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The failure to decarbonize the global energy education system: Carbon lock-in and stranded skill sets

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ABSTRACT

The energy transition involves the transformation of professions and labour markets, which in turn depend on the availability of a workforce with the right education and competence. This study assesses how quickly global higher education is transitioning from fossil fuels to renewable energy in terms of educational content. The article is based on a review of 18,400 universities and the creation of a dataset of 6,142 universities that provide energy-specific education in 196 countries. The study compares the prevalence of educational programmes oriented towards fossil fuels and renewable energy. The findings show that the rapid adoption of renewable energy worldwide is not matched by changes in higher education, since universities continue to prioritise coal and petroleum studies. In 2019, 546 universities had faculties and/or degrees dedicated to fossil fuels whereas only 247 universities had faculties and/or degrees in renewable energy. As many as 68% of the world's energy-focused educational degrees were oriented towards fossil fuels, and only 32% focused on renewable energy. This means that universities are failing to meet the growing demand for a clean energy workforce. At the current rate of change, energy-focused university degrees would be 100% dedicated to renewable energy only by the year 2107. Since a career may last 30-40 years, this creates a risk of long-term carbon lock-in and stranded skill sets through (mis)education. The results also indicate that developing countries lag behind developed ones in this area, even though the need for professionals trained in renewable energy is greater in developing countries. Along with lack of capital, underdeveloped regulatory frameworks for renewable energy, and entrenched fossil-fuel business interests, the mismatch between energy education and the needs of the renewable energy industry may hold back the energy transition in many developing countries.

1. Introduction

The world has embarked on a large-scale transition to renewable energy [1–4]. According to the International Energy Agency [5], there has been more investment globally in renewables than in fossil fuels every year since 2016. But if the the Paris Agreement targets are to be fulfilled, it is necessary to further accelerate the decarbonisation and transformation of energy systems, including even faster changes in the social, economic and political domains [6,7].

The global energy education system will also need to change. Energy education in the 20th century was centred on the needs of the fossil fuel industries. Reorienting energy education away from fossil fuels and towards renewables will be decisive for limiting global warming to 1.5°C by 2050 [8,9], since a large and well-qualified workforce will be vital for the energy transition [10]. The transition requires a new generation of scientists, engineers, technicians and other specialists with the skills needed to build and manage renewable energy systems [11–13].

Renewable energy requires more labour than fossil fuels. The wind power sector employs more people than the coal industry per GWh of electricity produced; the solar energy sector already employs more people than the oil and gas industries combined, and the biofuels sector requires more staff than the coal and nuclear fuel industries combined [12,14–16].

The global renewable energy industry employed around 8 million people in 2016 and 11.5 million in 2019 [17,18]. According to one analysis, if all electricity is generated from renewables in 2050, this will create nearly 35 million new jobs worldwide [19]. Other estimates show that a completely renewable electricity supply will generate 52 million full-time jobs across 139 countries by 2050 [20]. During 2010–2023, there was a growing shortage of skilled labour for renewable energy

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systems throughout the world, and even more severe shortages are predicted for the future [19,21]. These estimates diverge because of different input data and assumptions, yet they all show the same general trend: with expanding renewable energy generation, the world will need a large workforce dedicated to renewables.

The overarching research question that this study addresses is therefore: Are universities transitioning from fossil fuel to clean energy education? In addition, we discuss the factors that are holding back the transition.

The article has four main parts. First, we present the analytical framework and our contribution to the existing literature on renewable energy education. Next we present the empirical results, followed by a discussion, recommendations and a concluding section with some caveats about the study's limitations.

2. Analytical framework

We draw on Unruh's [22] concept of carbon lock-in, which refers to the self-reinforcing inertia of the fossil fuel-based energy system through structural path dependence. This prevents the introduction of alternative energy technologies despite their environmental and economic advantages. According to Unruh [22], 'industrial economies have been locked into fossil fuel-based energy systems through a process of technological and institutional co-evolution driven by path-dependent increasing returns to scale'.

Numerous studies have dealt with carbon lock-in effects in different areas and at different levels. Table 1 presents a typology of the forms of non-material carbon lock-in. However, no research has examined the presence of carbon lock-in in the global energy education system in terms of *educational content*.

Energy education deserves attention in a carbon lock-in perspective for at least four reasons. First, it has an impact on the techno-institutional complex by producing the workforce necessary to maintain the dominant fossil fuel-based system and further support it via multiple channels. Thus, the energy education system is an important part of what Unruh [22] referred to as the 'fossil fuel-based techno-institutional complex'. Second, energy education can be viewed as a complex in its own right, with features similar to larger fossil fuel-based systems: it educates millions of graduates every year who are employed by the fossil fuel industry and sets standards via accreditation and disciplinary and degree classification. Third, energy education feeds into and receives input from other domains of the fossil fuel techno-institutional complex. While Unruh [22] recognises education as an important part of the complex, no study has examined carbon lock-in in energy education globally in terms of educational content. Fourth, universities are important because they are commonly viewed as agents of change in the global energy system [38–41].

3. The existing literature and our contribution to it

We reviewed 92 academic publications on renewable energy education published between 1990 and 2023. Already in the late 1990s and early 2000s, various authors noted that the deployment of renewables would be difficult unless a large workforce was trained in the management, installation, operation and maintenance of renewable energy systems [8,42]. Similarly, the importance of educating non-technical professionals such as administrators and economists was emphasised [43].

Table 1
Sources of non-material carbon lock-in.

Type	Literature
Formal institutions (policies, rules, commitments)	[22–27]
Informal institutions (cognitive frames, norms, narratives)	[24–26,28–30]
Competencies, behaviour	[24–26,31–33]
Micro-economic factors	[32,34–36]

Source: Trencher et al. [37].

Existing research on renewable energy education has been focused on issues related to course and curriculum development, teaching methods, training materials, and university accreditation [8,13,44–58]. One of the major topics stressed by the scholars concerns the integration of renewable energy disciplines into educational degrees, both at undergraduate and graduate levels. Hasnain et al. [59] show that, in the 1990s, solar energy education was mainly available at the course level, not at the degree level. A survey of graduate solar energy degree programmes in developed countries showed that only three universities offered a master's degree in solar energy in 1997 [59]. Until the early 2000s, renewables were not recognised 'as a major component of the "energy" subject' [43], and the discipline lacked 'uniformity in approach and extent of specialisation of the graduates' [60]. Moreover, at that time, there was no international accreditation system for educational programmes in renewable energy [60]. Another group of scholars has emphasised the weak link between renewable energy education and the job market [8]. Many scholars have stressed that advancing this education is imperative as part of broader climate change mitigation measures [58,60], and some have noted that universities should become change agents in the global energy transition [61].

It was only after 2009 that renewable energy education established itself as a separate discipline within the framework of broader energy education, and this was largely limited to Europe and North America. Various scholars have studied the evolution of curricula, as well as teaching methods, course development, training needs, awareness raising and education of the broader public and decision-makers [62–91]. Scholars have also emphasised the importance of introducing more practical and digitally-based exercises and knowledge for university students on wind and solar power technologies [92–95].

A group of scholars has proposed enabling factors for advancing renewable energy education [96–98], while others have stressed the importance of quality education for the energy transition [99]. Studies increasingly have focused on the major barriers to integrating renewable energy education programmes into academic programmes [100,101]. According to Ciriminna et al. [100], for example, technical solar education should be merged with broader management and economic education.

Critical skills and workforce deficits and a mismatch between the available education and the industry demand for qualified workers have been identified as major barriers to the rapid deployment of renewables around the world [10,21,102,103]. Maier et al. [104] find a disconnect between universities and the renewable energy business sector in Europe, with only 73 universities offering master's degrees that include internships at renewable energy companies. This points to a lack of sufficient skills and implies a significant shortage of practical knowledge among graduates placed in companies for internships during or after their education. Furthermore, Tsoutsos et al. [105] found that 8 out of 10 photovoltaics market players have limited or no access to relevant technical training and education in Bulgaria, Croatia, Cyprus, Greece, Romania and Spain.

The existing literature converges on three accounts. First, in an attempt to satisfy the growing demand for renewables specialists after 2000, many universities simply added one or two courses on renewable energy to their traditional science and engineering degree programmes (e.g. [58]). However, this reportedly failed to produce graduates with sufficient skills and knowledge [13,58]. For instance, in India, Montenegro, Serbia and Turkey, scholars found that there was no degree programme in renewable energy after 2000; instead, one or two courses were added to the curriculum of general engineering degree programmes, resulting in limited preparedness of graduates to work in the renewable energy sector [8,106,107].

Second, the situation in renewable energy education is worse in developing countries than in the developed world because of underfinancing and a lack of skilled educators, institutional infrastructure and curricula. Energy engineers and technicians from developing countries therefore often need to go abroad to acquire a complete renewable energy education. At the same time, as energy demand is projected to grow faster in developing countries, the need for renewable energy education and a qualified workforce will be *greater* there than in developed countries.

Third, since the middle of the 1990s, scholars have pointed out that the global education system is failing to keep up with the needs of the renewable energy industry. Hasnain et al. [59] note that, while solar energy technologies have been rapidly developed, little attention has been paid to solar energy education. In Jordan, for example, the weak educational system and the shortage of qualified engineers and technicians specialised in renewable energy is a major obstacle [75,102,108]. In China and Southeast Asia, scholars point to a severe shortage of qualified specialists and a mismatch between renewable energy education and the needs of industry and advocate adopting comprehensive renewable energy curricula at universities [67,109].

Some authors have analysed the carbon emissions footprint of universities themselves. For example, Leal Filho et al. [110] surveyed 50 universities from different countries to establish whether they used renewable energy at their facilities and found that the majority still relied heavily on fossil fuels. Worsham and Brecha [111] examined the commitments universities have made about their own emissions. However, such studies did not look at universities' educational content, the effects of which are likely to be greater than their own emissions, since the knowledge and skill sets students gain can spread and form whole societies and industrial systems.

The ongoing energy transition highlights the importance of renewable energy education [112,113]. However, the world still faces a shortage of qualified engineers and technical and renewable energy policy specialists [18]. A branch of the literature discusses how skills can be transferred between the fossil fuel and renewable sectors and argues that workers can switch from one sector to another and that many people who work in the energy sector have a generic (e.g. economics, business, physics) education which could be used both in the fossil fuel and renewables sectors [114]. Several scholars examined the career pathways of energy managers in Norway and established that some of them decide to leave fossil fuel companies in order work in the renewable energy sector (see e.g. Rauter [115]). The transferability of staff and skill sets, however, may apply to some general and managerial skills, whereas the skills needed for more technical professions tend to be industry specific. Bryant and Olson [116] note that it is highly problematic to staff clean-energy industries with petroleum engineering graduates since clean-energy engineering requires skills and technical knowledge that are different from petroleum engineering. The shortage of skilled labour in the renewable energy industry is one of the major barriers to the rapid transition to alternative sources of energy [7,10].

It is also important to mention the impact of the COVID-19 pandemic on the state of higher education in renewable energy. Many authors show that the pandemic and the related shift to online teaching complicated and slowed the effective provision of renewable energy education [117]. Moreover, the pandemic widened the gap in energy education between renewable energy and fossil fuels since the former more often lack resources to invest in effective digital teaching solutions.

Our study makes several novel contributions to the literature. First, in terms of methodology, most of the existing publications are based on a case-study research design in which one or a few educational institutions in one or a few countries are examined [47,55,64,67,84,107,109,112,118]. These studies provide rich and insightful empirical material on the micro-level challenges and barriers to promoting renewable energy education in different specific locations. No researchers, however, have attempted to study and compare universities worldwide, as we do in this article. While most existing studies examine three to five universities, the present study covers 6,142 universities. Second, our study is also original in that it compares the evolution of renewable energy education with that of fossil fuels at the global level over time in order to gauge the shifting balance.

4. Methods

4.1. Data sources and research design

This study is based on data mined from the International Handbook of Universities published regularly by UNESCO and available from the World Higher Education Database (WHED), which is maintained by the International Association of Universities (IAU). The handbook does not have perfect coverage, but is the most comprehensive and widely recognized source of data on higher education worldwide. The handbook provides a unique and comprehensive compilation of detailed university data from nearly all countries in the world and has been used in studies across a variety of disciplines [119–121]. Each year's handbook typically comprises over 2000 large-format pages with very small print.

The data were extracted and analysed for three temporal data points: 1999, 2009 and 2019. The 2019 issue is the most recent edition of the handbook. Apart from the 2019 edition, the handbooks are only available in print. Therefore, we had to obtain data from the two other editions by manually scanning 4,730 pages (2,838,500 words) and subjecting these to optical character recognition with 99.9% accuracy. The text was then searched using keywords to identify energy-related educational elements at 18,400 institutions of higher education in 196 countries at three levels: the university, faculty and degree programmes.

The analysis enabled us to identify 6,142 universities that offer education specialized in energy. These educational programmes were analysed to ascertain whether they were oriented towards fossil fuels or renewable energy. The data enabled us to ascertain the pace at which educational programmes in renewable energy have grown and whether they have been outpacing those dedicated to fossil fuels over time. Our analysis covers only education that is specifically about energy, not general degrees in engineering, geology, economics, chemistry, administration, business, political science or other general fields whose graduates may also find work in the energy sector.

4.2. Levels of analysis

We included three levels of analysis in our study (see Table 2). This tripartite structure corresponds to the UNESCO system, in which the highest level is the university, the second level is faculties (sometimes referred to as departments or similar terms) and the third level is degree programmes. The three-level hierarchical structure also has an analytical function in our study. If a university establishes a whole renewable

Table 2
Levels of analysis

Levels	Criteria	Analytical significance
1. University	Renewable energy/fossil fuels in the official name of the university (e.g. 'Oil and Gas University').	The whole university focuses on fossil fuels or renewable energy education (it is the main priority).
2. Faculty	Faculties or equivalent, such as departments, divisions and centres (e.g. 'Faculty of Renewable Energy').	The university emphasises fossil fuel or renewable energy education (it is a major priority).
3. Degree programme	Undergraduate degrees (bachelor's, specialist), graduate (master's) and post-graduate (PhD) in fossil fuels or renewable energy; non-degree diplomas also included.	Renewable energy or fossil fuel education is available only at the degree level (it is a minor priority).

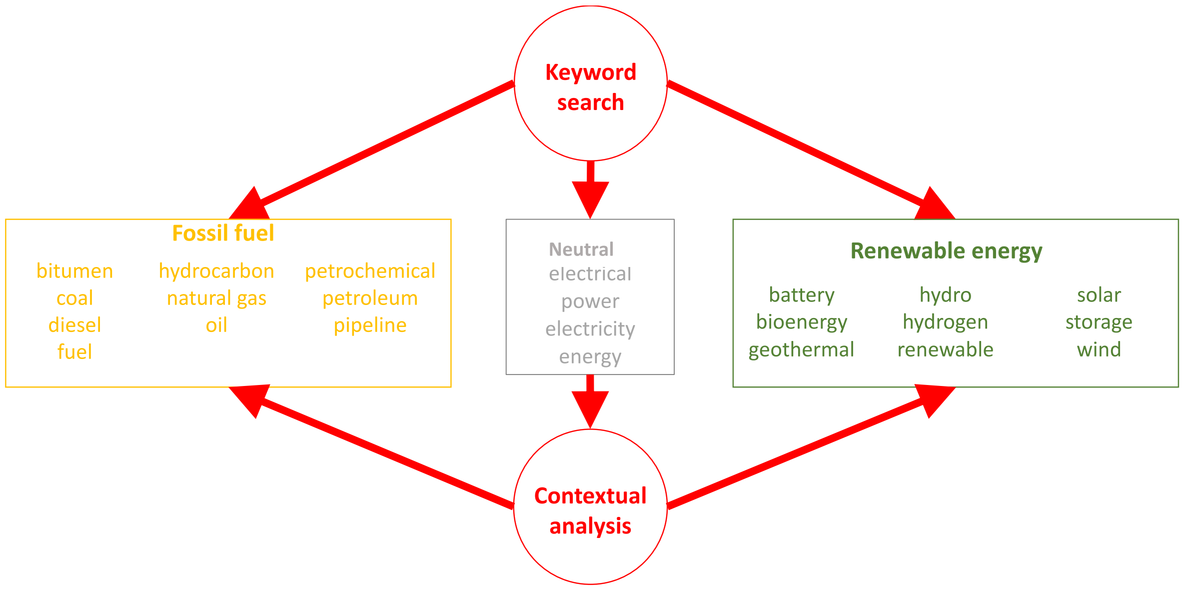

Fig. 1. Keyword groups

energy faculty, it likely signifies that it will invest more in renewable energy than a university that introduces only a single master's degree programme in that subject.

We used the same keyword search for each level of our analysis. For example, at the highest level, if a university's name included words such as 'oil', 'gas' or 'solar energy', we categorised this university as being dedicated to that type of energy.

4.3. Coding and data extraction

To ensure consistent data collection, educational entities specialising in fossil fuels and renewable energy were identified through keyword searches. We identified an initial set of 62 fossil fuel and renewable energy keywords based on the Eurostat glossaries for 'fossil fuels' and 'renewable energy sources' [122,123], as well as previous keyword selections developed by Overland and Sovacool [124] and by UNESCO [125–127]. We searched for these keywords in the handbooks and kept only those which generated at least one hit. All the keywords with zero hits were removed from the final list. This rendered 11 fossil-fuel and ten renewable-energy keywords in the final list (see Fig. 1).

We grouped the keywords into three categories: (a) fossil fuel related, (b) renewable energy related and (c) a neutral category (e.g. general programmes in electrical engineering). When we found one of these neutral terms in the text, we checked the context of the hit and qualitatively determined whether to assign the hit to fossil fuels or renewable energy.[1]

4.4. Content analysis and descriptive statistics

To ensure the reliability of our approach, we carried out both pilot content analysis and researcher triangulation. Both methods helped refine, nuance and improve the categorisation of educational units.

We applied the same strategy when analysing and quantifying information about our units of analysis at all levels (universities, faculties and degree programmes). Each university was examined using all keywords at all three levels. For example, if a university had a faculty of renewable energy, this was counted as one unit at the faculty level. Similarly, if a university had four different masters' degrees in oil and gas studies, these were counted as four units at the degree level.

5. Empirical results

5.1. Level 1: Whole universities

We identified universities that are dedicated to either fossil fuels or renewable energy. For instance, the large Gubkin Russian State University of Oil and Gas was founded in 1930 and is one of the main providers of fossil fuel education in Russia. Other examples include the Petronas Malaysian University of Technology and the University of Petroleum and Energy Studies in Dehradun, India. Such universities were established to serve the needs of the oil and gas sector.

Fig. 2 shows the number of universities dedicated entirely to fossil fuels or renewable energy. The gap between fossil fuel and renewable energy universities is large and widening *in favour of fossil fuels*. By the end of 2019, there were 33 universities specialising in petroleum studies. By contrast, only two universities in the world focused on renewable energy.

5.2. Level 2: University faculties

Often a university has more than one faculty dedicated to either fossil fuels or renewable energy. For instance, the same university can have a faculty of wind energy and a faculty of renewable energy law. The total number of faculties in our count is therefore greater than the total number of universities. If a university has no renewable energy faculty but only a degree programme, it typically means that less human and financial resources are allotted to the field. Fig. 3 tracks and compares the change in the share of energy faculties dedicated to renewables and fossil fuels between 1999 and 2019. Although the share of fossil fuel faculties decreased over time (to 68%), it remained much larger than that of renewables (32%) in 2019. In terms of absolute numbers, 546 universities had a total of 861 faculties dedicated to fossil fuels, while 247 universities had 543 faculties dedicated to renewable energy by 2020.

The dominance of fossil fuel faculties implies that education in fossil fuels is much more developed than education in renewable energy. Many universities offer a variety of specialised fields across a wide range

[1] We also identified faculties and university degrees dedicated to nuclear energy. Nuclear energy is a thorny issue, however, and views on it are divided among the energy transition community. We therefore left it out of our analysis. We plan to publish a separate article that would specifically focus on nuclear energy education and implications for the energy transition.

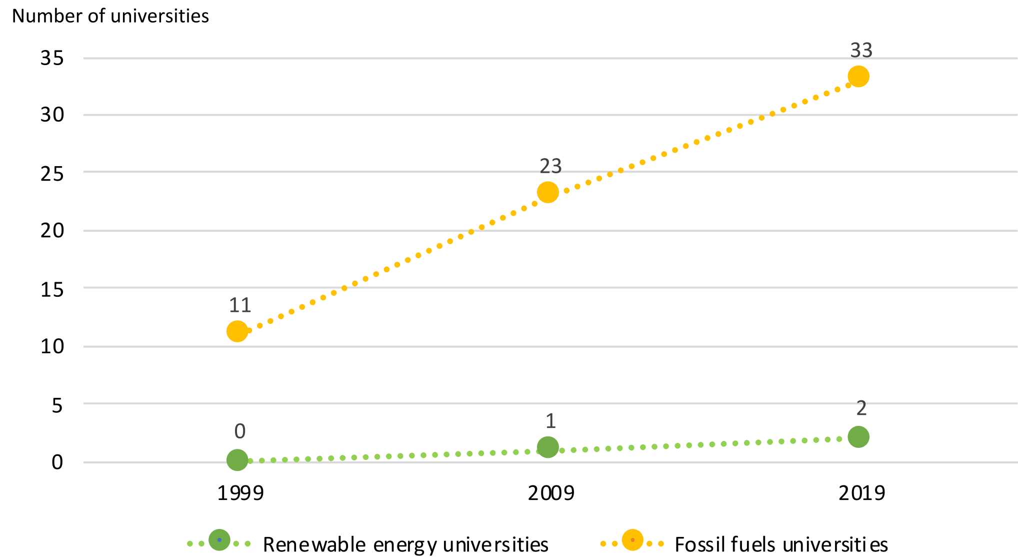

Fig. 2. Entire universities specialising in fossil fuels and renewable energy

of topics related to fossil fuels. For instance, universities focusing on fossil fuels typically have the following faculties or sub-faculties: oil and gas exploration, drilling, geology, petroleum engineering, and oil and gas markets. In contrast, most universities offering education in renewable energy have fewer specialisations and often have only one or several faculties or smaller sub-faculties.

Fig. 3 includes a projection indicating the year in which the global share of renewable energy faculties will reach 100% based on the rate of change between 1999 and 2019. At the current average rate, complete change will not be achieved until 2083, which is incompatible with climate change mitigation goals under the Paris Agreement.

5.3. Level 3: Degree programmes

Here we look at bachelor's, master's, PhD, and diploma degrees in renewable energy or fossil fuels. If a university offers a master's degree in renewable energy but has no faculty or sub-faculty in renewables, this indicates that renewable energy education is likely not a top priority, and limited human and financial resources are allocated to supporting the programme. According to the existing literature, this is a common issue worldwide. Some universities swiftly establish bachelor's or master's programmes in renewable energy in an attempt to follow the trend but do not carry out deeper structural changes, such as creating faculties or sub-faculties [38,102]. Often such programmes lack skilled and experienced staff, so that renewable energy subjects are taught by professionals with a fossil fuel or general engineering backgrounds.

Shifting from fossil fuel to renewable energy education is not straightforward. Renewable energy education is highly multidisciplinary and thus requires a different approach from that of fossil fuel education [43]. According to Jaber et al. [102], renewable energy education 'should include a study of conversion processes, technologies, resources, systems design, economics, environmental dimensions, industry structure and policies in an integrated package'.

Fig. 4 presents the global share of educational degrees (bachelor's, master's, PhDs, and diplomas) in renewable energy and fossil fuels. Despite growth in the share of renewable-focused energy degrees globally from 17% in 1999 to 32% in 2019, the share of fossil fuel degrees offered was still much larger in 2019, at 68%. In terms of absolute numbers, by 2020 a total of 546 universities (out of a total of 18,400) offered 1372 fossil fuel degrees, while 247 universities offered 653 renewable energy degrees. The number of degrees in renewable energy grew significantly, from a total of 95 in 2009 to 653 in 2019. However,

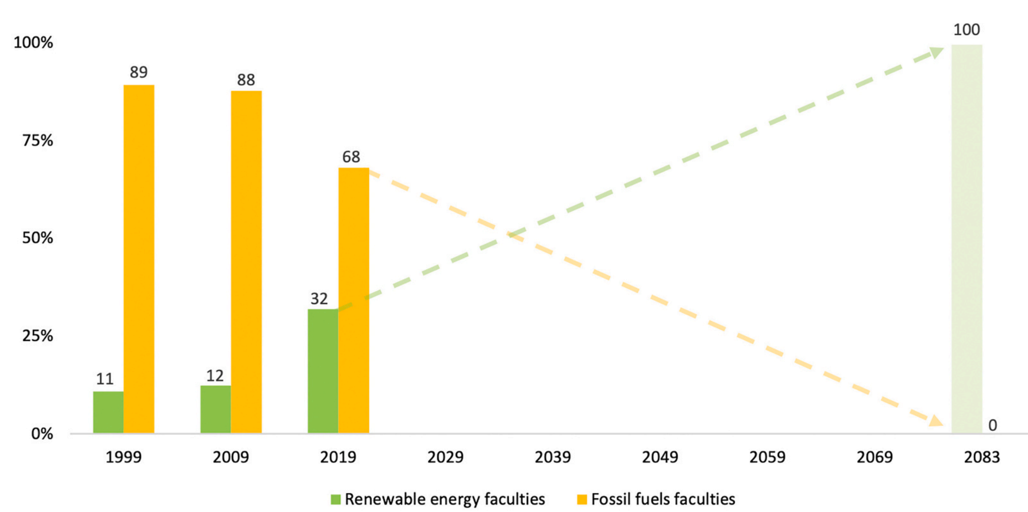

Fig. 3. Shares of faculties dedicated to renewable energy and fossil fuels. The dotted green line represents a simplified projection of when the share of renewable energy faculties would reach 100% if the average rate of change from 1999 to 2019 were to continue.

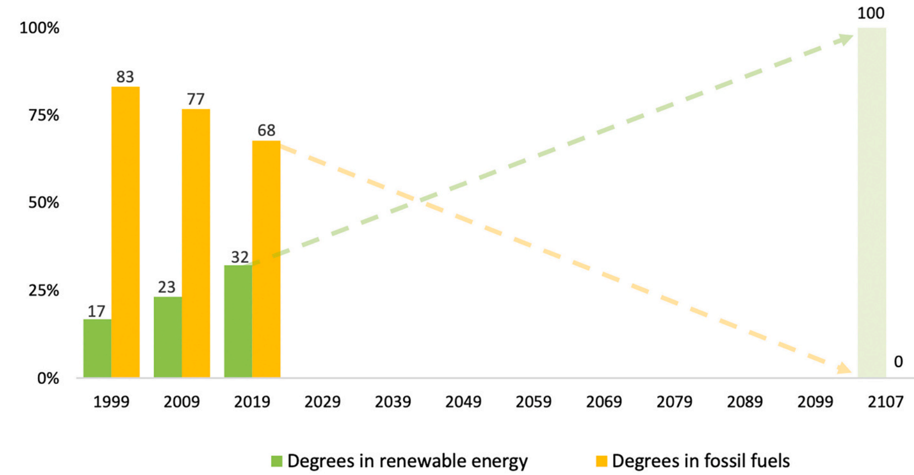

Fig. 4. Global share of degree programmes in renewable energy and fossil fuels. The dotted green line indicates a simplified projection of when the share of university degrees in renewable energy would reach 100% if the average rate of change from 1999 to 2019 were to continue.

this number is still much smaller than the 1372 degrees in fossil fuels offered to students globally. The shift from fossil fuel to renewable energy degrees was slower than that of faculty departments, and at the current average rate, a complete shift will not be achieved until 2107.

5.4. Comparison of regions

Fig. 5 presents the geographical distribution of shares of degrees in fossil fuels offered vs shares of degrees in renewable energy offered. In most parts of the world, renewable energy education still lags behind fossil fuel education, and the overall share of energy degree programmes for fossil fuels is still substantially larger than that for renewable energy. Asia Pacific, North America and Europe have come farthest in the educational energy transition in this respect. There is a notable gap between these regions and those of Africa, the Middle East, Central and South America, and Eurasia, where the share of degrees in fossil fuels is considerably larger.

Large countries that serve as global educational hubs, such as the USA, had a limited number of renewable energy programmes during this period. Country-specific case studies by other scholars support our findings. For example, Swift et al. [21] estimated that the USA will need more than 50,000 university-educated professionals with graduate degrees by 2030 to support wind sector development and that the current US education system falls considerably short of meeting this demand.

Our results also indicate that developing countries lag behind developed countries in terms of renewable energy education. Along with lack of capital, underdeveloped regulatory frameworks for renewable energy and entrenched fossil fuel business interests, this may encumber the energy transition in many developing countries.

5.5. Private and public universities

Fig. 6 compares public and private universities. The global share of renewable energy degree programmes at public universities rose from 16% in 1999 to 34% in 2019 and was lower than that of private universities, which saw an increase from 21% in 1999 to 39% in 2019. Thus, private universities have been slightly more active than public universities in shifting to renewable energy education. This may be because private universities are less prone to carbon lock-in effects (see Discussion section for more detail on carbon lock-in).

6. Discussion

Universities still focus on and produce more graduates for the fossil fuel industries than for the global renewable energy sector. This result is consistent with the concept of carbon lock-in, which has received increasing attention in the academic literature. Carbon lock-in could provide at least part of the explanation for the slow pace of the energy transition in higher education (see Section 2). It can occur at multiple levels (see Fig. 7). First, the global higher energy education system may be slow to reform because of the entrenched interests of the fossil-fuel industries, which have political and financial influence on higher education. For example, oil companies often help fund educational programmes in petroleum studies. There have also been many instances in

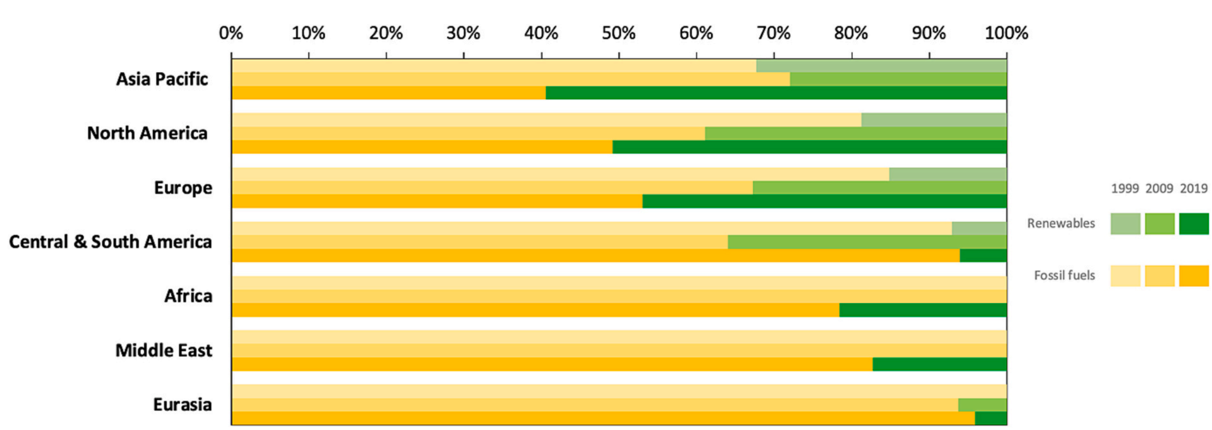

Fig. 5. Evolving share of degrees in renewable energy and fossil fuels by region

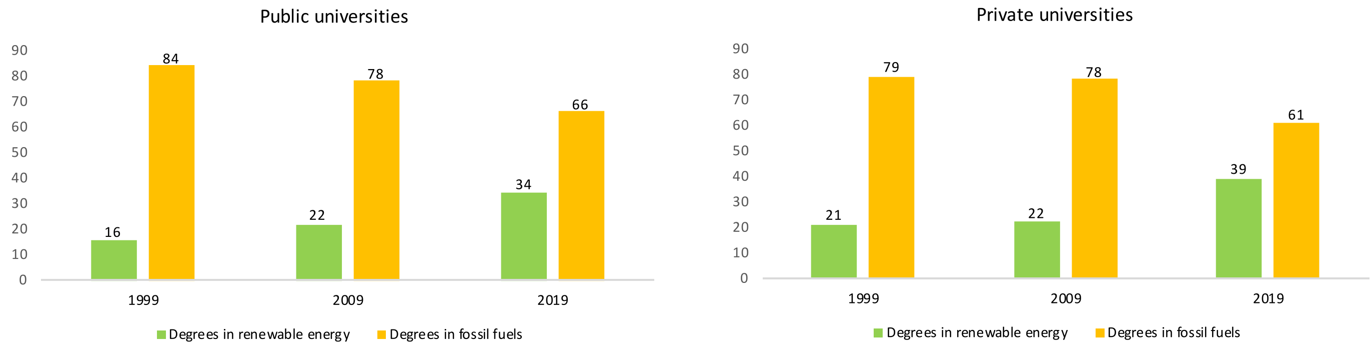

Fig. 6. Share of degree programmes in public and private universities over time (in %)

which senior oil company staff have become university board members [41]. In the US, many universities 'retain links with the fossil-fuel industry in a variety of ways, despite the growing pressure on them to cut them' [128]. According to the study by Data for Progress [129], six fossil fuel companies in the US have provided more than USD 700 million to 27 universities – including the University of California at Berkeley, the Massachusetts Institute of Technology, the George Mason University – from 2010 to 2020. In the view of Claire Kaufman, an organizer at the Divest Princeton group, the oil industry is 'not a neutral industry. It has an agenda, it wants to shape the conversation around climate change and energy' [128]. The graduates who obtain a fossil fuel education may return to their universities many years later and sponsor fossil fuel degree programmes.

Second, another source of carbon lock-in is government funding for education. In 2019, the governments of 196 countries spent on average 3.6% of their GDP on education, and a disproportionate part of this was spent on fossil fuel education [130]. These allocations are made by education ministries, energy ministries, public research funding bodies, and private and international donors who support educational institutions and often shape their academic agendas and curricula directly or indirectly. At the same time, renewable energy education remains underfinanced. Thus, educational reform may be needed not only at the university level but also at the level of the state, which could help prioritise renewable energy education by phasing out financing for fossil fuel programmes. At the same time, more research is needed to examine the variety of funding sources and the institutional structure of carbon lock-in within higher education in different countries.

Third, university accreditation systems and the codified educational standards of UNESCO and other organizations may also contribute to a carbon lock-in effect. For example, in the UNESCO classification system for educational disciplines, wind energy is not categorized as a discipline in its own right and is instead subsumed under energy engineering. By contrast, petroleum and coal are treated as separate disciplines and thus have a more prominent place in the UNESCO classification system. This issue requires further research to establish how and to what extent accreditation systems and codified educational standards contribute to

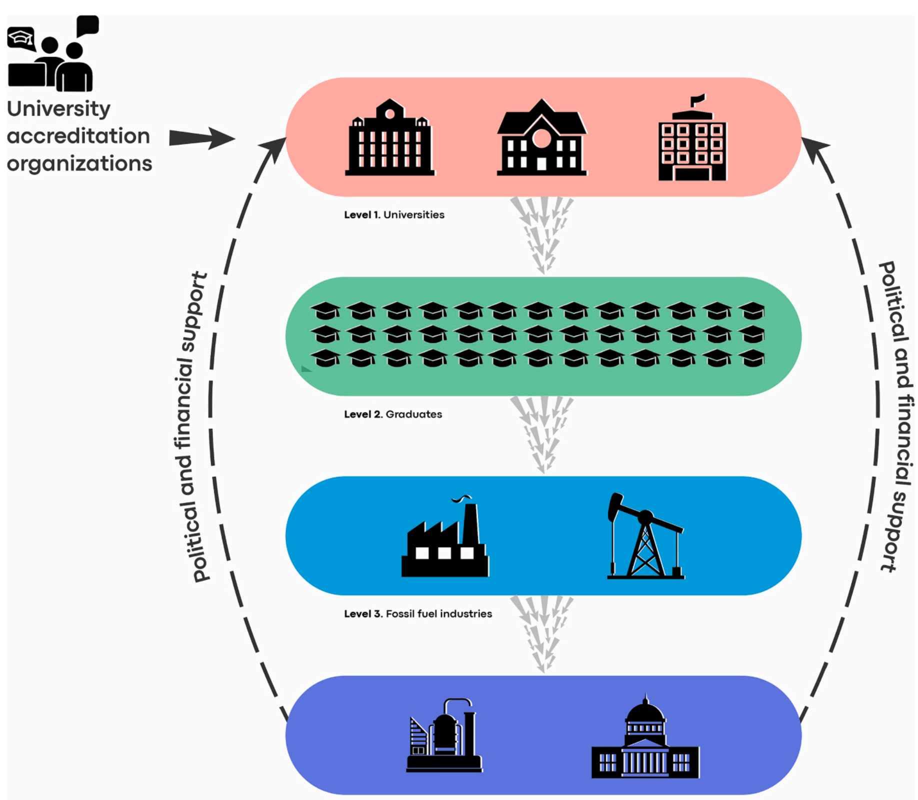

Fig. 7. The structure of carbon lock-in in higher education

carbon lock-in in higher education in different countries.

Fourth, people with a fossil fuel education may have fossil fuel mindsets for the rest of their careers. University education shapes people's beliefs, values, attitudes and actions. People with fossil fuel educations are more likely to be supportive of fossil fuel agendas, discourses and actions. Such education can also plant the seeds of a carbon lock-in mentality both via personal networks and within formal institutions. This may lead to fossil fuel graduates being left with stranded skill sets and a heightened risk of unemployment, and the cost of retraining them may be substantial. Therefore, universities could consider shutting down fossil fuels educational programmes and reorienting their resources towards giving students the skills for which demand is actually rising in the labour market.

7. Conclusion

From 2010 to 2024, there was a growing global shortage of skilled labour for renewable energy systems, and more severe shortages are predicted in the future [19,21]. If left unaddressed, the structural problem in the global energy education system may have a detrimental impact on the energy transition. The continued prioritisation of fossil fuel education by universities is likely to complicate the implementation of the Paris Agreement and the achievement of carbon neutrality, since the qualifications and skill sets of the workforce will be mismatched with the needs of the energy sector.

In this study, we firstly established that universities in developed and developing economies alike struggle to phase out fossil fuel education and to prioritize renewable energy education. We found that, although the availability of educational programmes on renewables has grown over the years, they are still outnumbered by fossil fuel-oriented programmes.

Second, we proposed that this may be due to the presence of carbon lock-in in institutions of higher education and the continued support and financing that universities receive from the fossil-fuel industry. To tackle carbon lock-in in higher education, it may need to be addressed at several levels. This topic, however, needs more research to establish the variety and types of carbon lock-in sources in different parts of the world. In particular, the impact of codification measures such as accreditation warrants further study.

The study is accompanied by four caveats. First, our data cover universities only, not organisations providing vocational programmes and on-the-job training. The latter also play an important role in preparing people to work in the energy sector [71] and could be the subject of another study. Creating new degree programs at university-level is often a slow process due to multiple levels of governance and quality control that can involve time-consuming and bureaucratic procedures. Smaller and nimbler technical and vocational education and training (VET) institutions may be less prone to carbon lock-in effects than universities and could thus play an important role in the acceleration of the energy transition in education. However, university-level qualifications clearly will also be needed for the energy transition, and on the current educational trajectory these are a missing link.

Second, after first surveying 18,400 universities, we focused on those that provide education specifically oriented towards fossil fuels or renewables and compared them to each other. This means that we did not look closely at universities that provide energy education that is not focused on renewables or fossil fuels, or that is not focused on energy at all but whose graduates go on to work in the energy sector. Such general educational programmes may have less of a fossil fuel bias. However, extrapolating from our data on those educational programmes that do have a clear profile, one might hypothesise that the generic programmes are also more focused on fossil fuels than renewables, especially as many of them have existed since the times when there was much less emphasis on renewables. Checking this hypothesis would require substantial further research on the contents of such educational programmes. In any case, the growing shortage of skilled labour needed for renewable energy systems indicates that the supply of talent from both specialized and generic educational programmes is insufficient for the energy transition. The supply of human capital is lagging greatly behind demand in the renewable energy sector.

Third, our counts do not include the numbers of students educated by different programs. In theory some programs could produce much larger student numbers than others. However, such data would be difficult to get hold of on the global scale that our analysis deals with. Since we cover institutional structures at multiple levels, it is unlikely that there are many more renewable energy students produced than our findings indicate. And if there is a systematic difference in size, it is more likely the older and more established fossil fuel programmes, which often have large-scale sponsorship from oil companies, that are largest. That would mean that the imbalance in favour of fossil fuels is even greater than we have found. However, checking that would require further research.

Fourth, some skills can be transferred between the fossil fuel and renewable sectors. For example, staff can switch from one sector to another, some companies are currently investing in both sectors (e.g. oil companies investing in wind or solar power), and many people who work in the energy industry have generic educations which could be used in either sector. Again, however, the reported growing shortages of high- and medium-skilled labour for renewable energy systems signal significant supply gaps of professionals for this sector globally, risking delays in the energy transition.

CRediT authorship contribution statement

Roman Vakulchuk: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. **Indra Overland:** Conceptualization, Data curation, Funding acquisition, Methodology, Resources, Supervision, Visualization, Writing – review & editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

Data availability

Data will be made available on request.

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