

Invited paper

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An overview of young chemists' expectations towards the sustainable development of the chemical sector. Opinions that matter

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Abstract: Young chemists play an important role in the transformation of the chemical sector in the next couple of years. They will have to do the heavy lifting and find the solutions needed for a sustainable tomorrow. Therefore, it is important to give them a voice in what their expectations are, how they believe they should be educated and prepared, and what opportunities they see for implementation levels in different areas to promote sustainable development. To shed light on these often under-represented opinions, young chemists across the globe were asked to express their views on the role and responsibilities of the chemical sector anonymously. The result is a snapshot of how young chemists perceive the future of chemistry and the immediate actions that need to be taken to get there. Throughout all answers, their hopes are expressed that the chemical sector will realize its great role and responsibility in leading and promoting sustainable development, thus limiting global warming, through cooperation with authorities, other sectors, and civil society. In this regard, young chemists do have numerous specific ideas about appropriate measures and are eager to take part in shaping a sustainable future.

Keywords: Chemical education; society; sustainability; sustainable development; young chemists; youth engagement.

Introduction

On September 25, 2015, the United Nations General Assembly adopted the Resolution 70/1 “*Transforming our world: the 2030-Agenda for Sustainable Development*” which defines, for the first time, a universally agreed set of objectives that not only address development but also its environmental aspects. The agenda aims to shape global development and prosperity in the environment, economy, and society in a sustainable way and announces 17 Sustainable Development Goals (SDGs, Fig. 1) and 169 targets. The ambitious resolution takes on (i) the fight against poverty, hunger, and inequalities, (ii) the protection of natural resources and the environment, the rule of law and democracy, peace, security, and justice, and (iii) a stronger focus on health, education, and responsible production and consumption [1].

Almost all of these require that chemists, chemical engineers, and the chemical sector in general take up a leading role in their achievement [2]. This is especially critical when it comes to the sustainable use and the preservation of resources: chemistry is an enabling industry for all other industry sectors, and innovation in chemistry can have a massive impact on the entire supply chain [3]. Chemical innovation can drive sustainable consumption and production patterns toward a circular economy, combat climate change, and assist in the realization of universal sustainable practices [4, 5]. However, it is important to point out that the benefits of

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Fig. 1: United Nations Sustainable Development Goals. [The United Nations (UN) have generously allowed us to use this infographic (<https://www.un.org/sustainabledevelopment/>). The content of this publication has not been approved by the United Nations and does not reflect the views of the United Nations or its officials or Member States].

chemical innovation today are often coupled with the consumption of vast quantities of nonrenewable resources, energy, and hazardous substances; thus, chemical innovation itself also needs to develop to fall in line with sustainable economic prosperity consistent with the UN agenda [3].

The development of the discipline in this sense is often described with the emerging concept of “Sustainable chemistry” which aims at achieving the benefits of chemical innovation without its trade-offs, thus protecting health and the environment. Sustainable chemistry is broader than green chemistry, yet the two are often conflated; it anchors ecological principles not only in the production of chemical products themselves but also in the product design of industrial and consumer products [6]. Reducing the use of hazardous substances from the onset will improve health and safety of workers and users alike. Sustainability-based chemical research and production offers broad opportunities for economic progress especially in developing countries and emerging economies [3, 7].

A clear framework for concrete action and many anchor points for the chemical sector to work on is set by UN Sustainable Development Goal 12 (SDG 12) “Ensure sustainable consumption and production patterns” [8]. When it comes to implementing SDG 12 and its sub-goals, the commitment of the chemical industry is the most demanded and expected one, as chemistry can offer many major solutions for emerging issues. Chemistry is ubiquitous and has a significant impact on lifestyle, health, and the environment, being at the core of everything. Issues that include plastic waste and packaging materials, solar energy conversion, air pollution, and many more will require intervention from the chemical sciences sector to move toward sustainable solutions [3].

It is important to realize that the youth and young people (up to 35 years) add value to discussions of future development, especially since they represent over 56 % of humanity (4.4 billion individuals in 2020) [9] and will have to be key contributors to today’s goals and decisions and live with the consequences. As access to schooling and further education increases [10], this population is the most educated population in human history and has a vested interest to add value to the sustainability discussion, making their voice an important perspective. Global movements around environmental and climate issues demonstrate the desire of young people to meaningfully contribute to public discussions, and this energy has carried over to young chemists.

Their expectations and opinions regarding the major changes needed to shape a long-lasting transformation of industry and society toward sustainability are an important factor in furthering sustainable chemistry. The now young generation of chemists are to be seen as the future inventors, decision makers, and lecturers of chemistry. Their voice should be heard when shaping the perception of sustainable chemistry and building the groundwork for their future.

As a result of the importance of youth participation in the dialogue, this work aims to give a voice to the younger generation through collaboration of multiple organizations that deal with chemistry and society.¹ Chemistry students and young professionals worldwide were approached and asked to express their opinions in a questionnaire (Fig. 2, Note a). Questions as to how young people perceive the chemical sector, its role, and responsibility with respect to the economy, environment, education, and overall society were posed. The outcome of said questionnaire is a snapshot reflecting the critical opinion of young students and professionals with a strong focus and high expectations on a sector which still has a controversial image [11–14]. This paper entails a vision for the chemical industry depicted by young people from Europe, Morocco, Nepal, the Philippines, Taiwan, South Africa, Nigeria, Singapore, Ecuador, Argentina, Canada, Malaysia, Brazil, India, Bangladesh, and the United States of America (Note a).

The following questions were posed:

- (A) What are your expectations toward the role and responsibility of the chemical sector?
- (B) What kind of products and processes are needed to shape a sustainable future?
- (C) What needs to be changed in chemical science and education?
- (D) How can politics and industry support the realization of the expectations of the younger generation?

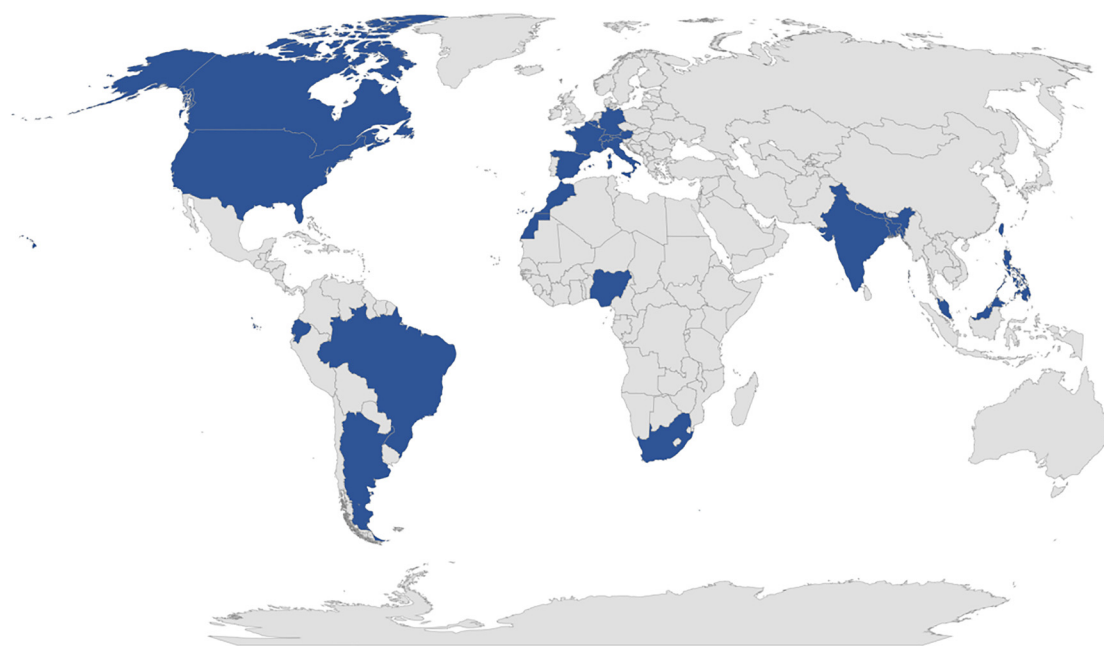


Fig. 2: International participation. Countries indicated by the participants are highlighted in blue (Note b). 61 respondents from 22 countries: Germany (16), Philippines (12), France (7), Belgium (3), Singapore (2), Austria (2), Italy (2), Nigeria (2), Morocco (2), South Africa (1), Spain (1), Nepal (1), Canada (1), USA (1), Switzerland (1), Malaysia (1), Argentina (1), Ecuador (1), Brazil (1), Taiwan (1), India (1), Bangladesh (1).

¹ International Younger Chemists Network (IYCN) associated with the International Union of Pure and Applied Chemistry (IUPAC), European Young Chemists' Network (EYCN) of the European Chemical Society (EuChemS), JungChemikerForum (JCF) of the German Chemical Society (GDCh), International Sustainable Chemistry Collaborative Centre (ISC₃), Bundesministerium für Umwelt, Naturschutz und nukleare Sicherheit (BMU), Umweltbundesamt (UBA).

Results and discussion

Important note: The following discussion references the original responses as categorized and listed in the Supplementary Material by using round brackets (...). These references are composed of letters (A–D) which refer to each individual question mentioned above and numbers (1–61) which refer to the consecutively numbered replies sorted alphabetically by country as indicated by the participants. In many cases, the original wording was used; however, this is not explicitly pointed out to maintain good legibility. External references are indicated by Arabic numerals in square brackets [1], and comments are given in brackets as (Note a–c), respectively. A directory is given at the end of the document.

What are your expectations toward the role and responsibility of the chemical sector?

The driving force of the future of the industry is a strong commitment to SDG 12

The chemical industry should take the lead^(A12) in advancing sustainable development, not least of all due to the massive influence of chemicals on almost all other industrial sectors. The chemical sector needs to recognize its role as a forerunner in fostering sustainable development. It also needs to self-regulate and demand high transparency to ensure that innovation goes hand in hand with responsibility, prevention, and care. Self-supervision^(A60) and transparency^(A58) are key to pursue true sustainable solutions rather than “green washing” for marketing purposes.

Moving from linearity to circularity

To minimize the risks of environmental pollution and public health concerns and to increase resource efficiency, the industry needs to change from a linear to circular business model.^(A29) A clear commitment to sustainability strategies based on and going beyond the 12 principles of green chemistry is mandatory [15]. Green and sustainable chemistry must become the norm rather than the novelty.^(A43) Advanced recycling systems allow the separation of complex materials for further use,^(A9) which entails less waste and recovers high-added value materials. A circular approach to chemicals and product management will ensure accessibility of limited resources in the future.

Cooperation with authorities – setting a global policy framework for sustainable development

Close cooperation of global players with national and international environmental authorities plays a leading role in defining and realizing the policy framework^(A58) necessary for sustainable development. Well-defined guidelines and regulations contribute to the development of appropriate systems for the management of chemicals and waste where these are non-existent or inefficient. The expertise of the chemical sector^(A59) often supports both the authority and civil society in mainstreaming such policies. Regular information exchange with, e.g., scientific societies, environmental organizations, and politics brings trust and transparency to the processes.

Cooperation with other sectors – promoting sustainable development beyond chemistry

Leading stronger synergies with other sectors and investment in renewable, green, and sustainable technologies will reduce society's dependence on limited resources. Taking the initiative will also have a positive influence on their advancement in the context of the SDGs^(A21) and reduce their carbon footprint.^(A32)

Cooperation with civil society – fostering trust and promoting a positive image for chemistry

Economic profit can go hand in hand with a moral and ethical commitment of industry toward society and the environment.^(D7) Taking responsibility for past legacies, being transparent in communication, and establishing good practices strengthen the willingness to collaborate between industry and civil society.^(A7) In developing upcoming projects, a dialogue with local community members is of value for the understanding of expectations and requirements as well as for fostering sustainable solutions and public trust. Active civil participation and the communication of an honest sense of urgency can promote awareness, engagement, and trust.^(D17) Bringing citizens into close dialogues with leaders of chemical companies would serve as an important signal and encouragement to other fields to follow the lead (relating to Section “Cooperation with other sectors – promoting sustainable development beyond chemistry”). The cooperation between industry and civil society would tackle four main issues at once: (1) re-positioning of the citizens at the center of (political) decisions, strengthening the sense of responsibility of the community; (2) restoring of the name of the chemical sector [11–14]^(B15); (3) motivating citizens to collaborate with industry; and (4) giving industry the support of the civil society and enabling it to be more agile and transparent.^(B15) This openness toward people and communities would contribute to building a new image of a sector which should strive to become a pollution-free, high-tech industry and a role model for a more sustainable yet successful sector within industry.

Summarizing the answers regarding the role and expectations toward the chemical sector, there is a clear emphasis on the strong commitment that is expected to be shown toward sustainability and the SDGs. Building and supporting a circular economy and being transparent in its work are important factors in regaining not only the public's trust toward the industry, but also the young generation's trust, that is, the upcoming workforce. See Fig. 3 for key aspects.

What kinds of products and processes are needed to shape a sustainable future?

Reuse, repurpose, recycle – ensuring the future of resources

A key principle that must be followed to achieve a sustainable future is the efficient use of limited resources and targeting a circular, zero-waste economy,^(B35) as mentioned in Section “Moving from linearity to circularity”. With

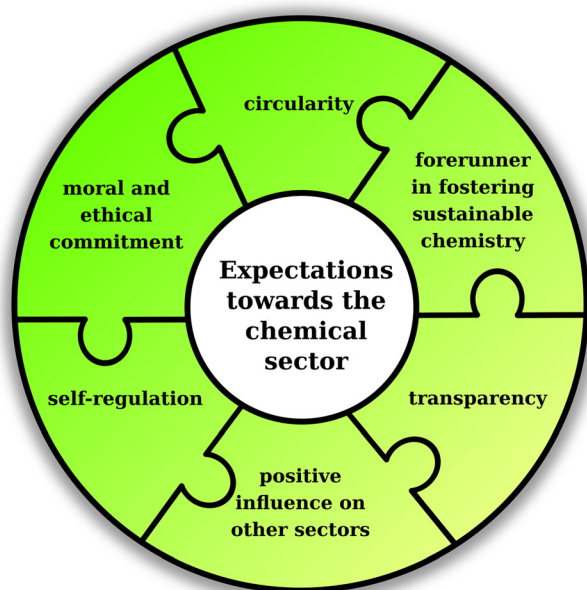


Fig. 3: Expectations towards the chemical sector. A summary of key aspects in the answers of Question A: What are your expectations towards the role and responsibility of the chemical sector?

a growing population, resources are becoming scarce, making it critical to pay attention to the efficiency of recycling processes and the reuse and repurposing of products and materials. More durable products may result in longer, more efficient use and less waste while biodegradable options help reduce hazardous waste and garbage dumps.^(B35) Instead of increasing production volume, industry should become a partner to customers, increasing the lifetime of materials by means of repair and consulting (see Section “From mass production to tailor-made solutions – securing growth in a changing society”).

Roughly one third of the respondents to this question explicitly mention recyclability as a key aspect for future products, more implied it (See Supplementary Material Section B for more detail). While biodegradable, reusable, and more durable products are the future, recycling processes need to evolve as well: Smart recycling processes must be capable of separating complex substances, reducing them to feedstock and reassembling them again. Single material alternatives to complex, multi-layered packaging products will aid in easy separation while enhancing the quality and value of recycled materials for further use. In line with a circular approach, valuable limited resources such as coal, oil, and gas should be used as carbon sources for organic synthesis rather than energy production. Any remaining carbon dioxide emissions should be concentrated and purified to enable treatment, binding, and redirection as additional carbon resources.^(B5)

Sustainable packaging materials – tackling an everyday issue for sustainability

Young chemists strongly desire sustainable packaging already on the market to be scaled up and further developed.^(B11,23,36,43,54,55) A ban of single-use plastic products (Note c) such as plastic straws and plastic bags can help change mindsets and perspectives and promote sustainable alternatives. This can encourage more sustainable lifestyles and reduce carbon dioxide emissions and plastic waste effectively.^(D59) Industry should create solutions for compostable, water-soluble, or reusable packaging, and if the bulk material of a product is not directly recyclable, companies should promote the product's disposal into specific trash bins in places which are easily accessible^(B36) and policy makers should use incentives like container-deposit legislation for returning, e.g., plastic bottles for recycling [16]. In this way, products can be properly disposed of or recycled.

Biobased and modular solutions for a zero-waste economy

To shape a sustainable future, we need a zero-waste approach using biobased materials with triggered degradation,^(B35) products with a predicted life cycle,^(B9) or modular products^(B7) composed of interchangeable or replaceable elements. The goal should be the production and use of safer,^(B39) less pollutant chemicals^(B41) and substances that are easier to treat and recover.^(B58) Life cycles of products should not depend on the life cycle of one component; interchangeable or replaceable parts^(B7) may help in extending the lifetime of a single product and result in less waste. Policies should support this approach for efficient resource use and avert planned obsolescence. Research should focus on the best and quickest ways to produce green and sustainable chemicals and biofuels from renewable resources, biodegradable plastics, sustainable building and energy-storage materials, carbon-based materials that can replace metals, and highly efficient drugs.^(B11,24) What is also needed are efficient assessment systems and tools that can evaluate the toxicity of new products and to develop a recycling plan before companies put them on the market.^(B60)

Nature-based solutions

Another important topic for the survey respondents is a genuine respect toward nature.^(A45) A code of conduct for chemists and professionals would be helpful to respond to an understanding of the impact of good and bad chemical practices on nature and to minimize environmental impact (compare to Section “Teaching sustainable ethical principles with the same relevance as personal and laboratory safety”). To start, research should concentrate more efforts on organic or biobased products that are naturally biodegradable or compostable by specialized synthetic biological organisms.^(B29) Plant-derived materials can act as alternatives to plastic materials.^(B45) Biology can also be an inspiration for highly efficient synthetic production: enzymatic

biocatalysis and biotransformation reactions are excellent examples for nature-based solutions with high economic, public, and environmental value to address the UN SDGs [17, 18]. Transferring such principles to the production of basic chemicals would greatly reduce cost, waste, and energy consumption.

Energy-efficient production – securing the future while cutting production costs

First, the chemical sector is a very energy-intensive industry [19, 20]. Research should focus on energy efficient production by utilizing the tools of electrochemistry, photochemistry,^(A14) and catalysis to optimize synthetic approaches.^(B35) At the same time, investments in process engineering and the use of renewables as primary energy sources^(A32) are crucial to achieve a holistic change toward sustainable, efficient production. Ideally, we need to optimize products in such a way that smaller volumes are required^(B20) (compare Section “Energy-efficient production – securing the future while cutting production costs”) and establish mild production processes and develop technologies that enable a quicker, more efficient recycling for added value of consumed products (compare Section “Reuse, repurpose, recycle – ensuring the future of resources”).^(B57) Second, the chemical sector plays a key role in the development of new and sustainable technologies to revolutionize the energy industry and civil society. Therefore, the chemical industry should lead and promote the development of materials for (1) high-capacity power storage;^(B28) (2) efficient and durable technologies to harness natural, sustainable energy sources;^(B24) and (3) low-energy consuming (organic) electronics.^(B28) A high investment in both areas will be necessary but targeted investments will secure the future of the industry, while more efficient procedures and patented solutions will benefit revenues in the long term.

From mass production to tailor-made solutions – securing growth in a changing society

An important consideration to bear in mind in sustainable development is that mass production will decrease while adopting more sustainable solutions: recycling, reusing, and repairing are not a significant part of our current lifestyle. Our consumption pattern is mostly linear: we buy, use, and discard. A change toward a more sustainable consumer behavior implies a more circular product use and thus a reduced demand. Additionally, a wider variety of products may arise as individual options gain popularity, some examples being environmentally friendly eco-responsible products, products that use sustainable packaging, vegan or vegetarian alternatives, and reusable and regional products with a low carbon footprint. The chemical industry should consider moving toward more tailor-made solutions specifically designed for circular use, zero waste, and smaller volumes or tonnage^(B20) (e.g., chemical leasing [21]). Through smaller production volumes, the use of resources and waste can be reduced significantly. Offering tailor-made solutions can enable the growth of chemistry as a service sector. This can positively contribute to the development of new segments within the chemical industry.

Overall, the expectations for products shaping a sustainable future are quite clear. A truly circular economy is expected, fueled by sustainable innovation, tailor-made solutions, and energy efficiency among others (See Fig. 4 for key aspects). If the topics mentioned are mapped according to world regions, different topical focuses have been highlighted. Young people from Asia and Africa mentioned more often topics such as reduced use of hazardous substances, sustainable energy, and clean water, innovations for the provision of basic needs and socially equitable products that are accessible to all. Young people from Europe and the Americas more frequently specified topics related to advanced technologies such as robotic and mimic simulations, nanomedical devices, digitalization processes, etc.

What needs to be changed in chemical science and education?

Teaching sustainable ethical principles with the same relevance as personal and laboratory safety

Among the main changes regarding teaching chemical sciences requested by young people, the introduction of environmental and sustainable chemistry in education reaches the highest ranks on the priorities of

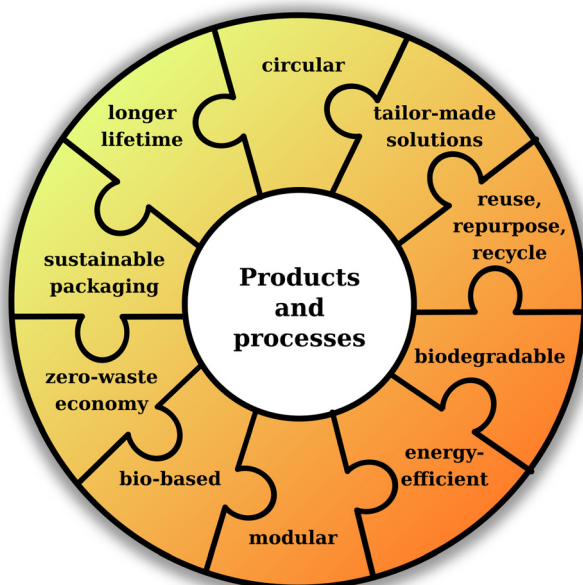


Fig. 4: Products and processes. A summary of key aspects in the answers of Question B: What kind of products and processes are needed to shape a sustainable future?

chemistry students mentioned in the survey.^(C5,10,11,17,20,21,22,23,24,27,35,36,43,59,51) Both should be part of chemical education as much as the handling of hazardous substances and laboratory safety.^(C20) Awareness of the impact of chemicals and chemical practices on the environment should become a prominent part of the basic chemistry curriculum.^(C5,43) This ensures the appropriate understanding of the scope and implications of environmental issues, product life cycles, and applied mass conservation in the different world regions.

Preparing young chemists to find the solutions the world needs

Fostering subjects such as green and sustainable chemistry (including toxicology and photo- and electro-chemistry) in teaching laboratories and introducing new research approaches will help increase the use of these technologies. Universities should incorporate subjects such as molecular design, treatment and recycling, impact of chemicals, relevant legislation and regulations, toxicology, etc. into the undergraduate curriculum.^(C3,9,11,17,27,32,43,50,58) The duty of demonstrating how young chemists can approach environmental issues and what to consider in the design of new products and synthetic pathways falls to them.^(C32) Currently, many young chemists do not feel prepared to contribute to sustainability strategies of companies after their higher education due to a lack of education in the field [22].^(C21) Complex, modern problems require interdisciplinary approaches and current education systems need to be updated to meet the requirements of the 21st century rather than the industrial age [23].

Laying the groundwork in school – painting a positive image of chemistry in an interactive way

If a sustainable change in the mindset is to occur, chemical education should start much earlier in school.^(C19,35) Early awareness of what chemistry is and how it relates to societal questions that impact our lives and future can increase in the interest and appreciation, and reduce the “fear of chemical names”.^(C3,60) Chemistry is generally still perceived as an intimidating subject and a dirty profession, and the rise of sustainability awareness could catalyze change and foster a higher interest in the chemical profession if it is communicated as an innovation driver for clean and efficient solutions.^(C36)

Nowadays knowledge is available to almost everyone via the internet. Students observe that chemistry could and should be taught in an interactive way by using methods such as modeling software, artificial reality, or detective-like questionnaires for, e.g., chemical analysis and organic synthesis reactivities.^(C15,39,57) It

should be taught with a “servant-leadership approach” [24] where students develop ideas under the guidance of a teacher as practically as possible.^(C45) This would improve the field’s attractiveness as well as the long-term memory and comprehension of complex notions by students.^(C50) Students need visionary teachers with convictions and a strong message to guide them.^(C15) Modern didactic approaches utilizing new media should, therefore, become part of the education of chemistry teachers.

The role of the chemical industry in education

Even in the education field, industry has been identified as an agent of change. A stronger participation in educational activities needs to be a priority; sponsoring scholarships, training programs, and providing well-equipped laboratories for young chemists in developing countries would help create a stronger generation of chemists better prepared to tackle the challenges of their own countries.^(C6,32,42) Also, the intensification of international research networks between universities and businesses could have positive implications when facing international challenges such as plastic waste or COVID-19.^(C7,33) Industry needs to realize their important role in education and build upon it.

Young chemists unanimously expressed a heart-felt desire for being well-prepared for the future and the “real world” through hands-on training, more practical classes, applied teaching in their field of study, and interdisciplinary studies addressing the implications of chemistry on society, politics, and economics. This is particularly important for students from Africa and Asia who strongly wish to apply their expertise on the ground by actively bringing their knowledge directly into their own communities. See Fig. 5 for key aspects.

How can politics and industry support the realization of the expectations of the younger generation?

Supporting education and research to speed up sustainable solutions

Governments should put a strong focus on education worldwide. An inadequately educated society can never fix the issues we currently face and the longer that we delay, the more time is wasted.^(D7) Hence, policy makers should focus on this duty first. Moreover, governments should invest more in education and research^(D1) by increasing the grants available for sustainable innovation projects and the budget for sustainable R&D activities, by supporting

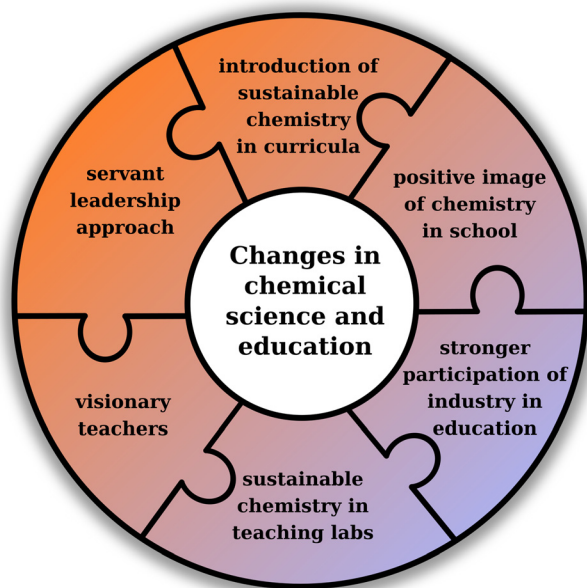


Fig. 5: Changes in chemical science and education. A summary of key aspects in the answer to Question C: What needs to be changed in chemical science and education?

multidisciplinary science-based projects, open-source science, and hackathons.^(D5,6,8,10,18,20,27,29,42,44,49) Green and sustainable chemistry-related research and the search for better solutions toward renewable energies should be increasingly supported, promoting them widely next to long-established research areas.^(D13,15,35) Funding for both academic and industrial research is crucial for the development of green and sustainable technologies.^(D29)

Introducing a regulatory framework that is pro planet and people with a focus on sustainability

A regulatory framework would provide incentives to industry to incorporate sustainable innovation solutions and impose international sanctions on companies that do not act sustainably.^(D18,21,32,36) Parallel action plans based on realistic timelines and science-related facts should be implemented and further developed.^(D7,28) To transform the linearity of whole industrial processes in a viable way (compare Section “Moving from linearity to circularity”), policy makers should work closely with experts from industry, academia, and non-profit scientific organizations to elaborate sustainability criteria for products, processes, and assessment systems for achievement of the SDGs (compare Sections “The driving force of the future of the industry is a strong commitment to SDG 12” and “Enhancing the communication of politics and science”).^(D20,21,22) Moreover, companies should be obligate to “internalize externalities,” meaning holding them accountable and responsible for the waste their products and packaging produces.^{(A33),(D33)} These criteria would serve as a basis for binding sustainability guidelines which companies would incorporate in their corporate policies.

Encouraging innovation for a circular economy

Big changes on short time scales involve risks for companies, though they are an absolute necessity to secure our future. To encourage the chemical sector to seek more sustainable solutions, governments could introduce a tax reduction or award system in the form of incentives or subsidies for companies converting their product lines into green and sustainable portfolios.^(D18,21,29,31,32,36,52) Regional funds for innovative companies and entrepreneurs and special training programs for start-ups working on solutions aimed at decarbonization and circularity are measures which can be easily implemented and minimize the risks for an economic transformation.^(D6,24,35,60) More innovation calls for more collaboration among companies, universities, consortia, and agencies, fueling progress in the sector.^(D42,44) Furthermore, governments should keep investing in industrial digitalization.^(D28)

Ensuring honest commitment

Where there is money involved, there will always be those who seek ways to cut costs or gain personal benefits, often to the detriment of the mission.^(D7) An independent overseeing board or organization could help administer incentives and sanctions to avert wrongfully claimed funds that do not support the mission. This body could ensure correct funding allocation and investigate and punish intransparent greenwashing and corruption that is harmful for a truly sustainable transformation.^(D7)

Integrating civil society efforts in the decision-making process

To obtain long-lasting sustainable changes in consumer behavior, people should understand the significance of their role. If participation and engagement in local initiatives, especially by young chemists is included in the decision-making process, then local or national initiatives can be transformed into environmental programs with clear and concrete goals: e.g., the decrease in carbon dioxide emissions through sustainable transit or e-mobility, vertical gardens, new recycling strategies for recyclables, and waste management.^(D11,17) The public communication of state-of-the-art analysis and goals while making measurable efforts for the community is a good method to make people feel part of the solution.^(D35) This happens most in communities led politically by non-partisan leaders open to new ideas and ready to listen to the new generation.^(D22,47,60)

Enhancing the communication of politics and science

Since the complex issue of sustainable development requires good knowledge and understanding of the natural sciences, policy makers should significantly increase the number of scientific advisors to help develop the most promising strategies for a sustainable economic and societal transformation.^(D14,20,21,25,44,47,57,58,60)

Young people seem to have clear ideas about what politics should do (or should not do) to direct change positively toward sustainability (See Fig. 6 for key aspects). The prerequisite for any change in this direction is that governments make sustainability not only a priority but also a necessity – independent of political parties or election platforms. Sustainability should become part of their statements, missions, and, most importantly, actions. When it comes to fostering change, politicians have the power to stop or speed up processes and ignite changes in behavioral patterns. Politics can steer, fuel, and promote sustainable development by using targeted investments, subsidies, and sanctions. Industry should be motivated and supported by these political measures to drive innovative solutions and to educate employees to act sustainably and decouple growth from production volume (compare Section “From mass production to tailor-made solutions – securing growth in a changing society”). Young chemists name six main implementation levels paired with concrete actions while answering this question.

Conclusions

Global sustainability challenges have moved to the center of public awareness and the world has seen a tremendous increase in the number of commitments, as well as the level of ambition. Over recent years, sustainable innovation and awareness has grown remarkably, driven by increasing consumer demands, sustainability commitments by industry, and political guidelines and regulations. However, to address future challenges, we need a stronger commitment and a hand-in-hand action of civil society, industry, and governments.

Young chemists express their hopes that the chemical sector will realize its great role and responsibility in leading and promoting sustainable development. Being aware of the strong impact the chemical industry has on all other industries and, therefore, the great influence it has, young chemists see the opportunities to change for the better by building on four specific areas: science-based solutions, chemistry education, cooperation, and trust (Fig. 7). By leading the change, all other industries must follow, as chemistry and the chemical industry are at the very start of most product supply chains.

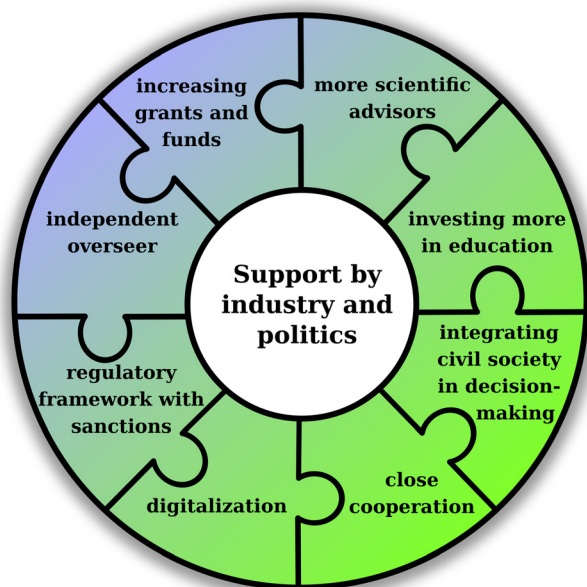


Fig. 6: Support by industry and politics. A summary of key aspects in the answers of Question D: How can politics and industry support the realization of the expectations of the younger generation?

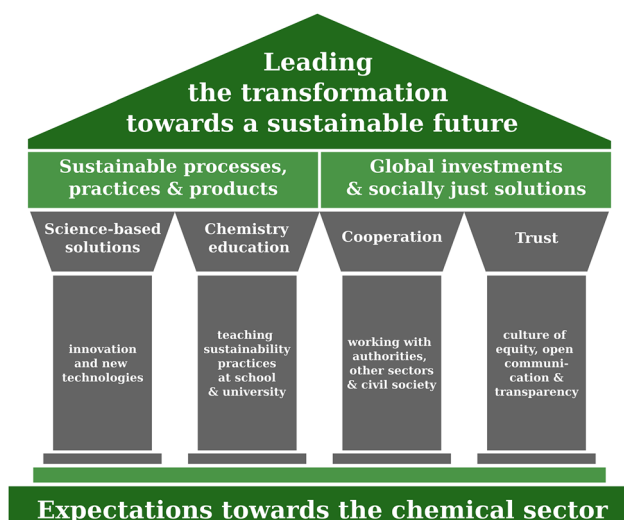


Fig. 7: Leading the transformation toward a sustainable future. Four pillars to build on as perceived by young chemists.

Through the cooperation of the chemical industry, authorities, other sectors, and civil society, the UN SDGs can be met in the coming years, hence limiting global warming and conserving our ecosystems and biodiversity alongside economic development. A culture of open communication, trust and transparency is believed to be crucial for this purpose. “Business as usual” is no longer possible as young people claim rightfully that we should be doing everything we can to realize a future where people live well and within the planetary boundaries. Numerous concrete strategies for raising sustainable products and processes, such as circular economy, biobased materials, or energy-efficient production, are desired to be implemented in the next few years, certainly by the end of the decade. Although young people are eager to take part in these processes, they feel insufficiently prepared to meet today’s challenges. Therefore, there is a strong demand for the implementation of sustainable chemistry practices and ethics into curricula at universities and schools, whereby industry could play a key role. Furthermore, as climate change and plastic waste are complex global problems, global solutions are also required, highlighting the importance of education, collaboration, and sustainability-controlled investments by authorities and industry. Solutions need to be effective, science-based, and driven by honest commitment toward a sustainable future.

There is a clear commitment by young chemists to help pave the way for a more sustainable chemistry in general, to work on solutions and foster change. Young chemists from the Americas and Europe put their hopes in AI, digitalization, and technical advancements, while young chemists from Asia and Africa see the biggest opportunities in decreasing the use of hazardous substances and providing safe, basic needs. Despite these geographic differences, young chemists in general expect to take part in shaping not only the chemical world toward a more sustainable one but also to follow the examples given by implementation now. This expectation is one that should be welcomed with open arms and supported by policy makers and companies alike.

Altogether, besides the significant technological advancements and innovation, young chemists see high value in collaboration, education, research, and a no-compromise policy to support and enforce sustainable development. The chemical sector should be responsible, lead by example, and act now.

Notes

- (a) This work aims to summarize the opinions of young chemists and does not necessarily reflect the views and opinions of the authors. Since this work contains the opinions of individuals and may overrepresent certain world regions and groups of higher socio-economic status, it is not to be taken out of context. All answers can be found in the Supplementary Material. See Supplementary Material for procedural comments.

- (b) Supported by Bing© GeoNames, Microsoft, Navinfo, TomTom, and Wikipedia.
- (c) It is important to keep in mind that the responses were given through an online form; therefore, this and other statements are coupled to a demographic with a socio-economic status that can probably afford more expensive alternatives. Moreover, this statement in particular is undifferentiated but probably means to exclude, e.g., biodegradable options in necessary areas and products with sanitary and medical purposes where no alternative exists (author opinion).

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