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Where are the Women in the Engineering Labour Market? A Cross-Sectional Study

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ABSTRACT
Traditionally, engineering has been a male bastion throughout the world. However, during the past 15 to 20 years, the need for gender diversity has become increasingly understood by stakeholders. Against this background the study discusses the participation of women in engineering education and employment from across the world to uncover specific differences and similarities. Today, in almost all countries, various stakeholders are taking affirmative action to enhance participation. Yet not all actions are equally effective, and progress is sometimes much slower than might be expected. An array of various socioeconomic-political factors provides the reasons for such outcomes. The countries studied have been divided into four groups based on the impact of various socioeconomic factors on women's participation across engineering. Example actions are discussed again for different levels of engineering—from students to practicing engineers. These, together with an understanding of what works, where and why, could be the start of a library of case studies that organisations such as the International Network of Women Engineers and Scientists (INWES)[1] may share with those working to increase gender equity in science, technology, engineering, and mathematics (STEM) around the world. Even though there is a paucity of research or data for some areas of the globe, particularly in the engineering workforce, one point that emerges from this paper is that, in order to enhance the effectiveness of affirmative programmes, socioeconomic-political factors must be taken into consideration.

KEYWORDS
Women; engineers; affirmative action; engineering education; labour market; STEM

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INTRODUCTION

Engineering is a profession that is typically male-dominated, and women's participation remains low (Küskü, Mustafa, & Lerzan, 2007; Nguyen, 2000; Singh, 2013b; Wyer, 2003). The advent of globalisation and Information and Communication Technology (ICT) has affected the market in two ways. First, the marketplace has become very competitive due to the blurring of geographical and economic boundaries. Second, manufacturers can now shift part of the production process to remote locations where the work can be performed at less cost without compromising technical requirements. Manufacturers are exploiting this new dynamic by continuously upgrading the technology they employ and relocating their work in order to realise reduced costs (Singh, 2013a). This new dynamic has led to a growing need for highly skilled engineers and technologists in both developed and developing countries. Consequently, the workforce transitions that have occurred over the last two decades are predicted to continue due, not least, to automation technologies that will require more engineering skills, more innovation, and a greater ability for engineers to think critically. Increasing the size and diversity of the workforce will bring long-term economic benefits (McCauley, 2018) and this realisation has led to efforts by governments and other stakeholders to increase the participation of women in the engineering labour force.

Against this backdrop, the paper locates women in the global engineering labour market via an assessment of both demand and supply. In the second section we outline our objectives and methodology, and discuss the system of classification we applied to the countries in the study. Narratives of supply and demand within the engineering labour market for women are discussed in the third and fourth sections, respectively. The fifth section discusses affirmative actions to increase the participation of women in engineering and also presents case studies with macro-level assessments. The final section concludes with an outline of the analysis and recommendations.

OBJECTIVE, METHODOLOGY, AND COUNTRY CLASSIFICATION

As per the theory of human capital, engineers of similar experience and skills, irrespective of their gender, should have an equal opportunity of employment and similar earnings (Becker, 1993; Devey-Tomaskovic, 1993). However, this is not the case, as the data referred to in this paper highlight. In this section, the objectives and methodology of the study are discussed, along with the segregation of the countries into four groups.

Objective and Methodology

The paper has three basic objectives:

- to contrast and compare the levels of participation of women in engineering education and employment amongst various countries in order to uncover specific differences and similarities;[2]

- to identify and assess the affirmative actions taken by stakeholders in order to increase the participation of women in engineering; and
- to discuss the issues in different sectors of engineering and different levels, from students to technical leadership.

The ultimate aim is to provide organisations such as the International Network of Women Engineers and Scientists (INWES) a starting point for a library of case studies of affirmative actions and some indication of where and why they may work.

Qualitative research does not represent a monolithic, singular approach to research, but rather, is a vibrant and contested field with many contradictions and different perspectives (Brinkmann, Jacobsen, & Kristiansen, 2014). Despite the paucity of data, especially for developing countries, an attempt is made to present an overview of women in the engineering labour market in different parts of the world. The population for the study is mainly research findings supported by data generated by UNESCO (2017) as well as government and national bodies, whilst additional information from newspapers, blogs, and corporations has been used at times to support the arguments presented. The intention has not been to provide an exhaustive list of case studies, but rather a sample that illustrates the actions being taken in different countries, thus highlighting the range of affirmative interventions taking place across the world.

Categories of the Countries

For the purpose of the analysis, the countries have been separated into four categories based on shared traits and characteristics. However, it should be noted that the classification is very broad, and such differences are thus not overly rigid. Table 1 provides brief descriptions of the four categories employed. Although a global view was considered, many of the cases, data, and examples in this paper focus on countries in categories 1 and 3, particularly the United Kingdom and India, where the authors have much experience.

Table 1. Countries classification for the study.

Category	Countries	Characteristic
First Category	United States of America, United Kingdom, Canada, France, Italy, Germany, Spain, Australia, New Zealand, etc.	Countries of North America, Australia, and Europe that have never become communist/socialist countries Developed countries as per the World Bank classification High per capita income High participation of women in education Historically, middle to high participation of women in employment
Second Category	Countries from the dissolution of the USSR, including China, Vietnam, Cuba, etc. Also Denmark and Cyprus.	Erstwhile socialist countries of Eastern Europe, Asia, and elsewhere; Nordic and Levant region countries High participation of women in education Historically, very high participation of women in employment
Third Category	Various countries of Asia, Latin America, and Africa, many of which are former colonies of European countries: India, Bangladesh, Pakistan, Sri Lanka, South Africa, Malaysia, Ethiopia, Argentina, Costa Rica, Peru, Nicaragua, and Brazil.	Developing countries as per current World Bank classification, but at different levels of economic development at present Historically, low women's participation in education Historically, low participation of women in employment
Fourth Category	Tunisia, United Arab Emirates, Qatar, Ethiopia, etc. Also, Turkey and Cyprus.	Countries of the Middle East and Northern Africa region, and the Levant region Variation in per capita income from middle-low to very high Variable participation of women in education Very low participation of women in employment due to many cultural and political restrictions, and sociocultural constraints

Source: Classified by the authors.

THEORETICAL FRAMEWORK

An ever-growing body of research exists on women and their advancement in higher education, yet relatively little research considers women engineers. The classical explanation for the low representation of women in education and employment is the traditional differentiation between production and reproduction. Globally, women carry the burden of household responsibilities, and in most countries paid employment outside the home is considered a secondary responsibility to them (UN, 2010). They may, therefore, leave their secondary responsibility any time to focus on their role as a homemaker, and this may hamper the overall performance of women's economic activity. Below, we outline the four reasons given for the lower participation of women in engineering.

The Image of Engineering

Engineering is a profession that is generally related to machines, with perceptions, sometimes based in reality, that it involves hard, tough, physically demanding, and dirty work. This influences the image of engineering as masculine. This perception can, for example, be contrasted with medicine and healthcare sectors, in which professionals require equally high levels of technical skill and knowledge, and where handling patients may require as much physical activity and discomfort, but which has a traditionally feminine image. Initially, engineering started with two distinct branches—military engineering and civil engineering—and although the boundaries between the two were porous, their history and links to the military still have an impact on perceptions (Kumar, Sengupta, & Kumar, 2003). Additionally, perceptions of engineering and access to engineering roles are not helped as, in many countries, there are at least some job roles that are prohibited to women—many of which are closely related to engineering (Werft, 2017).

Gendered Organisation

In much of the literature on the subject, an organisational structure is discussed in terms of a managerial culture in which the leader represents a hero figure at the top of a power hierarchy (Baldridge, Curtis, Ecker, & Riley, 1977/2000)—a hierarchy that was, and remains, male-dominated (Acker, 1990). The field's entire structure holds women back. The implications of such a masculinist organisational culture are most directly felt by women, since the determinant culture governs the criteria for the distribution of rewards and the availability of advancement opportunities. For instance, women tend to be clustered in entry level positions and are rewarded for loyalty and supporting roles whereas men tend to enter positions that foster opportunities through exposure, visibility, information, and connections (Meyerson & Fletcher, 2000; Longman, Daniels, Lamm Bray, & Liddell, 2018).

Glass Ceiling and Sticky Floors

A "glass ceiling"—a term coined in the 1980s—presents an invisible barrier that restricts an otherwise qualified person from advancing within a given organisation or in the job market more generally (see Carnes, Morrissey, & Geller, 2008; Falk & Grizard, 2005). The most tangible evidence of a glass ceiling is unequal pay for comparable work (Booth, Francesconi, & Frank, 2003). A study conducted by the American Association of University Women (AAUW, 2007) found that, one year after graduation from college, women were earning 5% less than men. Ten years from graduation the gap had increased to 12%. The AAUW explained the gap as a clear example of gender discrimination. Yet an explanation for the glass ceiling phenomenon remains elusive. Some studies have examined the impact of very specific factors on women's advancement, such as the role of mentoring (Anderson, 2005). In her analysis of women entrepreneurs who left corporate careers to start their own businesses, Mattis (2004) foregrounded the lack of role models and mentoring as one of several factors associated with the corporate glass ceiling. Morongiu and Ekehammar (1999), in their study of the influence of individual/personal and situational/external factors on the career advancement of women and men, found that masculinity is positively linked to (and the major predictive factor of) managerial advancement. Indeed, many women do not ascend high enough to even reach the glass ceiling. Rather, they become stuck to the "sticky floor" where they get fewer chances to advance, or even enter, a career path in engineering (or another profession; Alberici, 2018; Iverson, 2011; LaCosse, Sekaquaptewa, & Bennett, 2016).

Self-perception for Unpaid Care Work

The capability (or potential to provide "freedom") of paid work is given centre stage in Amartya Sen's (2000) framework of development as freedom. His contention is that paid jobs help women become financially independent from their husbands and fathers, and to make their own choices in the consumer and financial markets. Sen adds that the freedom that accompanies paid labour brings important benefits for women, such as self-esteem, dignity, and autonomy (Sen, 2000). However, in all likelihood, women would be overburdened with a double workday and that may be one reason why girls from many countries are not opting for an engineering profession, which is seen as very time-intensive.

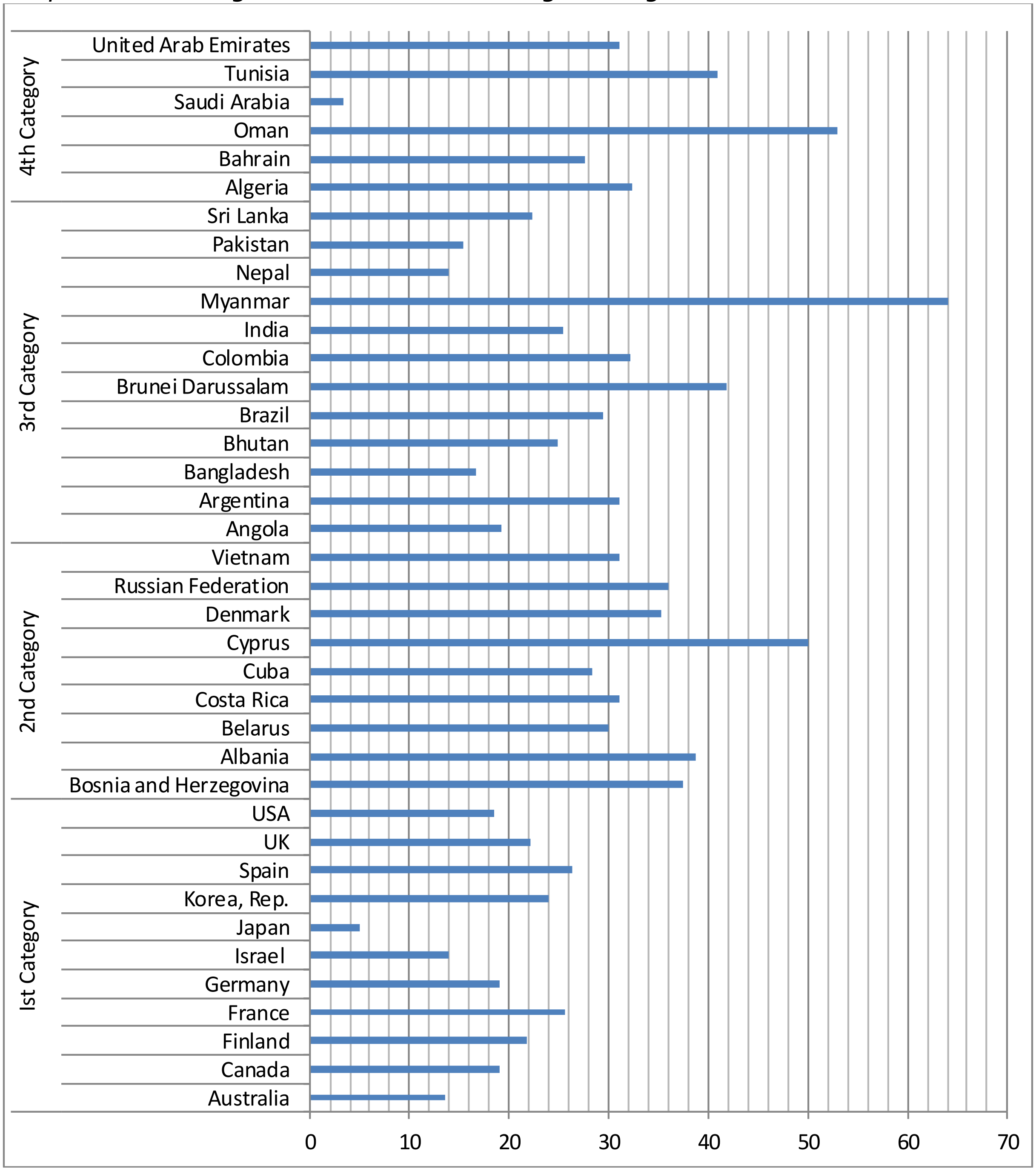
WOMEN IN THE ENGINEERING LABOUR MARKET

There exists a complex array of socioeconomic factors that affect the participation of women in engineering and hence, the participation of women in engineering is not the same throughout the world. In the proceeding, factors from both the supply and demand sides of the equation are discussed for all four country categories.

Supply: Factors Affecting Women's Participation in Engineering Education

Prevailing perceptions of engineering have an impact on participation and this is true across the world, as shown in Graph 1. Amongst the first category of countries (Table 1), the participation of women in engineering ranges between 10% to 20% of the engineering labour force, with variations between different specialisations or branches of engineering. A notable exception in this regard is Japan, which has only 5% participation of women in engineering as shown in Graph 1.

Graph 1. Percentage share of women in engineering education.



Source: UNESCO Science Report (UNESCO, 2015);[3] for India (UGC, 2014); and for Pakistan (PCST, 2018).

In the United Kingdom, according to collated statistics by Peers (2018), even though the proportion of women pursuing a higher education degree has increased from 40% in 1980 to 56% in 2018, only 16.2% of first degrees in engineering and technology went to women (HESA, 2018). It is important to note that between 2012–2013 and 2016–2017, participation and achievement rates in UK universities have remained almost constant, hovering around 15% with occasional slight increases. The figures do, however, vary across branches: the branches with the highest and lowest level of women obtaining their first degree were chemical engineering (27.5%) and mechanical engineering (9%) respectively in the year 2015 (HESA, 2018). Although the overall participation figures are the lowest in Europe, the situation is only marginally better in other Western European countries (Peers, 2018).

In the United States, according to the Society of Women Engineers (SWE), the participation rate in university-level engineering education is currently around 21% (SWE, 2018). In fact, women's enrolment in engineering in the last 10 years has at times dipped (see Figures 2–11 in NSB, 2018). Most mothers are working and daughters have seen their mothers shouldering the bulk of the domestic responsibility without much scope for domestic help (Kan & Gershuny, 2010). Girls understand the social demands of their time and consequently do not wish to opt for a very demanding profession such as engineering (Kan & Gershuny, 2010). The situation is more or less the same in Australia and only little better in Canada (Engineers Australia, 2017; Engineers Canada, 2017; see Table 2).

Table 2. First degrees achieved in engineering and technology by women, 2012–2017.

	2012	2013	2014	2015	2016	2017
United States of America	18.4	18.9	19.1	19.9	20.8	21.3
Australia	12.4	14.3	11.9	13.4	12.4	NA
Canada	NA	18	18.5	18.5	18.9	19.7

Sources: Yoder (2017, p.15); Engineers Australia (2017); Engineers Canada (2017).

When considering the countries in the second category, the importance of skill formation and the significance of technical skills has long been realised in socialist countries and has resulted in a high level of participation of women in all sectors, particularly in engineering (Barabanova, Sanger, Ziyatdinova, Sokolova, & Ivanov, 2013). Although the levels of women in engineering is now dropping in these countries, they remain at much higher levels than may be found in any of the other groups of countries. For example, in the former Soviet Union, women made up 60% of engineers, however, in recent times this has dropped to 40% in Russia—a trend that continues downwards (Barabanova et al., 2013). This category of countries is not considered further in this paper: the situation of women in engineering in these countries would require a careful explanation of the social changes arising from political developments and would require much more space than this paper can provide.

In the third category, tertiary education amongst women has traditionally been low. However, in more recent years, increasing levels of education of mothers (Choudhury, 2015), easily available and cheap domestic help, and the high prestige as well as high returns associated with an engineering education (Singh & Fenton, 2014) has encouraged women to take up the field.[24] In India, and as described by Singh & Fenton (2014), the number of women in engineering was as low as 3.8% in 1980–1981 and rose to 7.6% in the year 1990–1991. The increase beyond 1990–1991 is marked; indeed, during the first decade of globalisation (1991–1992 to 2000–2001), the number of women in engineering grew almost threefold, rising still further to 28.5% in 2016–2017. There are similar upward trends in other countries of the SAARC region (Singh, 2018).[5] Despite access to increased opportunities, women engineers have often complained about discrimination (Parikh & Sukhatme, 2004; Singh, 2014).

Elsewhere, there are many developing countries where the participation of women in engineering remains low. For example, in Ethiopia, the percentage of women in engineering education was only 17.64% in the year 2011 (GoE, 2011).

In Latin America, whilst there are mixed cultural and socioeconomic issues creating barriers for women, there is an accompanying rapidly growing appetite to create change. The figures are within the ranges quoted in Graph 1, so for example in Nicaragua, women make up around 30% of engineering students. The issues in South America are fairly common throughout the region and include social pressures on women, the status of engineering, educational barriers for women, and perceptions of what is considered "suitable" for women (Communidad Mujer, 2017; Gutierrez, 2018).

As the governments of the Arab region—countries in the fourth category—are implementing a policy of moving towards knowledge-based economies, the status of engineers and of technical engineering education continues to hold high social respect in these countries, reportedly higher than either the United States or the United Kingdom ("Emirati women engineering bright future at robotics institute," 2015; Engineering UK, 2018). As can be seen from Graph 1, in the countries of the Middle East and North Africa (MENA), women's participation in engineering education is quite high. In Algeria, 41% of college graduates in science, technology, engineering, and mathematics (STEM) fields are female (Khazan, 2018). When countries with a majority Muslim population are compared, the countries of the Middle East and North Africa have a relatively high proportion of women in engineering education (Tunisia had 42% in 2013) compared to Bangladesh (16.6% in 2012). However, as can be observed in Graph 1, there are significant variations in this category. For example, in Cyprus and Turkey—both countries in the Levant region—the percentage of women in engineering education is almost 50% and around 25% respectively. Notably, Saudi Arabia has an extremely low participation rate.

To sum up, low rates of participation of women in engineering education may be due to the following factors:

- Issues of social prestige: The low social prestige associated with engineering education results in low participation of women in engineering in the United States and the United Kingdom. Conversely, the very high prestige associated with such an education in developing countries enhances the participation of women.

- Traditionally low participation, due to low investment in human capital amongst developing countries.
- Engineering is associated with a "for boys" mindset.
- Low education of mothers affecting the decision-making process coupled with an absence of suitable role models available to their children.

Demand: Factors Affecting Women's Participation in Engineering Employment

Whilst women engineers from the countries within the first category exhibit high levels of labour force participation, as discussed in the previous section, the engineering profession is very low on their preference list. Of those who do graduate in engineering, many do not go on to join the profession, and of those who do join, many leave as a consequence of the barriers they encounter. The SWE (2018) finds that only 11% of engineers in the United States are women. Some of this can be attributed to embedded biases, which become clear when blind recruiting and promoting of engineers is trialled (Alberici, 2018). Additionally, part of the reason for women's low participation rests with the choices women make. A study conducted in the United States by Fouad, Singh, Fitzpatrick, and Liu (2012) of over 5,300 women who had graduated with an engineering degree found that 38% of them left the engineering profession. Out of those who left, 30% gave their reason for leaving as either the organisational climate, a non-supportive supervisor, or a generally insensitive environment. The need for frequent travel, a lack of opportunities for career advancement, and poor salaries were the reasons given by at least half of the respondents. Tellingly, two-thirds of those who left have since taken up management or executive level posts in other fields. Only 25% of those who left opted to stay at home to take care of the family (Fouad et al., 2012).

Similar issues have been highlighted in the United Kingdom with the so-called "leaky pipeline." A survey conducted in 2014 showed that women reported a general lack of support and flexibility in their workplace (WES, 2014). In the United Kingdom, in 2015–2016, the proportion of women with engineering degrees that did not work in an engineering role (41.4%) was greater than that of men (35.2%; Peers, 2018). For similar reasons, in Australia there was a high percentage of women who left the profession (Matchett, 2011). In fact, there appears to be a downward trend in Australia: the percentage of women engineers was almost 12% with a four-year degree course in 2015, but 15% in 2000 (Singh & Fenton, 2014).

As discussed above, in the United Kingdom and the United States, the engineering profession is not well regarded, even though engineers enjoy very good prospects in the labour market. This is especially true for technical-level engineering roles (e.g., operators and technicians) where technical/low-status roles are very masculine. For example, in the United States, women make up only 1%–4% of the total in technical trades (US DoL, 2012). Similarly, in the United Kingdom, women in technical-level (i.e., beyond compulsory education, but below graduate levels) educational programmes are similarly masculinised (Peers, 2018). In contrast, some Western European countries benefit from the perception of engineering as a professional "white collar" role and this has some influence on the greater proportion of women engineers in countries such as France, Spain, and Italy (UNESCO, 2017).

When considering the countries in the second category, women's participation in the engineering workforce is nearly 30% in Latvia and Bulgaria (Kiss, 2013). In China, 40% of engineers are women, and in the former Soviet Union, women accounted for 58% of the engineering workforce (Barabanova et al., 2013). However, with the collapse of the Soviet Union and its industrial model, the situation reversed, as women were the first to be fired (Barabanova et al., 2013). In 1998, women accounted for 43.3% of engineers, whilst in 2002, that number had fallen to only 40.9%, and the numbers continue to decline (Warton University, 2010).

In India—a country in the third category—the number of women dwindles as one moves up the hierarchal ladder (Wij, Rao, & Rao, 2010). In this category of countries, the reasons for leaving become a complex mix of forces. The literature shows that gender stereotypes are deeply embedded in the work place. In general, the image of the ideal worker in a given organisation is associated with stereotypical masculine characteristics such as independence and assertiveness, and equates to a male unencumbered by familial responsibilities (Acker, 1990; Brumley, 2014; Collinson & Hearn, 1996). Furthermore, sociocultural beliefs and stereotypes form the basis of gendered practices in such organisations (Acker, 2006; Ridgeway, 2009) and cultural differences lead to differences in stereotypes across national contexts (Steinmetz, de Vries, & Tijdens, 2014). In India, a reasonably good salary, independence, and social respect are some of the attractions of a career in engineering. Parents of young women are also encouraged by the recognised growth of opportunities, the quota/target policies of universities and increase in women joining the engineering labour market subsequent to the enhanced participation in engineering education (Singh & Fenton, 2014). There is little gendered difference between high- and low-status engineering occupations: both are similarly masculinised. Amongst degree holders and diploma holders, women constitute a low percentage in the respective engineering labour markets (NTMIS, 2006). Furthermore, their numbers dwindle as one moves upward towards more senior or leadership roles (Padmanabhan, 2011).

Among other SAARC countries, historically, Sri Lanka fairs better than India in the context of general education, however, India's performance is better than Sri Lanka if only engineering is considered (Chaudhary & Singh, 2015; Menezes, 2018; Parera, 2017). In Pakistan, only 4% of professional engineers are women (PCST, 2018). In the Asian countries, the social status of engineers varies; for example, their status is lower in the Republic of Korea than in India (Singh & Fenton, 2014).

The findings of a survey of 112 women engineers in Istanbul, Turkey—a country in the fourth category—discusses the existence of three barriers: the existence of a male-dominated organisational culture; a general lack of job satisfaction; and the work-family conflict (Çaha & Turgunali, 2016). Together these forces restrict women from entering and/or remaining in engineering occupations (LaCosse, et al., 2016). The work culture in industry alone can contribute to create a formidable glass ceiling for women with families, in effect forcing them to confine themselves to middle management levels and preventing them from reaching their true career potential (Küskü et al., 2007).

Even in the Nordic labour market, where in general there is high gender equality and a substantial awareness of such issues as noted in a report by the OECD (2018), there is a great deal of sex segregation in engineering occupations, both horizontally and vertically. Not only do men predominate, but men are also more likely to occupy the higher status and better paid roles compared to women (Anker, Meelkas, & Korten, 2003). A review by Muelders, Plasman, Rigo and O'Dorchai (2010) confirms the existence of striking horizontal and vertical gender segregation in the science and engineering labour markets across Europe, noting that segregation has in places increased in recent years. However, some commentaries note the situation changing with the ever-increasing use of ICT (UN, 2005).

Another significant issue is the pay differential faced by women in all professions, including engineering. Indeed, the gender gap in starting salaries amongst UK engineering and technology graduates widens as the level under study increases, such that the largest gender gap in starting salaries is observed amongst research postgraduates. Among research postgraduates, men have a mean starting salary that is 8.4% higher than that of women (Engineering UK, 2018). Yet there are also some "silver linings" in some parts of the world. For example, according to gender equality data published by the Australian Bureau of Statistics (ABS, 2018), for the first time, female engineering graduates have a slightly higher salary than their male counterparts—a factor which some suggest may result in lower dropout rates.

The factors outlined above can be summarised as follows:

- The "leaky pipeline," which causes women to drop out of engineering at each and every stage from education to technical leadership, is evident in all countries. However, there are differences, not only in the levels at which the most acute dropout occurs, but also the reasons for that dropout.
- Woman engineers face discrimination in both employment and earnings, with discrimination in earnings being generally the more pronounced of the two.
- Difficulties in work-life balance, frequent travel, a lack of flexibility, a lack of advancement opportunities, and low salaries are some of the reasons why women engineers migrate from engineering.

AFFIRMATIVE ACTIONS AND CASE STUDIES

Stakeholders worldwide have mainly understood the need for action to overcome shortages and skills gaps in the engineering labour force. This is reported by many countries and also by global recruiters (Hays, 2017). In many countries affirmative actions are in place to raise the participation of women in engineering as a way to tap into a larger pool of skills. To increase the effectiveness and impact of any affirmative action, it is crucial that actions are designed only after evaluating the specific factors impeding women's participation.

Education and Academia
In both secondary and university education sectors, programmes are being implemented in order to: increase the number of young women studying engineering; to widen participation; and to retain and advance women in academia.

Entry into engineering studies
There are examples of outreach programmes for school children in many countries, particularly the United States and the United Kingdom. Some of these programmes are run by regional industry groups in partnership with schools, whilst others are run by universities in association with organisations and other agencies. The following are a sample set of typical outreach activities:

- Lake Park High School in the United States hosts the "Breaking Boundaries" series for the DuPage County Workforce Development Division. The series is a career exploration initiative targeted at school districts and college-age women interested in learning about in-demand careers that are traditionally considered male-dominated. Working in collaboration with several of the area's manufacturers, engineers, and other local industries, Lake Park West Campus hosts this free programme that is open to all students, families, and the public (Panega, 2018).
- In England and Scotland, the Engineering Development Trust (EDT) has been running a variety of programmes for over 30 years, including summer schools, providing 40,000 STEM activities a year (EDT, 2019). The Inspire programme is intended for girls only—those aged 15–16, just before they make any final decisions of the subjects they wish to study up to the age of 18. The programme consists of a three-day course at a university, meeting role models from industry, and each year reaches over 400 girls (EDT, 2017).
- Also in the United Kingdom, Talent 2030 is a girls-only engineering competition. In 2018, nearly 750 girls took part (NCUB, 2019). Awards and demonstrations are given during the "Big Bang Fair": regional one- to three-day events with universities, companies setting up stalls, and demonstrations reaching over 70,000, mainly school children, but also parents and teachers (Big Bang Education, 2019).
- In a similar vein, Engineers Australia's Sydney division run a programme called "Experience It" for girls. All major technical universities in Sydney take part in the one-day event, setting up stalls and organising hands-on and fun-filled activities to familiarise girls with the world of engineering (Engineers Australia, 2017).
- In Spain, the Real Academia de Ingeniería (RAI – the Royal Academy of Engineering) runs TECHMI, a fairly typical outreach programme intended to introduce engineering to parents, teachers, and young people—particularly girls (RAI, 2018). TECHMI runs team-based projects with the interesting feature that it does not require that all participants be female, instead requiring that all teams taking part are made up of at least 50% girls.
- A short EU-funded project, Miss STEM, which ran from 2017 to 2018 in Northern Ireland, focussed on providing girls with a voice. The project supported girls, encouraging them to speak about their views and experiences of STEM to their teachers, politicians, and school heads (SWC,

2018). In informal communications with one of the authors, the project lead noted that the girls had raised issues that had not previously been understood by the adults around them, such as their personal experiences of the lack of inclusion in engineering and technology education.

- Aside from the activities noted above, in the United Kingdom, there are many other STEM and engineering outreach activities funded and run by a variety of organisations. STEM Ambassadors are volunteers who champion STEM and the wide range of STEM outreach activities in schools (STEM Learning, 2016). The plethora of activities and multiple engineering-specific programmes can be confusing (RAEng, 2016, pp. 4–5).
- One of the issues that arises in many countries is that the plethora of STEM outreach activities can be overwhelming and can actually work to obscure locations with no access to outreach. "Komm, Mach MINT" (which translates to "Come on, let's do STEM") is the national network initiative in Germany with the aim of inspiring and informing girls and women about STEM programmes and careers (Komm Mach MINT, 2011). It was promoted in 2008 as a national pact for women professionals with 46 partners, and now has more than 270 partners from industry, business, politicians, scientific research, education, social partners, the media, and associations. Its website (www.komm-mach-mint.de) provides a "one-stop-shop" to find programmes and identify gaps, and unusually the scheme includes, to-date, two evaluation studies to assess its effectiveness.

Whilst programmes such as those mentioned above do appear across the world, they are more prevalent in countries that appear in the first category. Some outreach programmes are specifically intended to widen participation and enable people, particularly women, from disadvantaged socioeconomic groups—to enable access to engineering and the skills needed for the roles in demand. In this area are those programmes that offer mentoring and coaching to support young women and to identify new opportunities. Some examples are:

- Coaching girls from poor households so that they can pass entrance tests. Anand Kumar coaches bright, economically disadvantaged students for the entrance test of the famous Indian Institute of Technology. As the entrance test is highly competitive, even high-achieving students undertake special (and costly) coaching ("Anand writes a super success story yet again," 2017).
- Opageste in Africa was set up to run STEM mentoring programmes for African girls, pairing girls with teachers with an interest in engineering and science. This programme has the interesting by-product that teachers are also motivated to teach STEM and engineering (Opageste, 2018).
- STEM Talent Girl, a large and growing programme running primarily in Spain, supports school girls aged 15–16 and older to continue in STEM by providing technical and engineering mentors from industry. The programme includes work shadowing and other short programmes. The programme is funded by industry partners and the women mentors are volunteers (STEM Talent Girl, 2018).

What is surprising about the many outreach and mentoring programmes for STEM is that it is rare to find robust evaluation studies or even reflection on the effectiveness of such actions. Additionally, the actions also have a tendency to be short-lived—perhaps indicating design faults in the programmes, making them unsustainable.

Curriculum and academics

The other areas in which educational organisations work to increase the participation of women are in the curriculum itself and in employment. Dartmouth College in the United States incorporated several actions aimed specifically to address the imbalance of women in their engineering programmes. All students are encouraged to take STEM courses irrespective of their chosen "major" and via this approach, more women are then able to progress to engineering. Women are attracted to the programmes by the offer of engineering taught around practical problems—particularly to invent or develop new solutions. In addition, humanitarian engineering modules were incorporated into the programmes to increase the awareness of the value of engineering to solve world problems. These actions, together with work to ensure inclusion within the curriculum, has led to over 50% of Dartmouth engineering graduates being women (Dartmouth University, 2016).

In the United Kingdom, the Athena Swan Charter scheme for higher education aims to recognise universities or individual departments committed to equality and diversity (ECU, 2014). The first phase of the scheme focussed on science, engineering, technology (SET) and later on STEMM (SET with mathematics and medicine) departments. The charter is awarded for putting in place cultural and systemic changes—such as policies and affirmative actions—that drive gender diversity and inclusion so that staff and students are able to participate fully and progress in STEMM. An evaluation study in 2014 concluded that the scheme was effective and "the visible representation of more women in key positions and senior roles was a widely reported positive change" (ECU, 2014, p. 10), although the scheme did not have such a positive impact on students—neither undergraduates nor postgraduates. However, it would appear that simply the fact that a university department examines its data, policies, and culture can lead to positive change.

These outcome-focused programmes are catalysts for change, encouraging higher education institutions, research institutes, and others to transform their internal cultures and make a real impact on the lives of staff and students. The Athena Swan scheme not only makes institutions look for ways to embed gender inclusion, but also enables the identification of effective affirmative actions (ECU, 2014). Anecdotally, Athena Swan was adopted far more readily when UK research councils started to include requirements to evidence progress towards diversity and inclusion for funding. This leads to the conclusion that such actions often require a business case before they become accepted.

Quotas and reserved places

Some countries allow universities to set admission quotas or reservations, or to offer women-only programmes. In India, the Indira Gandhi Institute of Technology (IGIT) under the Guru Gobind Singh Indraprastha University (GGSIPU) scheme continues its focus on providing more opportunities in engineering education for women, and the University Grants Commission (UGC, 2014) in the 12th Five Year Plan by the Indian government has upgraded IGIT to women's Technological University. In the Delhi Technological University (DTU) and PEC University of Technology, Chandigarh, places are reserved (one and two seats respectively) for girls in all branches of engineering. Again, 30% of places are reserved for women students in all engineering colleges of Maharashtra, and 33% in Madhya Pradesh and Rajasthan (Singh, 2012). For the academic year 2018–2019, 14% of seats were reserved for women candidates in each programme, in each Indian Institute of Technology, and in each class/category of seats. These reserved places increased from 14% in 2018 to 17% in 2019 and will continue to grow to 20% in 2020 (Gohain, 2017). Anecdotally, parents of young women are encouraged, not only by the recognised growth of opportunities, but also by the quota/reservation policies of the universities themselves.

In Scotland, the City of Glasgow College, a technical college, created programmes reserved for women only in mechanical engineering and construction to run in addition to the usual programmes. This could only be set up as a time-limited, five-year project, yet during this time it proved highly effective in increasing the number of women on their technical level programmes, which in the United Kingdom have even lower shares of women compared to university programmes (Peakin, 2017). The overall proportion of women on their engineering programmes was reported to have reached 12% compared to only 2%–4% pre-intervention, although it is important to also note that there were some negative impacts, in that parents of young men required assurance that their sons were not losing out (Morrison, 2018).

Governmental educational and women in STEM policies

The level to which governments set policy on gender and engineering in education varies widely across countries. One of the authors is involved in an initial project in Uruguay by the state department for education to develop an integrated plan for school programmes across the country in order to increase the proportions of girls and young women participating in STEM, particularly in the technical and engineering programmes. This is a live project, which is part of a much larger EU-funded programme EUROsociAL (2018) and therefore not yet reported on.

In the United Kingdom, the Scottish government has clear STEM and gender policies supported by the department for education, Education Scotland; and the department for workforce skills, Skills Development Scotland (SDS; Scottish Government, 2017). The remit of the SDS is to include apprenticeships, careers guidance, and planning for workforce skills, with a particular emphasis on engineering and STEM as a recognised skills gap for Scotland. Since 2015, SDS and Education Scotland have been implementing the programme "Improving the Gender Balance" for skills and work, which is now embedded in education policy in order to ensure that gender issues in STEM, and engineering in particular, are tackled all the way through the education and training system (SDS, 2018).

Integrated and coherent governmental approaches aimed at embedding gender diversity as a requirement across education with the further aim of reducing the gender imbalance in STEM are unusual. In most countries, efforts have a tendency to be rather piecemeal and driven primarily by individuals, industry, or NGOs. However, there have been recent and welcome announcements by governments and policymakers in the first category of countries of sizeable investments to improve STEM equity, with a focus on entry and education: In the United Kingdom, £5.5 million in 2018 for research into the issues and a further £2.4 million for girls into computing ("£5.5m for equality, diversity and inclusion," 2019; Heathman, 2019). More impressively, the Australian government has pledged $3.4 million to accompany a 10-year plan specifically for women in STEM (AusMIST, 2019a, 2019b). It is hoped more governments will adopt such approaches.

Corporations and Industry

In an era of stiff competition, industry has also realised the business value of women engineers, as evidenced in recent hiring policies specifically targeting women. In many countries (and for many companies) a significant factor behind the hiring of women is merely that of a lack of skills. However, increasingly, employers are becoming more aware of the role of diversity in increasing innovation and even productivity. Women bring a different perspective to the workplace and their presence can have a long-term positive impact on a company's performance (Hunt, Layton, & Prince, 2015).

Examples include two giants in the automotive sector, Maruti and Yamaha, both of which are hiring more women mechanical engineers—both for better productivity, and their aesthetic input into design (Biswas, 2012). In the United Kingdom, HS2—a large consortium to build new railway infrastructure, creating 25,000 jobs mainly in engineering—has implemented an innovative recruitment process (Lomas, 2017). Instead of the standard UK approach of CVs or resumes matched against job descriptions, HS2 uses a "blind audition" process. The process entails the removal of any identifying factors, plus asking applicants to carry out tasks associated with the competences required. This approach has proved to be extremely successful and the proportion of women recruited into technical roles at HS2 has increased from 17% to 47% (Lomas, 2017). The overwhelming narrative here is thus one of "fixing the system" rather than "fixing the women."

Engineering firms are coming forward to accommodate the preferred work-life balance of women engineers. For example, Shell, a global corporation, highlights its policies on flexible working, maternity leave, and programmes to ensure women remain in the oil and gas sector (Shell, 2018). Microsoft has a re-employment programme for women engineers who have taken a break from their regular career (Singh, 2012). Organisations such as Women Returners and STEM Returners in the United Kingdom have run successful returner and transferrer (i.e., transferring from one sector or role to another, often more technical) programmes, for a variety of engineering and tech employers (Women Returners, 2015). By running programmes for multiple employers, lessons can be shared, and sometimes employers and managers can be educated to understand where the issues lie. These programmes increase retention and reduce some of the leaks in the middle of the so-called "leaky pipeline."

The Women First Council is a new chapter in India-based corporation HCL Technologies' "employee first" philosophy. It is a council providing an organised platform from which to address the needs of women employees and to empower its members to make a difference in their lives and those of their women colleagues. Many of the firms involved are organising seminars for their staff aimed at gender sensitising—i.e., increasing awareness of the gender gaps. Other companies and organisations in India, such as the United Group for Consulting, All India Council for Technical Education (AICTE) and the Department of Science and Technology (DST), also have several programmes for women scientists and engineers who are currently unemployed or underemployed to hone their R&D skills (Singh, 2012).

Some actions are related to raising the profile of women in STEM as a way to promote STEM and provide role models. The L'Oréal-UNESCO Women in Science Awards annually awards a sizeable grant to advance their research to five female postdoctoral scientists, one per continent. This is part of a larger scheme of over 50 national and regional programmes offering fellowships to support such scholars in their research (UNESCO, 2019a). Until 2019 this programme focussed on the natural sciences, but this year it has extended the programme to include mathematics and computer science. This has meant that some of the regional awardees have come from the engineering world (UNESCO, 2019b).

Finally, what about governmental policies on gender and the engineering labour market? In general, it is unusual to find governments that set policies to drive gender diversity in engineering industries. It is often left to employers to identify the business case for diversity, although laws often help to finally embed cultural change when needed. The investments in gender and STEM mentioned above in the United Kingdom and Australia do include some aspects of making the business case clearer to industry ("£5.5m for equality, diversity and inclusion," 2018; Australia MIST, 2019a, 2019b; Heathman, 2019). These are very welcome advances.

Engineering Organisations and Societies

There are many national and local women in STEM societies and groups, some mentioned above, providing a variety of programmes and services: supportive networks for women who might otherwise feel isolated; information on coaching or mentoring services; and awards to raise the profile of otherwise "hidden women." One of the most powerful roles for these groups is to provide a voice for women by advocating equity of opportunity—both within education and in the labour market. In this way, not only do they influence policies in industry, government, and education, but they also champion diversity in innovation and thus build a better future.

Engineering organisations often include committees dedicated to women. Two such examples are the World Federation of Engineering Organisations (WFEO; www.wfeo.org) and the Institution of Engineering & Technology (IET; www.theiet.org) in the United Kingdom. These groups generally seek to influence internal policies and are valuable in terms of holding organisations to account. The International Network of Women Engineers and Scientists (INWES; www.inwes.org)—a global network of networks across four continents—is another example of an organisation supporting the full and effective participation of women and girls in all aspects of STEM. A crucial role of these organisations should be to gather data and share knowledge. However, it is often noted that there are many gaps in the available data on women in the engineering labour market, as noted in the *Telling SAGA* report, discussing the data held by professional engineering institutions and describing scattered data for women in STEM careers (UNESCO, 2018, p. 73, p. 104). This is also evidenced by the UN (2010) data, providing much detail on women researchers in STEM, but little in relation to women in the engineering industries. Furthermore, knowledge sharing can be inefficient, not least as many programmes are replicated without any awareness that they have already been carried out elsewhere.

ANALYSIS AND RECOMMENDATIONS

Women engineers in all countries join the labour market at the lower levels of professional engineering, but their numbers diminish as they progress up the hierarchical ladder. This is the so-called "leaky pipeline." Significantly, exactly where the largest leaks are, varies according to the category of the countries concerned.

There is often the assumption that women have the most access to engineering education and the engineering labour market in the most developed countries, included in category 1. Yet, clearly, this is not the case. It is also clear that there are countries in other categories pursuing much more aggressive affirmative actions than those in the first category—e.g., the quotas and reservations at Indian universities. Whether current programmes of quotas/targets actually work is a moot point (for example, on quotas for women on company boards, see "Are gender quotas needed?," 2015), however, the message is clear: engineering is open to women. Most actions in category 1 countries such as the United States, the United Kingdom, and Australia are focussed on sensitising and attracting young girls and women to fix those leaks at the start of the pipeline, namely, at school or university. Of course, it is never wrong to encourage education and outreach activities, but the lack of data to evidence effectiveness is surprising. It may be that effectiveness comes from policies aligned to practical programmes or, in other words, via "joined-up thinking." Programmes should thus seek, not only to support women as individuals, but more importantly, to drive cultural change or inclusion so that women feel that their place in engineering is valued and respected.

Programmes targeting the young need to consider how to extend the contact and how to guarantee sustainability in order to ensure there is a long-lasting effect. Much more thought needs to be put into longitudinal evaluations of any action to assess its effectiveness, and to learn what works and what does not. Unsurprisingly, the actions carried out by employers to increase the recruitment and retention of women are often scrutinised for effectiveness, and metrics and measures are often quoted. One point that has emerged strongly from this initial global comparison is that in order to enhance the effectiveness of affirmative programmes, socioeconomic and socio-political factors must be taken into consideration. What might work in the United Kingdom, might not work in India.

One of the roles of INWES is to provide a common platform for women and those who support their objectives, in order to share knowledge and programmes. Our aim here has been to start to identify the socioeconomic drivers in different countries that lead to different rates of participation of women in engineering, and also to explore the wide range of affirmative actions. The intention is to build up a library of case studies of affirmative actions and some indication of where and why they may work. What is clear from the initial survey is that much more work is needed, particularly on methods of evaluation for programmes to encourage girls to take up engineering, as well as with regard to the sharing of information. This paper is just a starting point to open those discussions with those working to increase gender equity in STEM around the world.

ENDNOTES

[1] The authors are members of the 2017-2020 Executive Board of INWES.
[2] Only post-secondary undergraduate engineering has been considered in the discussion.
[3] The UNESCO data for engineering include architecture, which in some countries, such as the United Kingdom, has a very high proportion of women. Thus, the figures in these graphs may vary from the figures quoted within the text.
[4] Undergraduate degree holders with only four years post-secondary education get a respected job with a high salary, which is not possible in any other profession.
[5] The South Asian Association for Regional Cooperation (SAARC) is the regional intergovernmental organisation comprising Afghanistan, Bangladesh, Bhutan, India, Nepal, the Maldives, Pakistan, and Sri Lanka.

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