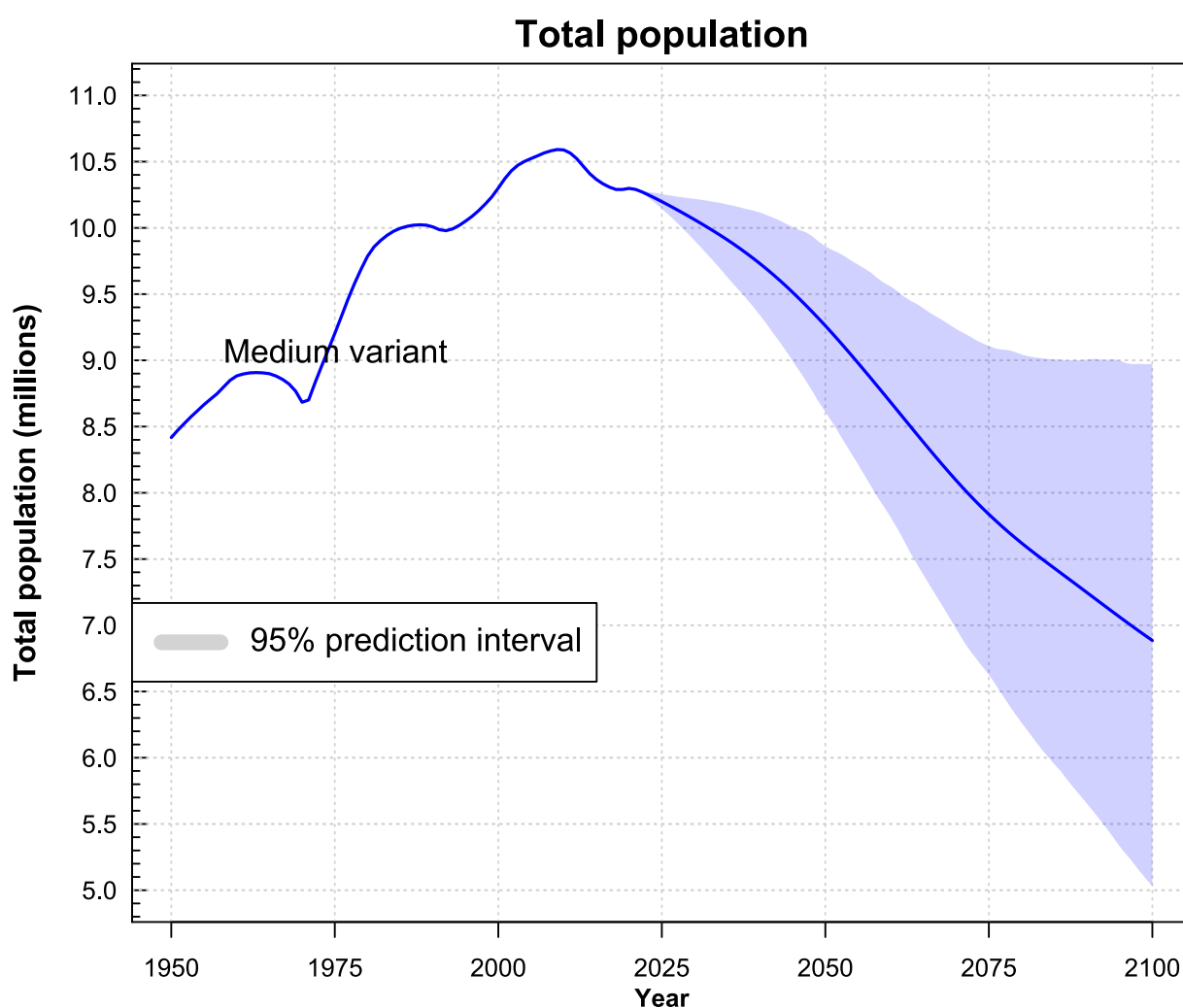


Figure 4: Portugal: total population. UN, 'World Population Prospects 2022', [2].

In the next section reference will be made to the concept of economic complexity, that offers insights in the evaluation of the economic performance of countries. Suffice to say here that economic complexity describes the capability of an economy to design, produce and market

sophisticated products and services, and of course a prerequisite is the level of education of the country or region considered.

Macroeconomics

Globalization as promotion of trade and financial flows, exchange of ideas and movements of people worldwide [4] is a trend for which the Portuguese gave a very important contribution with their groundbreaking – more to the point: sea-conquering - voyages of the 15th century [5].

Recent worldwide trade statistics show, up to the beginning of 2022, two deep troughs – one associated to the subprime crisis in the USA that preceded the Eurozone crisis, and another associated with the 2020-2021 COVID crisis. A globalization period, whose heyday seems to be associated to the period after the end of the cold war, is now abruptly interrupted by the Russian invasion of Ukraine with consequent breakdown of usual trade of food, energy, etc., but also of circulation of information (in Russia, but even in Europe where the Russian state channel RT was banned to protect citizenry against the dissemination of Russian narratives).

An 'Atlas of Economic Complexity', published by Harvard and MIT in 2011 [6], is associated to a very useful database where the international trade of all countries is recorded in detail, displaying the economic sectors that contribute more or less to the exports or imports of each country. It shows the strong dependence of the Portuguese economy on tourism (as other very well-known facts like the importance for Russia of its energy exports). But the usefulness of the Atlas lies in the worldwide coverage and level of detail it offers. A MIT spin-off enlarging the original data now requires subscription to access services and trends/forecasts (Observatory of Economic Complexity - OEC [7]); Harvard's Growth Lab data is freely available [8].

According to Moskowitz, the percentage of economic growth attributable to advanced technology was of the order of 40% in 1970 and is expected to be of the order of 90% in 2030, [9], illustrating the need for high levels of STEM education for a society to prosper in the future.

Trends in China and India deserve particular attention, because of the size of their populations and economies. Figure 5 shows the evolution of their GDP, as compared with that of the USA. India's GDP will overtake that of the USA probably before 2050, to become second to China only, [10]. Population-wise, although since 2021 Chinese women are allowed to have three children, the current figure is 1.2; population in India will continue growing, peaking at 1.7bn in 2064, approximately 1.3× that of China in the same year, [2].

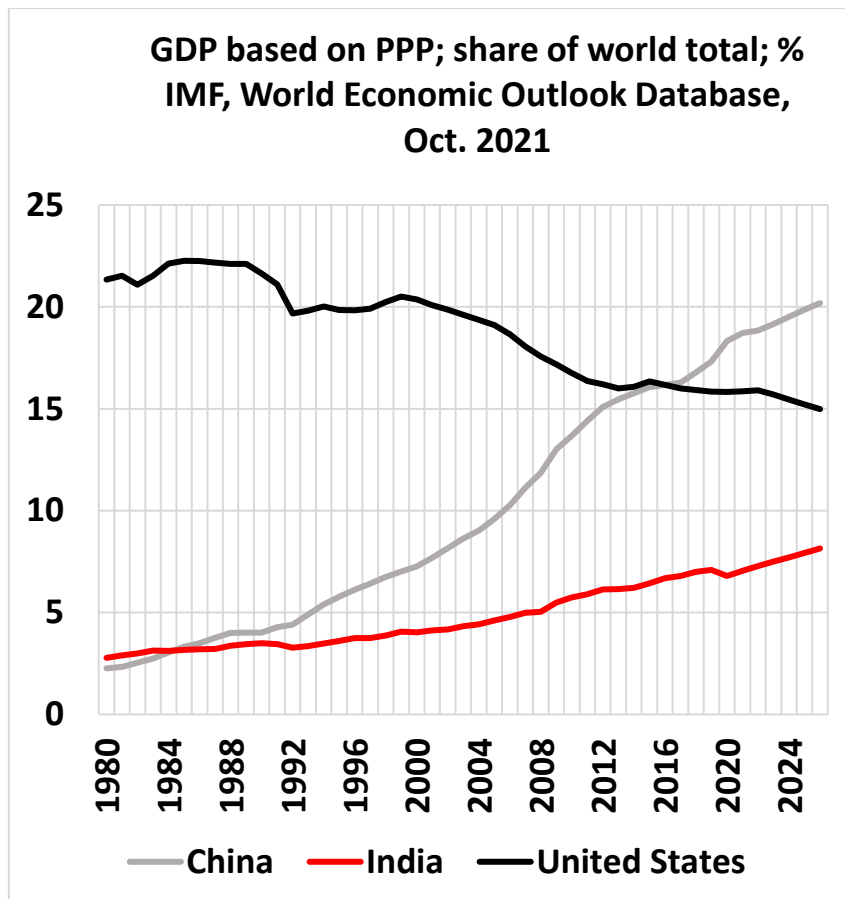


Figure 5: GDP based on PPP; share of world total; %. IMF, World Economic Outlook Database, Oct. 2021.

Inequality

Egalité was one of the mottos of the French revolution. Entitlement to political rights was the object of many struggles, and progressively generalized throughout the XX century. Serfdom persisted in Russia until the XIX century. In the USA *de jure* discrimination only ended in the period 1964-8. Swiss women may vote in federal elections just after a 1971 referendum, and in South Africa apartheid persisted until 1991.

Attempts at ensuring *de facto* equality include many failed experiments in social engineering. If inequality is an unavoidable feature of humanity reflecting the different circumstances of each one, that does not mean that efforts should not be taken to ensure a less inequalitarian world, promoting or enforcing adequate sharing of the wealth generated.

A matter of concern is the huge differences in wealth between the very few very rich and the vast majority which in many countries is very poor. The fight against this state of things is helped by knowledge of quantitative data. Among other organizations, OXFAM dedicates particular attention to inequality, as shown by the suggestively titled 2022 report 'Inequality kills' [11] or earlier 'An economy for the 99%' [12]. The World Inequality Lab³ publishes reports on the subject: 2018 [13], 2022 [14], the last one together with UNDP.

The World Bank through Lakner, Milanovic *et al.* is one source of studies of income distribution. One main result is shown in Figure 6a, the so-called 'elephant curve' because of the shape of the graphic. Horizontal axis represents income groups arranged in ventiles of the

³ based at the Paris School of Economics and led by Thomas Piketty *et al.*: <https://inequalitylab.world/en/>.

global income distribution; vertical axis shows absolute income growth in the 20-years period under study (1988-2008) for each ventile. The availability of data permitted to include finer detail for the wealthiest segment – the top 1%. Lakner and Milanovic [15, 16] show (i) for the first 75% percentile, a general trend of wealth growth (except for the segment of the poorest), (ii) for the 75% to approx. 95% percentile, a trend of modest growth or stagnation, and (iii) a fast growth for the remaining group, corresponding to the higher incomes. What does this mean? a possible interpretation: (i) concerns mainly population in the developing world that alleviated poverty or acquired a modest degree of welfare; (ii) includes the so-called middle classes of the industrialized world squeezed or comparatively impoverished in the period, and finally (iii) represents a huge growth for the very high-income group - recall basic arithmetic: growth of 70% on 1000 is 700; on, say, 10^6 is 7×10^5 ...

More recently, Alvaredo *et al.* studied the 36-years period 1980-2016, [17]. Their result is shown in Figure 6b which includes finer detail for the very high-income segment. They found that the bottom 50% captured 12% of total growth whereas the top 1% captured 27%. The shape of the curve no longer recalls an elephant, but the qualitative description of the results is in line with the earlier results of Lakner and Milanovic. In particular, the very high-income segment displays an even greater concentration of wealth. (for methodological details see the original papers [16, 17]; notice that Alvaredo *et al.*, Figure 6b, present results ‘per adult’).

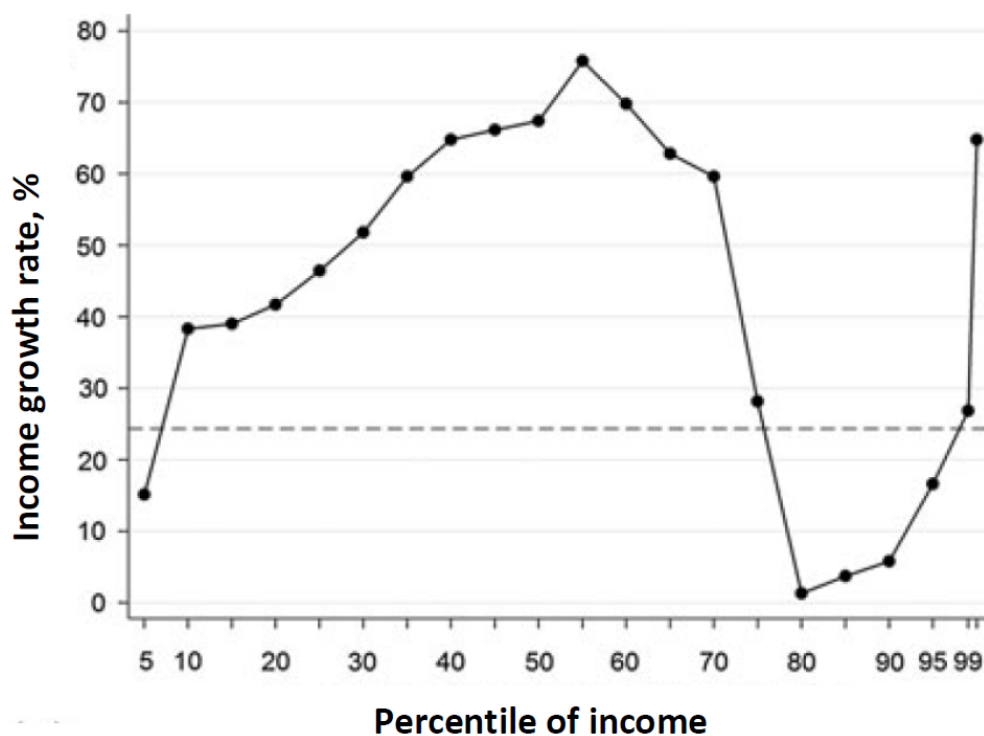


Figure 6a: Income growth rate per percentile of income distribution, 1988-2008, adapted from Lakner and Milanovic [15].

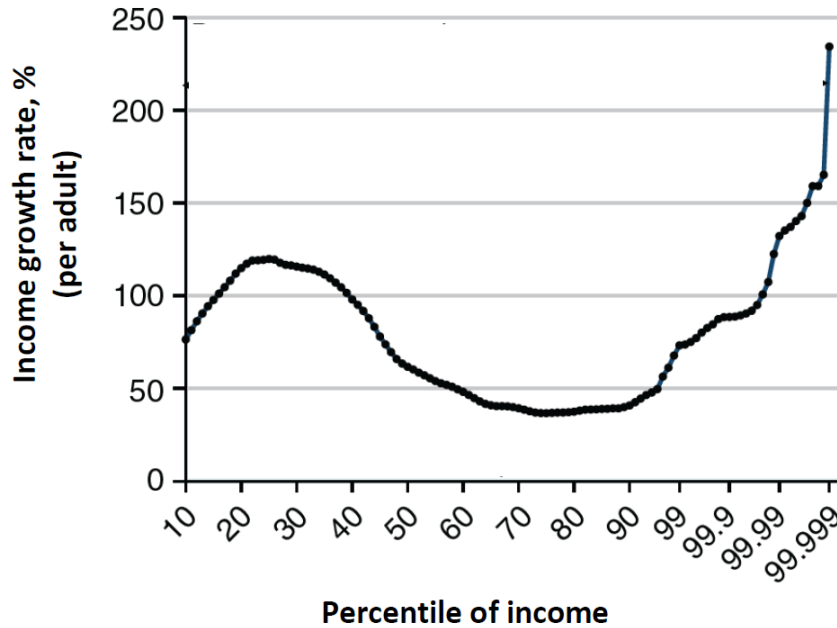


Figure 6b: Income growth rate per percentile of income distribution, 1980-2016, adapted from Alvaredo *et al.*, [17].

A concept frequently used in inequality discussions is the Gini index G . This is based on a curve showing in vertical axis the income of the income percentile indicated in the horizontal axis – the Lorenz curve, in red in Figure 7. The Gini index is defined as a ratio of areas,

$$G = \frac{\text{area } A}{\text{area } A + \text{area } B}$$

The extremes are either the diagonal which corresponds to everybody receiving the same income (Gini index 0), or a horizontal line coinciding with the x axis, corresponding to the wealthiest element receiving all the income (Gini index 1 or 100%). Figure 8 illustrates the recent evolution of Gini index values for an equalitarian country, Finland, as well as for the USA and Portugal⁴. Associated to the consequences of the ‘subprime’ and Eurozone crises, an interruption for a trend of decreasing inequality in Portugal is identified.

⁴ <https://datatopics.worldbank.org/world-development-indicators/themes/poverty-and-inequality.html> .

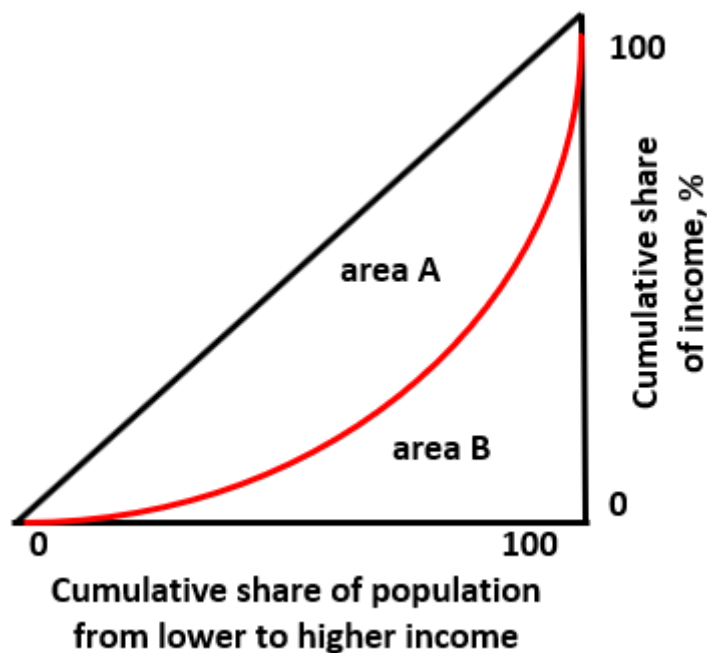


Figure 7: Schematic representation of one hypothetical Lorenz curve (in red).

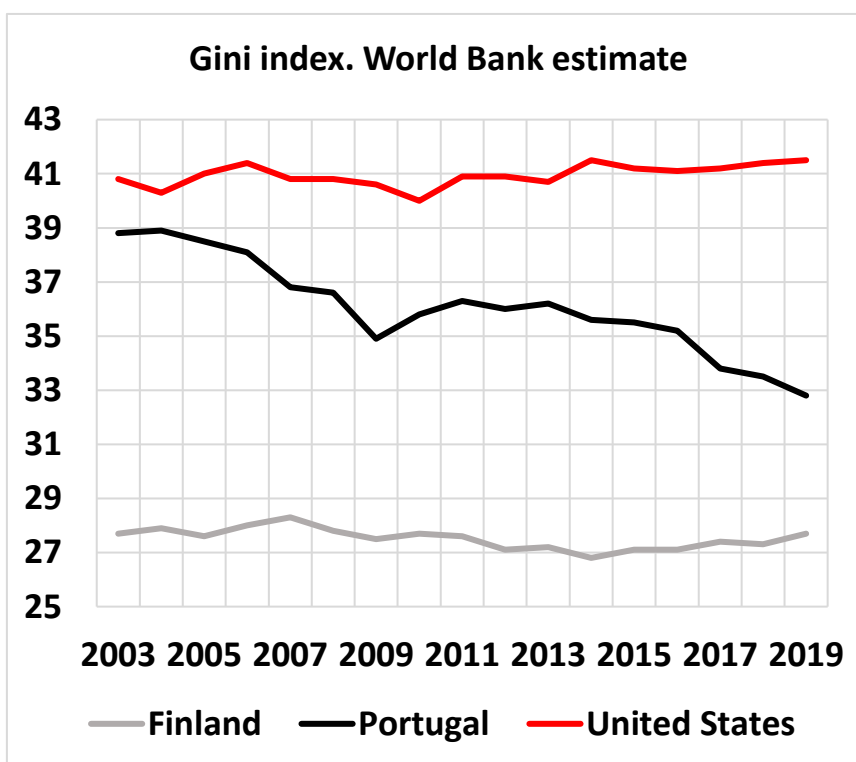


Figure 8: Gini index. World Bank estimates.

World Bank databases are sources of data concerning inequality. Figure 9 shows the evolution of the income share held by the poorest 10% in France, Germany, USA, and Portugal. Policies affect inequality rather directly, as shown by the Portuguese data: the shaded area of Figure 9 shows the decreasing income of the poorer 10% Portuguese in the period 2010-2013, a 22%

decrease (2.7% to 2.1%,) to be contrasted with the approximately stable income share held by the highest 10% in the same period (approx. 28%)⁵.

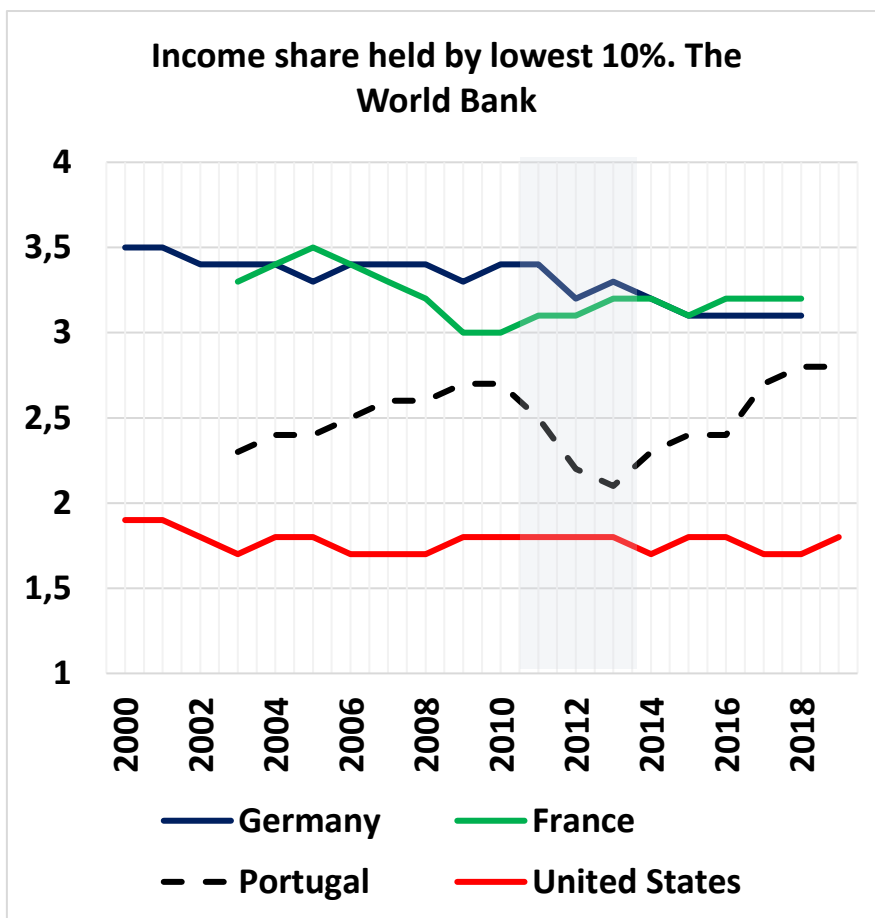


Figure 9: Income share held by lowest 10%. The World Bank⁶.

A 17th century Portuguese priest, António Vieira SJ, said ‘*The greatest misery of human life [...] is that there is no one in this world to trust*’ (e.g. [18]). Trust is inversely linked to inequality: research shows that the more equalitarian societies present higher levels of trust. Trust in others is highest in the Nordic countries [19]. Wilkinson and Pickett report that Sweden, Norway and Denmark, with a highly equalitarian income, show approximately 70% of positive answers for the question ‘*most people can be trusted?*’, as compared with Portugal, with far higher income inequality, where only approximately 10% responded affirmatively, [20]. Although with different figures, the same trend is found in EUROSTAT data from 2013⁷ showing trust in others as 8.3 (out of 10) in Denmark and 5.3 in Portugal (published by the OECD [19]).

⁵ The World Bank. Income share held by highest 10% (SI.DST.10TH.10)

<https://databank.worldbank.org/reports.aspx?source=2&series=SI.DST.10TH.10&country=FRA,DEU,PRT,USA#> .

⁶ The World Bank. Income share held by lowest 10%

(SI.DST.FRST.10).<https://databank.worldbank.org/reports.aspx?source=2&series=SI.DST.FRST.10&country=DEU,FRA,PRT,USA#> .

⁷ EUROSTAT. Average rating of trust by domain, sex, age, and educational attainment level.

https://appsso.eurostat.ec.europa.eu/nui/show.do?dataset=ilc_pw03&lang=en .

Innovation

Schumpeter recognized the need for a constant flow of innovations to sustain a modern society - the mechanism of 'creative destruction' that keeps the economy going. Innovation implies positive, tangible change, as increased efficiency, improved social responses, creation of market opportunities etc., [21].

Products life cycle was analyzed by Rogers [22] who proposed that the adoption of the new product, as a function of time, follows a bell shape curve: early adoption, conquest of market, and finally death of the product perhaps because of the appearance of improved competitors. This scheme may be wrong (or at least incomplete) because it suggests a sequence of phases that may not exist in some cases; in particular, just after the introduction of the product, a chasm may occur where the progression of the product is under threat, see Moore [23].

A related concept is the so-called Gartner hype curve, which plots expectations concerning new technologies vs time, showing a strong first peak, followed by a trough until the start of a steady growth at lower positive derivative [24-27].

Administering questionnaires and tests to groups of people, Kruger and Dunning studied the gap between self-evaluated and actual understanding of concepts [28]. They found that participants with actual low grades usually overestimate their abilities, whereas for high performers there is some consistency between self-expectation and the actual grade. Why am I mentioning Kruger and Dunning? because a similar pattern in the Gartner hype curve and in the Dunning-Kruger effect is worth noting. Of course, the Gartner hype curve concerns technologies whereas the Dunning-Kruger effect concerns people. Nevertheless, there may be some affinity between both: the initial very high peak of expectations / interest in some novel technology could be associated to the initial incomplete understanding of the matter, whereas the trough and subsequent steady slow increase stages would correspond to a subsequent enlightened understanding period.

Creativity may be hampered by schooling, or is it promoted? Certainly, countries with highly educated citizenry tend to generate higher levels of innovation!

Personal characteristics and circumstances determine the innovation and creativity potential of each one. Among these, willingness to take risks, trust in others, self-confidence and acceptance of eventual failures, capacity to focus on and get passionate about a subject, certainly play a role. The University of California at Berkeley makes available a questionnaire aimed at evaluating the creativity potential of each one, [29]. This was administered in April 2022 to a part of the Mechanical Engineering 1st year students of FEUP, with the result presented in Figure 10 (100 is max. creativity potential). It would be interesting to see how the response of the same group varies in next years.

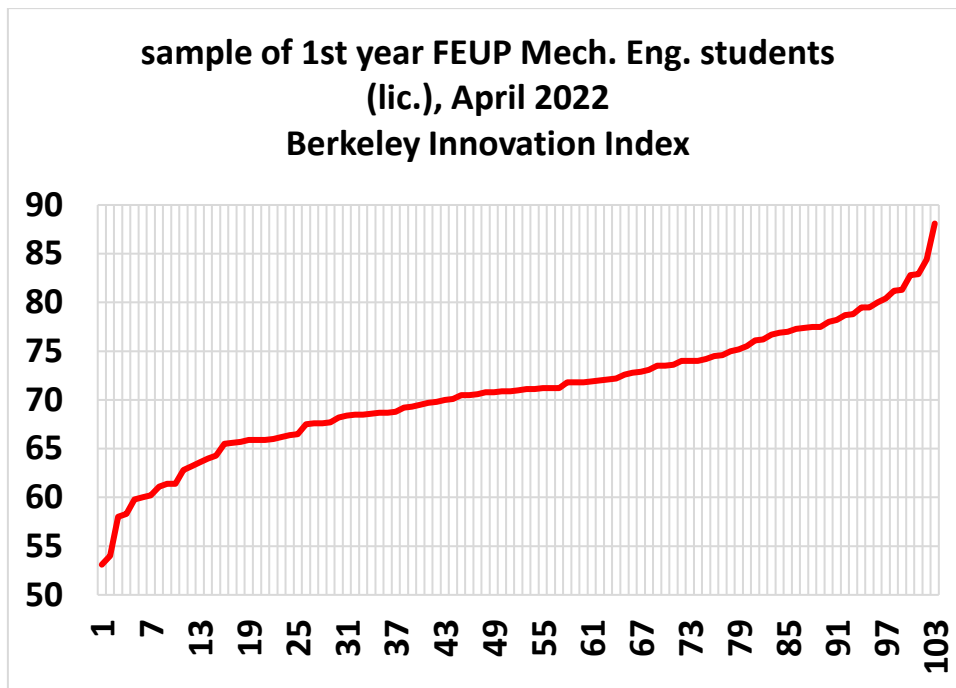


Figure 10: Sample of 1st year FEUP Mech. Eng. students (*licenciatura*), April 2022. Berkeley Innovation Index.

Skills

Skills are a matter of concern for human resources departments but more generally for the efficiency of society. Boeing's list of desired attributes of an engineer is an example of the concerns of high-tech companies [30, 31]. The US Department of Labor sponsors a detailed description of requirements, skills and knowledge pertinent for an extensive list of activities, the O*NET Resource Center; as an example, details for mechanical engineering are found in [32]. In Europe, CEDEFOP (an agency of the European Union) provides valuable intelligence and information on current and future skills and labour market trends [33].

Given the role of engineering and related fields in shaping the future, STEM - science, technology, engineering, and mathematics - is of particular interest in this communication. Interest for STEM careers must be promoted early in the students' path. This may be achieved through educational strategies that bring Mathematics and Physics closer to the heart of young school students, with real life cases of applications that may raise their interest and minimize rejection that a more abstract approach might create. This matter is developed in detail in the EURYDICE report 'Increasing achievement and motivation in mathematics and science learning in schools' [34]. An example of promotion of school students in aeronautics is the Learn&Fly Erasmus+ project where HE institutions were involved in the preparation of educational kits [35].

Skills are an essential ingredient of the human capital, a most valuable intangible asset of any society. Human capital is a dynamic asset, susceptible to be improved through correct public policies including those promoting lifelong learning [36]. It is the object of attention of many large and small organizations *e.g.* the New Club of Paris [37]. Lifelong learning is particularly needed in technology-driven societies, namely for older people, *e.g.* in Portugal where older people have levels of education below the EU average and are candidates to info-exclusion. With the initiative 'Pact for Skills' the EU attempts to overcome those problems, through European wide actions intended to '*mobilise and incentivise private and public stakeholders to take concrete action for the upskilling and reskilling of people of working age*', whilst

‘working against discrimination and for gender equality’ [38-40]. An associated matter, given the huge discrepancy on the level of educational attainment of the young and old segments of the Portuguese labour force, is the brain drain effect, briefly addressed in the EU ‘A new skills agenda for Europe’ [41, 42]. This leads to the emigration of the younger and better qualified, as engineers, nurses, etc., and reasons associated to salaries are touched upon in the next section of this communication.

Education

From OECD [19]: *‘More educated people do better in most areas of well-being except long working hours’*, and from The Health Foundation, UK, [43]: *‘Education has an important influence on health. It provides the skills, attributes and specialist knowledge needed to secure good jobs and participate in society – building blocks of a healthy life. Investment in further education specifically can contribute to a healthier and more prosperous society. in the UK, people who leave school with the lowest education levels have a life expectancy 4 years lower than those educated to the highest levels, by the time they are 30 years old.’*

Further to the general statements on education above, importance of mathematics education is suggested by studies that associate personal economic success and even improved health to mathematical training. Mathematical literacy underpins financial literacy, a topic object of study *e.g.* by Lusardi *et al.* at the Global Financial Literacy Excellence Center (GFLEC) of The George Washington University School of Business, [44, 45]. Financial literacy rates vary widely across the EU, with northern Europeans showing the highest literacy rates. Compared with those, Portugal has a very low financial literacy rate, according to data of Standard & Poor’s ratings services [46], (see also [47]).

The role of education in advancing a technology-driven society was touched in previous sections. Here I emphasize the contribution of STEM knowledge to enable the society to benefit from – and contribute to – the progress made possible by advanced knowledge.

Mathematics and science education are tools preparing for integral citizenship in societies ever more driven by technological progress. Nevertheless, OECD’s Programme for International Student Assessment (PISA) [43] reveals that in the EU 23% of the 15 years old present deficient levels of mathematics and science knowledge; furthermore, this is related with socioeconomic status, the low achievers coming mainly from the disadvantaged groups. Possible policy measures to overcome low achievement are *e.g.* presented in the already mentioned EURYDICE report [34].

Some propose an enlarged concept, STEAM - science, technology, engineering, arts, and mathematics. Arts education, and humanities in general, are essential parts of the education and their value is not disputed. Liberal education, as discussed by Feijó and Tamen [48], gives post-secondary students great freedom to combine courses of their choosing in formatting their educational experience. But my focus here is on STEM - hard science, technology, and mathematics. While recognizing the irreplaceable role of humanities, arts and so on in sustaining a civilized society, STEM subjects give the means for scientific and technological progress and innovation, without which sooner or later society emaciates, as stated by Schumpeter in the ‘innovate or perish’ paradigm [49]. In a Schumpeterian interpretation of the 2008 economic crisis in the US, Michael Mandel even suggests that it was partially due to a period of lack of high-impact commercial innovations [50] (see also Florida [51] and Dubina and Campbell, [52]).

Hanushek and Woessmann [53] demonstrate that long-run economic growth of a nation is a function of the cognitive skills of the population, its ‘knowledge capital’, a conclusion equally applicable to developing and developed countries. This calls for an increasing access to tertiary education. OECD data for 2013 and 2019 shows that in Portugal 25-34 year-old adults with tertiary attainment earn 1.5× more than those with secondary education, [54].

EUROSTAT data for 2014 [55] and 2018 [56] on the impact of education on earnings shows that in Portugal the premium associated with tertiary studies was among the highest in the EU. Having said that, a very recent publication by the Fundação José Neves [57] shows a decreasing trend of the higher education premium, perhaps linked with increases of the minimum wage. The specificities of the Portuguese economy include the difficulties in generating well paid jobs and fully benefitting from the dramatic improvement in educational attainment of the population in the recent decades. A number of job seekers only find occupations below their level of qualification: among the 25–34-year-olds, 15% of engineering graduates are in that situation, nevertheless a substantially lower figure than *e.g.* social sciences or services where it is of the order of 30% or 50%, [57].

Data on income by educational attainment level is made available by EUROSTAT [58]. The situation of Portugal for the 18-64-year-old with tertiary education is shown in Figure 11a where vertical axis unit is PPS⁸. According to EUROSTAT, in 2020 the income associated with secondary education in many EU countries is higher than the income for the population with tertiary education in Portugal, Figure 11b, a fact discretely treated in the media [59].

R&D

Academe, government agencies, industry and general media produce a continuous flow of studies and reports - with varying levels of detail and credibility - listing emerging technologies or identifying likely advances in S&T, *e.g.* [60-66]. Typically, they show a diversity of fields where research efforts should take place to keep abreast of, anticipate, or drive the evolution of society.

A large diversity of areas finds support in the EU framework programmes for R&D [67], started in 1984. The 9th framework programme, ‘Horizon Europe’, runs from 2021 to 2027 with a budget of around EUR 95.5 billion. Unlike that large scope programme, specialized initiatives concentrate in given areas, as for example the EU Clean Sky Joint Undertaking (renamed Clean Aviation Joint Undertaking), which is a public-private partnership between the European Commission and the European aeronautics industry intended to promote aeronautics innovation and research in Europe.

Nationwide R&D funding institutions like the Portuguese FCT have a role of supporting science and are likely to intervene in all areas where convincing research groups propose high quality research projects. Areas of possible interest to get R&D funding are of course many; I mention a few with direct implication in Portugal.

The Lisbon 2022 UN Ocean Conference spotlighted the role of the oceans in global sustainability, [68]. In Portugal, the economic value of sea activities – the ‘blue economy’ - is estimated at 5.1% of the GDP and 4.1% of employment (2017) [69, 70]. The legal frame for exclusive economic zones (EEZ), and the vast Portuguese EEZ, due partially to the Portuguese

⁸ Purchasing power standard (PPS):

[https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Purchasing_power_standard_\(PPS\)](https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Glossary:Purchasing_power_standard_(PPS)) .

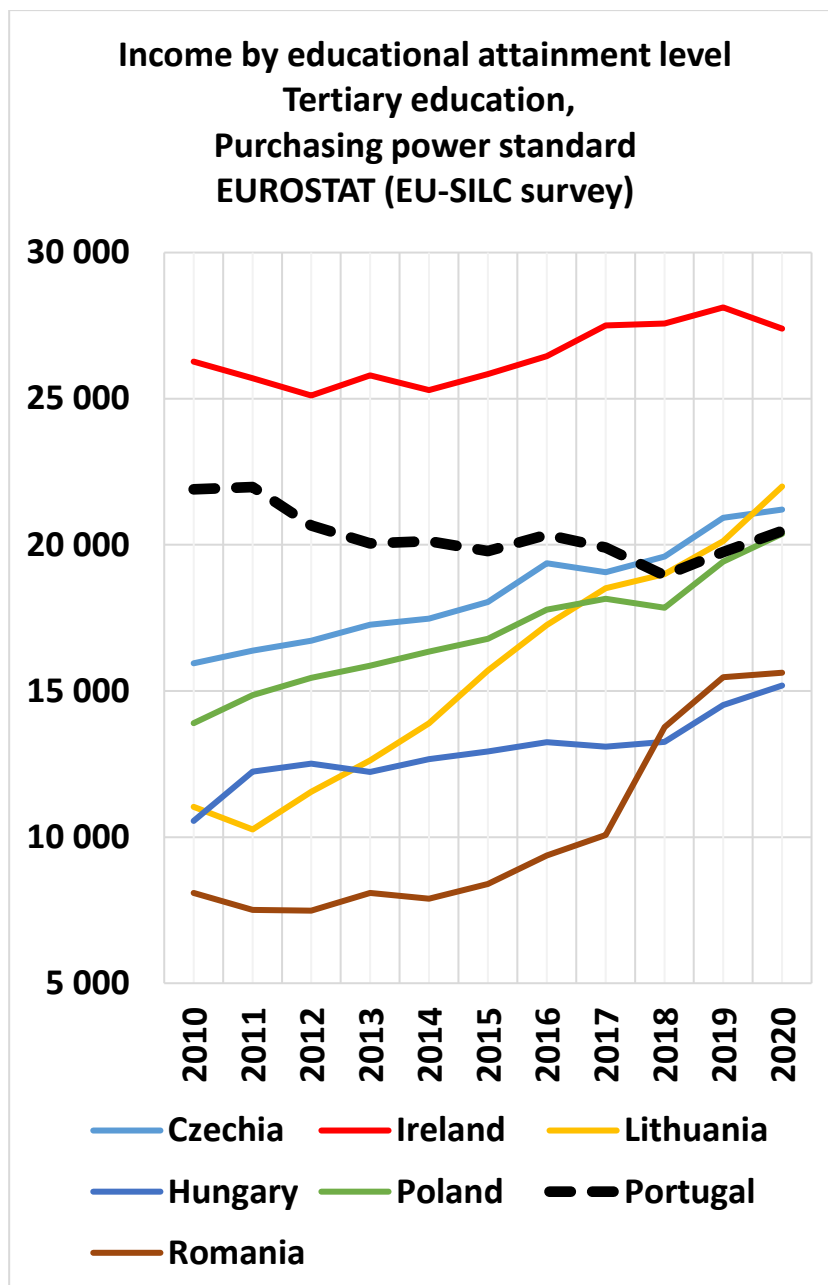


Figure 11a: Income by educational attainment level. Tertiary education. Purchasing power standard. EUROSTAT (EU-SILC survey).

archipelagos in the Atlantic, suggest the relevance for investing in this area⁹ e.g. as regards energy or marine biotechnology, whilst fighting pollution and unsustainable practices.

⁹ in the XXII Portuguese government (2019-10-26 up to 2022-03-30) a ministry of the sea was created, originating the Estratégia Nacional para o Mar 2021-2030 (resolução do Conselho de Ministros n.º 68/2021). The ministry of the sea was short lived (<https://www.publico.pt/2022/03/21/opiniao/opiniao/portugal-prescindir-ministerio-mar-1999410>). In the current government the ministry for the economy also includes sea matters (Ministério da Economia e do Mar).

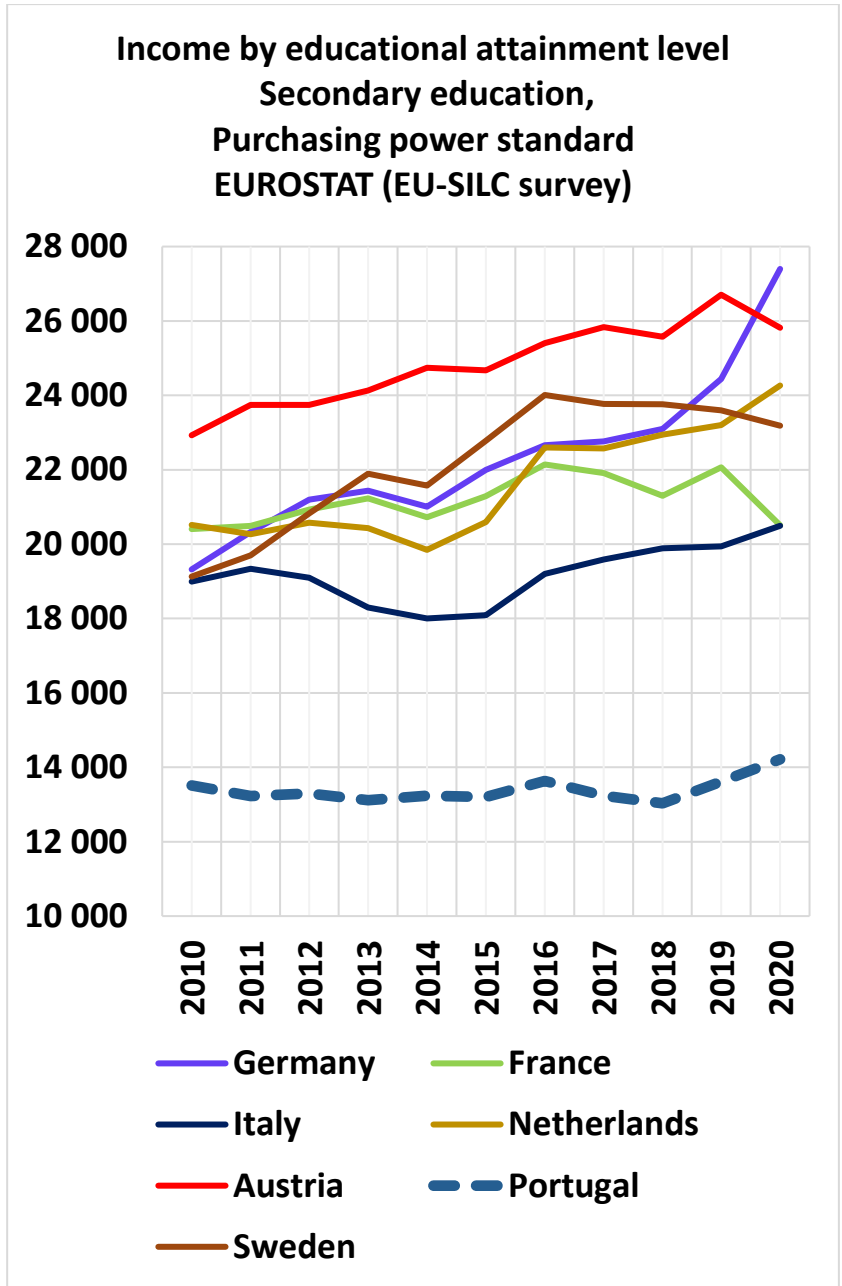


Figure 11b: Income by educational attainment level. Secondary education. Purchasing power standard. EUROSTAT (EU-SILC survey).

Worldwide, CO₂ sequestration in the sea as a contribution to the 1.5°C 2015 Paris IPCC target is a prospect, as well as enhancing alkalinity to reverse ocean acidification – always bearing in mind the potential negative consequences of further messing with the sea [71, 72]. Among the exhaustive listing of challenges of the 2022 UNESCO doc. ‘State of the Ocean’ [73] I highlight the #8, ‘create a digital representation of the ocean’, aligned with the pervasive trend for digitalization of the reality, (currently the rage in the aeronautics industry for ex.).

Sustainability implies electrification of transportation, where the role of Lithium is likely to be major. Lithium was added to the EU list of critical raw materials in 2020 [74, 75] (and curiously is not even mentioned in the OECD foresight study [76]). Portugal has meaningful quantities

of Li¹⁰, suggesting the importance of research on sustainable exploitation techniques. In parallel, it is noted that uses of Li are not only for batteries. Al-Li alloys also have a role in sustainability, a consequence of light-weighting of load-bearing structures resulting from the improvement of mechanical properties brought about by Li.

Other important contribution to the Portuguese economy comes from paper products¹¹; here all efforts to make eucalyptus – an active pyrophyte - compatible with sustainable safe communities are paramount. According to Silva *et al.*, [77] ‘*several eucalypt species are known for their capacity to massively regenerate through seeds in recently burned areas, becoming an ecological problem in regions where the species is not native*’. It is interesting to notice that simultaneously with the penetration of the www, the worldwide consumption of writing paper and paper for press is decreasing [78]; however, the cardboard sector is expanding, this compensating for the decline of writing paper consumption [79]. In Portugal eucalyptus occupied 845 thousand ha in 2015, approximately 26% of continental Portuguese forest and showing a systematic increase over the last 50 years, [80]. The value of the forest is not limited to serve the paper industry, and efforts to valorize the forest and promote its diversity are needed.

The aeronautics and aerospace sectors experience growth in Portugal¹². The space sector has its own sustainability problems, particularly the increasing quantity of debris orbiting. For aeronautics the main sustainability issue is the GHG emissions - per passenger and km aviation produces far more pollution than trains, [81]. However, if for distances as Madrid-Lisbon a high-speed train would be an obvious sustainable choice, for very much longer and intercontinental journeys aviation is irreplaceable. Sustainability of air travel is a main concern, and the EU is responding through the Clean Aviation initiative (formerly Clean Sky). Electric, hybrid electric, hydrogen and even changes in operations (as stop overs) are being considered, with research on batteries, fuel cells, SAF, etc.. The vast majority of flights are short-haul, although 2014-5 data shows that 50% of fuel is burned by flights greater than 3000 km, [82, 83]. Currently important stakeholders seem to favor hydrogen, as AIRBUS with the ZEROe concept¹³. Obviously, solutions for decarbonizing a small personal aircraft single engine piston category cannot be scaled up for larger aircraft, as regional (intended for short haul flights) or large passenger aircraft used for short, medium, and long-haul missions.

¹⁰ According to Volkswagen <https://www.volkswagenag.com/en/news/stories/2020/03/lithium-mining-what-you-should-know-about-the-contentious-issue.html> Portugal has 60 kt known lithium reserves, 6th largest out of worldwide 14Mt. In 2018 the worldwide production volume was 85 kt.

¹¹ In 2018 CELPA’s members (Altri, DS Smith, Renova and The Navigator Co.) recorded 2,9 bi euros sales, that is, 1.44% of national GDP. <https://eco.sapo.pt/2020/06/24/industria-do-papel-quer-fazer-parte-da-recuperacao-verde-investe-100-milhoes-em-sustentabilidade/> . CELPA: <http://www.celpe.pt/apresentacao/> .

¹² In Portugal, according to ‘AED Cluster’, in 2021 the 3 sectors aeronautics, space and defense represent an aggregate turnover of over 1.7 billion Euros, with export values around 90% and employing more than 18500 people. IAPMEI, ‘Clusters de Competitividade – Pactos para a Competitividade e Internacionalização’, 2021, p.16; <https://www.iapmei.pt/PRODUTOS-E-SERVICOS/Empreendedorismo-Inovacao/Eficiencia-Coletiva-e-Clusters/DOCS/Brochura-Clusters.aspx> . See also: <https://jornaleconomico.pt/noticias/aeronautica-espaco-e-defesa-valem-entre-16-e-18-mil-milhoes-448653> .

¹³ <https://www.airbus.com/en/innovation/zero-emission/hydrogen/zeroe> ;

Airbus, ‘Hydrogen: an energy carrier to fuel the climate-neutral aviation of tomorrow’, 2021;

Airbus, ‘Airbus increases its UK innovation footprint to develop new hydrogen technologies’, press-release, 2022; <https://www.cnbc.com/2022/02/17/airbus-ceo-says-hydrogen-plane-is-the-ultimate-solution.html> .

Many other sectors of the economy could be cited; the ones chosen above are just exs., among many, with societal and economic impacts. T. Pitta e Cunha said that Portugal is *'more backward and less indebted or less backward and more indebted'*¹⁴ ; contributions from the R&D community to overcome that perverse choice between two bad alternatives are urgently needed.

Sustainability

The 1987 UN Brundtland Commission report [84] defines sustainability as *'meeting the needs of the present without compromising the ability of future generations to meet their own needs'* (*ibidem*, p.8, p.43, p.363). As the report notes, *'our inability to promote the common interest in sustainable development is often a product of the relative neglect of economic and social justice within and amongst nations'*. (*ibidem*, p.49).

The current 17 UN sustainability goals are concisely listed in the following headings:

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 work,
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. Partnerships for the goals.

They are spelled out in the 2015 document *'The 2030 Agenda for Sustainable Development'* [85], a step in the progressive acknowledgement of the need for change to ensure a future for humanity. Previous steps include the already mentioned 1987 Brundtland report, and many other contributions from academe or religion – as Pope Francis' encyclical letter *'Laudato Si'* - on care for our common home' [86].

Persistent inequality is not the sole culprit though. Resource allocation is also to blame, as noted by Garcia in *Nature* - *'Redirect military budgets to climate and pandemics'* [87] - asking for a stop to the arms race, compliance with the Arms Trade treaty, implementation the 2015 Paris climate agreement, and promotion of the UN SDGs. Invasions and military aggressions as in Ukraine may be strong excuses to forget the above aims – as remarked by Pope Francis when he *'note[s] the interest in testing and selling weapons'* [88].

¹⁴ <https://www.dn.pt/cultura/o-mar-vai-ser-uma-carta-fundamental-no-seculo-xxi-14420366.html> .

The increasing attention of populations and governments to the effects of global warming and to the warnings of scientists concerning the climate emergency, led to the elaboration of plans for decreasing the GHG emissions, with ambitious steps concerning the decommissioning of fossil fuels power plants (coal, oil and gas), see e.g. [89, 90]. The European Commission included in 2022 specific nuclear and gas energy activities in the ‘EU taxonomy’ [91, 92], a transparency tool for companies and investors aimed at clarifying what is - or what is not - directed towards sustainability (European Green Deal, [93]).

A consequence of the 2022 Russian invasion of Ukraine was the turbulence of markets and a new geopolitical situation that led some countries to delay decommissioning or even to consider returning to operation decommissioned plants – implying increasing difficulties to comply with the IPPC targets. This is just an illustration of the need for engineers to be fully aware of geopolitics, given its fundamental impact in shaping our world.

Change implies overcoming difficulties. The IPPC reckons, in 2022, that there are still efforts of promotion of fossil fuels, and mentions the 1994 Energy Charter Treaty with its mechanisms for dispute settlement (ISDS) ‘*designed to protect the interests of investors in energy projects from national policies that could lead their assets to be stranded*’, [94-96]. Ascensão *et al.* [97] express concern at the sustainability issues associated with the implementation of the Chinese Belt and Road Initiative in developing countries.

Aggressions to sustainability may come from unexpected sources. An example is ‘bitcoin mining’ - intriguing designation for many - which alludes to computer networks crunching complex algorithms to finding new ‘tokens’. Fossil fuel power plants are finding a new life to satisfy the huge amounts of energy involved in mining the digital cryptocurrency bitcoin (thus squeezing some final revenue out of condemned plants) [98, 99]. The Center for Alternative Finance of the University of Cambridge estimates the annualized energy consumption for running the computer networks and corresponding refrigeration as 84.87 TWh (July 11, 2022 – this site is updated daily)¹⁵. To comprehend that figure note that electricity generation in 2021 was 48.78 TWh in Portugal or 268.25 TWh in Spain, [100].

Future

‘It is very difficult to predict — especially the future’ (attributed to the Danish physicist Niels Bohr [101]).

Predictions are frequently associated to some sort of strategic planning, intended to drive organizations or groups of individuals in a desirable path whilst ensuring that alternative scenarios are fully accounted for.

Portugal was under a right-wing dictatorship from 1927 to 1974. After Salazar internalized that planning is not a specific socialist tool, the ‘*planos de fomento*’ [102] were started in 1953 [103] (carefully avoiding any conceptual assimilation with Stalin’s ‘Five-Year Plans’ developed by the USSR’s Gosplan [104]). Later, in 1973-1986 GEBEI - Grupo de Estudos Básicos de Economia Industrial [105, 106] was involved in studies of industrial economy and contributions to planning, with J. Félix Ribeiro as an influential figure who would pursue planning and prospective studies in Junta Nacional de Investigação Científica e Tecnológica – JNICT (a precursor of FCT) and other organizations. Very recent works by J. Félix Ribeiro include the coordination of a major foresight work promoted by the Calouste Gulbenkian Foundation

¹⁵ <https://ccaf.io/cbeci/index> .

[107], or his contribution to the strategic planning of FEUP for the period up to 2037 [108], a project animated by A. Torres Marques.

Predictions are helped by a variety of techniques [109]; suffice here to mention RAND's pioneering work by Olaf Helmer-Hirschberg [110] based on peer discussions – the Delphi method - leading to inventories as those of the Japanese government agency National Institute of Science and Technology Policy – NISTEP [111]. Delphi method is also used by the EU e.g. in 'Shaping and securing the EU's Open Strategic Autonomy by 2040 and beyond' [112] and subsequent foresight efforts [113].

Prospective studies with diverse intentions and depth are nowadays easily accessible thanks to the www. Occasionally large-scale conferences of a prospective nature are organized by UNESCO [114]. Though not strictly foresight, the UNESCO Science reports, typically published every five years, present detailed monitoring exercises and include a prospective dimension [115].

Exercises at national level include the French 'Technologies Clés: Préparer l'industrie du futur' [116] or the British horizon scanning exercises, as 'Technology and Innovation Futures 2017' [117]. The French Direction Générale des Entreprises (DGE) [118] or the UK Government Office for Science [119] are two of the many government directorates, agencies etc. promoting foresight studies in many different areas. Among these, 'materials' is taken as an example, because of the impact of materials research.

Magee found that materials account for approximately 2/3 of the total technological progress in the generic functional area information transformation (computation). More generally, according to [120, 121], approximately 70% of all technical innovations are directly or indirectly dependent on the properties of the materials used. Moskowitz [9] estimates that the percentage of economic growth attributable to advanced-material technology was of the order of 12% in 1970, and is expected to reach 78% in 2030. These figures are to be compared with those presented above (section #2) concerning the contribution of advanced technology, estimated by Moskowitz as 40% in 1970 and 90% in 2030. This shows emphatically the increasing importance of the materials sector in advanced economies – a fact that should be considered by young people when choosing their higher education field of study!

The initiative Materials 2030 associated to the French presidency of the EU led to the prospective report 'Materials 2030 Roadmap' [122] which discusses in detail perspectives for materials based sustainable progress in 9 sectors - health care, construction, new energies, transport, home & personal care, packaging, agriculture, textiles, electronic appliances. With a very different perspective, SPM elaborated a study on economic aspects of materials in Portugal focused on polymers, ceramics and cork [123] (very concise summary in [124]). Many journals are dedicated to materials science and engineering advances, as *Nature Reviews Materials*, *Annual Review of Materials Research* (ex-*Annual Review of Materials Science*), *Journal of Materials: Design and Applications* (of the IMechE), *Materials and Design*, etc.

Geopolitics

The Roman empire towards 120 AD was composed of two different types of territories – the senatorial and the imperial provinces. Whereas the core of the empire were the senatorial provinces, at the borders of the empire the imperial provinces had defense objectives of protection against possible invasions by the barbarians. Up-dates and refinements throughout times show the persistence of the concept of a core and surrounding area of influence where the main power does not tolerates messing up by competitors. For example, a system of areas

of influence was created in the aftermath of the second world-war, leading to the iron curtain separating the USSR from the west. This separation was materialized by a selection of countries intended as a buffer zone. More recently, the attempt by the USSR to install nuclear missiles in Cuba led to a major international crisis – the Cuban missile crisis of October 1962. A very mild testimony to the susceptibility of these situations is the 2022 Australia’s reaction to the eventual installation of a Chinese naval base in the Solomon Islands.

The re-organization of the world in the aftermath of the 2nd world war with the creation of the UN, international law concerning conflicts (namely the Geneva conventions of 1949), the evolution of the EEC to present day EU, among others, brought peace to Europe ¹⁶ notwithstanding the cold war and occasional conflicts elsewhere as in Vietnam, Iraq, Syria, etc. .

Stella Ghervas, in ‘Conquering Peace: From the Enlightenment to the European Union’ [125] gives an overview of evolution of peace throughout time, up to present day EU. Of course, peace has been a matter of concern since there is war; for ex. Kant’s 1795 ‘Perpetual peace: a philosophical sketch’ outlines his views of the requirements for stable peace. The birthplace of Kant reflects the power games and post-war arrangements: Kant was born in Königsberg, East Prussia, now Kaliningrad - an area given to the USSR in the 1945 Potsdam conference that together with the earlier Tehran (1943) and Yalta (1945) conferences designed a post 2nd world war Europe. This exclave is the westmost part of the Russian Federation, separated from Belarus through a 70 km stretch of land, the Suwałki corridor which for obvious reasons is a matter of great attention for the geostrategy community [126, 127]. Above I mentioned the historian Stella Ghervas, born in Moldova. Again, the fluidity of geopolitics comes to mind: Moldova was earlier known as Bessarabia, passing from Ottoman to Russian hands, then Romanian, then to the USSR, and after the collapse of the USSR to today’s Moldova the candidate to membership of the EU with the peculiar feature of a part of its territory, Transnistria ¹⁷, being *de facto* self-ruled under the influence of Russia.

In 2022 the concept of using force to alter the *status quo* in Europe seemed unthinkable, when a reality check was imposed by the Russian invasion of Ukraine, bringing back the need to deal with the law of the stronger – instead of complying with international agreements and law.

Cynics may say that aggression is part of the human nature, even if that assertion is disputed by anthropologists, [128, 129]. Wars to conquer, plunder, steal and generally exert authority upon others are a permanent feature of history (and, since history is written by the winners, there is always a chance that the authority becomes ‘legitimate’ in the future). Many derive from that assumption their tools to deal with the reality. Others don’t give up the idealistic view of requiring adherence to the law, abhorring the law of the jungle where the strong eat the weak.

War is a source of questions of a moral nature. Can it be justified? is it always wrong? three main theories try to answer these questions: realism, pacifism, and the theory of just war. While pacifism sees war as always wrong, war may be sometimes justified; the just war theory or *bellum iustum* prescribes when it is legitimate to resort to war, how to conduct war and

¹⁶ although occasional aggressions were recorded in Europe, but not within the EU or its antecessors: the 1956 invasion of Hungary by the USSR, the 1968 invasion of Czechoslovakia by the Warsaw Pact, or the Balkans convulsions of the last decade of the 20th century. More recently, in 2014 the annexation of Crimea by the Russian Federation, as well as war in the Donbass region of Ukraine are noted.

¹⁷ with the increasingly famous Sheriff football club of Tiraspol.

what must be done once the war is over. The already mentioned 1949 Geneva Conventions are rooted in this theory.

The realism viewpoint sees no other rules except those imposed by the states, a “realpolitik” so well summarized by Thucydides reporting, five centuries BC, the Sparta vs. Athens wars: *‘the strong do what they can and the weak suffer what they must’* [130]. This *dictum* was recently taken by Yanis Varoufakis as the title of his book *‘And the weak suffer what they must? Europe’s crisis and America’s economic future’*, where he discusses the 2010-2015 Eurozone crisis and hardships imposed upon the Greeks, [131] ¹⁸. Niccolò Machiavelli provides insights in *‘Il Principe’*, and current exponents of this school include Henry Kissinger (ex US Secretary of State) and John Mearsheimer (University of Chicago) among many others.

Readings of the classics help identify present day threats and opportunities. An example is Graham Allison’s book *‘Destined for War: Can America and China Escape Thucydides’s Trap?’* [132], where the consequences of the emergence of China as a world power are discussed in the light of Thucydides writings of the 5th century BC: *‘What made the war inevitable was the growth of Athenian power and the fear which this caused in Sparta’*. The already mentioned RAND Corporation developed a tool to assess risk of conflict based upon the Global Power Index (GPI) which takes into account the military, economic, technological, political, and demographic capacity of nations, [133]. This indicates that the USA might have been already overtaken by China as far as the GPI index is concerned.

To conclude this section I mention a recent ranking concerning peace and prepared by the Australian think tank IEP – Institute for Economics and Peace [134]. The rank is based upon 23 indicators including terrorism impact, perceptions of criminality, weapons exports and imports, violent crime, access to small arms, neighbouring countries relations, etc.. Among 163 countries analyzed, the first 4 places are Iceland, New Zealand, Denmark, and Portugal. As a matter of curiosity, the USA and the Russian Federation are ranked 122 and 154, respectively. Rankings such as this, and the associated data and data-gathering may perhaps help to promote ideals of peace, particularly in more violent societies. And if that is the case, they are certainly worthwhile endeavors.

Concluding remark

The presentation aimed at recalling the wide context where the action of engineers takes place, with emphasis on aspects underlying their activity as innovation, the need for STEM and continuing education, and the Portuguese and wider economic context. Inequality issues were discussed, as well as orientation of R&D efforts to promote the UN’s sustainable development goals, including the promotion of an environment of peace and valorization of the human capital, ingredients for a happy progress of society.

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¹⁸ an excerpt: *‘[Varoufakis] shook with rage at the sad fact that my signatures were guaranteeing more than 50 billion euros of private bank debt while our state could not rub together a few hundred million euros to pay for our public hospitals, our schools or Greece’s old-age pensioners. ...’*

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Acronyms

AD	anno domini
AdI	Agência de Inovação (predecessor of ANI)

AEA	American Economic Association
AED	Aeronáutica espaço e defesa (cluster)
AI	artificial intelligence
ANI	Agência Nacional de Inovação (started as AdI)
ASEE	American Society for Engineering Education
BC	before Christ
CCS	carbon capture and storage
CEDEFOP	Centre Européen pour le Développement de la Formation Professionnelle
CELPA	Associação da Indústria Papeleira
DGPM	Direção-Geral de Política do Mar
EEA	European Environment Agency
EEC	European Economic Community
EEZ	exclusive economic zone
EJIL	encontro de jovens investigadores do LAETA
EPRS	European Parliamentary Research Service
ESHET	European Society for the History of Economic Thought
EU	European Union
FCT	Fundação para a Ciência e Tecnologia
FEUP	Faculdade de Engenharia da Universidade do Porto
GDP	gross domestic product
GEBEI	Grupo de Estudos Básicos de Economia Industrial
GHG	green-house gases
GPI	global peace index (IEP)
GPI	global power index (RAND Corporation)
HE	higher education
IAPMEI	Agência para a Competitividade e Inovação (formerly Instituto de Apoio às Pequenas e Médias Empresas e à Inovação)
ICNF	Instituto de Conservação da Natureza e das Florestas.
IEA	International Energy Agency
IEP	Institute for Economics and Peace
IFN	Inventário Florestal Nacional
IMEchE	Institution of Mechanical Engineers
IPPC	Intergovernmental Panel on Climate Change
ISDS	investor-state dispute settlement
JNICT	Junta Nacional de Investigação Científica e Tecnológica (predecessor of FCT)
JRC	Joint Research Centre (EU)
LAETA	Laboratório Associado em Energia, Transportes e Aeronáutica
MIT	Massachusetts Institute of Technology
NAE	National Academy of Engineering
NISTEP	National Institute of Science and Technology Policy (Japan)
OEC	Observatory of Economic Complexity
OECD	Organisation for Economic Co-operation and Development
OXFAM	Oxford Committee for Famine Relief
PISA	Programme for International Student Assessment
PPP	purchasing power parity
PPS	purchasing power standard

R&D	research and development
S&T	science and technology
SAF	sustainable aviation fuel
SDGs	sustainable development goals
SES	structure of earnings survey
SJ	member of the Society of Jesus (Jesuit)
SPM	Sociedade Portuguesa de Materiais
STEAM	science, technology, engineering, the arts, and mathematics
STEM	science, technology, engineering, and mathematics
UN	United Nations
UNDP	United Nations Development Programme
UNESCO	United Nations Educational, Scientific and Cultural Organization
USSR	Union of Soviet Socialist Republics
WEF	World Economic Forum