

Women in Green Chemistry and Engineering: Agents of Change Toward the Achievement of a Sustainable Future

Cite This: *ACS Sustainable Chem. Eng.* 2022, 10, 2859–2862

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Defined in the 1990s as the “design of chemical products and processes that reduce or eliminate the use and generation of hazardous substances”, green chemistry, and the companion concept green engineering, currently represent important social, cultural, philosophical, and practical tools for achieving sustainability.¹ Both green and sustainable chemistry and engineering can broadly reach and interconnect different aspects of our society, and therefore, it is of utmost importance in addressing and tackling the 17 United Nations Sustainable Development Goals (UN SDGs) and their associated targets.^{2,3} To promote peace, protect our planet, and end poverty by 2030, the systemic change enabled by the holistic and inclusive perspective of green and sustainable chemistry and engineering is essential. Within this context, women and girls occupy a unique position: (1) They are disproportionately more impacted by the consequences of climate change and pollution.⁴ (2) They are excluded when comes time to build solutions, through the continued lack of gender equity in research, in innovation, and in power-holding positions. (3) They have been shown to be positive and ethical agents of change, whose exclusion may slow the inception of necessary sustainable solutions. Gender inequity is currently recognized as a prominent barrier to sustainable development; out of the 232 unique indicators toward the UN SDGs progress, 54 are classified as gender indicators.⁵ The UN SDG 5 (Gender Equality) is also acknowledged as central and will compromise the fulfillment of all other goals if not achieved.^{5,6} Women are important agents of change whose contributions in economic, social, and environmental systems are crucial for the achievement of a sustainable future (Figure 1). In this editorial, written on the occasion of the 2022 International Women’s Day, we want to make the case for how a more systematic integration of women within all aspects of green and sustainable chemistry and engineering is paramount to preserving and improving our planet.

Although the preeminent and inherent role of women in the pursuit of sustainability has been increasingly recognized, the current situation remains unbalanced, inconsistent, and inequitable. In the hazardous chemicals space, women are among the most vulnerable groups, as they are disproportionately impacted, exposed, and affected by toxic compounds.⁷ Furthermore, the effect of gender on toxicological effects of chemicals is often overlooked.⁸ The different susceptibility to the consequences of hazardous chemicals exposure could include types of chemicals, concentrations, and frequency and could be caused by family traditions, cultural norms, laws and regulations, physiology, and well-documented economic,

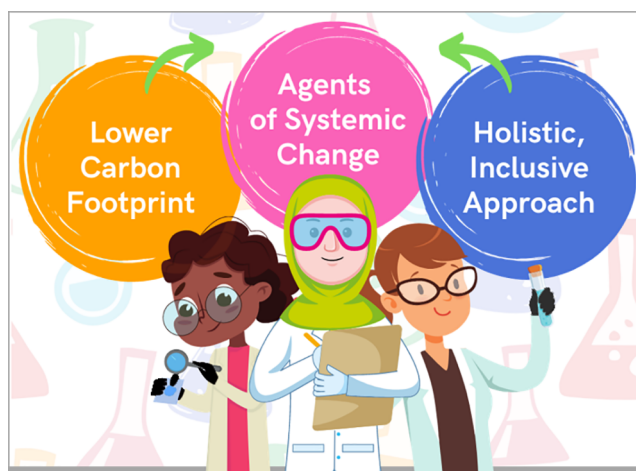


Figure 1. Through the inclusive approach of green chemistry and engineering, women in sustainable science are agents to lead the systemic change required to tackle the UN SDGs and achieve a sustainable future.

social, and occupational inequalities.⁹ Further vulnerability may occur during pregnancy, when exposure could be particularly harmful to both mother and fetus. While women are more affected by chemical exposure, so are they by the devastating effects of climate change, since the likelihood of women and children dying in natural disasters and extreme weather events is greater than men.¹⁰ Data acquired during Asian tsunamis, cyclone disasters in Bangladesh, and heat waves in Europe show that a significantly high percentage of victims (70%–90%) were women.¹¹

On the other hand, research and innovation in STEM plays a central role in being able to understand, mitigate, and address the effects of climate change, pollution, and unsustainable development.³ Yet women are still underrepresented in STEM at large. UNESCO reported that in 2017 females only accounted for 35% of students enrolled in STEM-related fields of study.¹² This disparity perpetuates and increases as women progress throughout the course of their studies,

Received: February 17, 2022

Published: March 7, 2022



transition to the job market, and even as they progress in their careers. Women are less represented than men in the STEM workforce meaning sizable STEM potentials go untapped if we consider a 49.58% world female population. In 2019 in the United States, they accounted for 34% of this workforce: an increase of 2% in 9 years, although they make up 48% of the population.¹³ A 2019 Canadian study highlighted that 10 years after graduating women are more likely than men to have quit their career in a STEM field.¹⁴ As STEM jobs are usually associated with a high pay grade, this situation was evoked to explain in part the gender gap seen in salaries. This gap was measured to be 77% globally in 2020 and 86% in the United States in 2021.^{14–16} In academia, the Royal Society of Chemistry and other organizations are investigating the barriers and biases that women experience in the chemical sciences.^{17–20} In their own study and those performed by others, it has been shown that women are underrepresented in all aspects of scientific publishing from authorship to editorial boards. Systemic barriers, such as these experienced by women in STEM, act to discourage participation and further reduces gender diversity across the scientific arena.

Another dimension of sustainable solution implementation is the need for strong and committed leadership, as climate change calls for political, economic, and societal actions. Underrepresentation of women in positions of influence has been well documented. Parity in the boardroom is often used as a measure of women's access to key power positions. Current data show that women hold 19.7% of board seats across 51 countries.²¹ Interestingly, this number has increased by 2.8% since 2018, suggesting parity could be achieved in 2045.²¹ Furthermore, companies with female leadership tend to undergo a faster growth of their parity in the boardroom, suggesting a catalytic effect at play and thus a path to trend acceleration.²¹ If we consider the American Chemical Society as an example, Anna J. Harrison was the first woman president (1978), and there have been 13 more women presidents since then with seven of these since 2010. This is a sign of positive change and possibly evidence that role models in such leadership positions can inspire others. Achieving parity in positions of influence is not only the right thing to do, an Organisation for Economic Co-operation and Development (OECD) study states that “When women do participate in governance, there is a greater chance that policies will reflect more closely the needs of all citizens”.¹⁰ Women play a structural role in our societies and as such contribute strongly to the use, conservation, and management of natural resources and environmentally friendly products. According to a report published by the OECD, women have more sustainable consumption patterns than men, and for those reasons, their carbon footprint and further impact in the environment is smaller.¹⁰ This assessment also shows that those high levels of environmental concern begin at an early stage, since girls as young as 15 present a greater sense of responsibility for sustainable development than boys.¹⁰ Therefore, an increased and equitable contribution of women in our society, especially through their contribution to research and innovation, is also fundamental for reducing our environmental impacts.


The importance of women in sustainability has been stated by the UN in 1992 during the Rio Declaration of Environment and Development: “Women have a vital role in environmental management and development. Their full participation is therefore essential to achieve a sustainable development”.²² However, 30 years later, while significant improvements were


measured, we still perpetuate gender inequity, resource scarcity, and poverty. Sustainability goals can only be achieved if the role of women in sustainable chemistry and engineering as the agents of this systemic change is fully recognized, acknowledged, strengthened, and drastically amplified.^{6,23} A comprehensive approach including all marginalized scientists is also needed for a truly systemic change. Addressing our current environmental challenges requires reducing all inequalities in STEM, not just gender-related ones, thus promoting the advocacy and support of scientists from all backgrounds and parts of the world.²⁴


Inspiring mentorship and sponsorship are also important aspects of this comprehensive change. Studies show that an influential mentor, sponsor, and “cheerleader” can strongly impact women's professional trajectories and be “the single biggest thing that supported their progression”.^{25–29} However, women in STEM programs receive less mentorship than their peers, and the absence of mentoring is a barrier associated with the difficulty of women in rising to the top of organizations.^{27,28} In general, women are also less likely than men to have sponsors.^{26,29} Having a “cheerleader” goes beyond feedback and advice; it can serve as a “catalyst” to accelerate women's careers and provide them with the correct networks.²⁸ It can also help all individuals to build “an identity so connected with science that does not undermine other distinct visible and invisible attributes or identity”.²⁷


Another long-standing obstacle for attracting women to research careers is the culture in many research institutions where it is perceived that long hours in the laboratory are required, which may not be compatible with family commitments. This is partly responsible for the large drop-out rates among postgraduate and postdoctoral levels.³⁰ However, things have started to change over recent years. Since 2019, the International Union of Pure and Applied Chemistry (IUPAC) has established the Global Women's Breakfast, a celebration of the accomplishments of women in science that hopes to inspire young generations to pursue a career in STEM.³¹ About 20,000 people participated in the 2021 edition of the event, which increased attention to diversity issues in more than 300 organizations around the world.³² Several journals have also dedicated their space to publish special issues highlighting the work and research of women in varied areas of chemistry.^{33–37} Other examples shining a light on the work of women in science are the social media campaigns #WomenOfGreenChemistry organized by the Green Chemistry Initiative at the University of Toronto and #WomenInChemistry promoted by Andy Brunning from Compound Interest.^{38,39} The practice of science and engineering is also undergoing a seismic change in recent years, moving toward a wider adoption of laboratory automation and digital technologies. This change could lead to a cultural shift and create a more level playing field, thus enabling women to remain active and engaged with R&D.⁴⁰ Gender roles and intergeneration dynamics have also been changing. In 2009, men accounted for 34% of the total family caregivers in the United States.⁴¹ Ten years later, this number increased to 40%.^{42,43} The normalization of men as professional and family caregivers is increasingly seen as an important aspect of achieving gender equity; it represents a transformation of undervalued jobs into respected work for people of all genders and a recognition by workplaces and public policies that all career paths should be open and available to everyone.^{41–45}

The path is still long, but hopefully our knowledge, capabilities, and constructive networks will continue to empower women in sustainable science to solve our current environmental challenges, address the UN SDGs, and achieve a sustainable future for us all. Collectively, we can follow the lead of the many women visionaries who have alerted us of the urgency to protect our planet, from Rachel Carlson to Wangari Maathai and Jane Goodall.¹⁵ On 2022 International Women's Day, we celebrate the achievement of all women in sustainable chemistry and engineering and raise awareness and call all for action to #BreakTheBias.⁴⁶


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