

# Integrating ‘The Triangle of Geography, Geology, and Geophysics’ into Sustainable Development

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## Abstract

In the context of tackling climate change in the eastern Mediterranean and the Middle East, HRH Prince El-Hassan bin Talal has called for an integrated approach to human and natural resources management that takes account of “the triangle of geography, geology, and geophysics”. The lack of application of geoscientific knowledge to sustainable development issues is surprising given that advancing human progress lies at the roots of modern geoscience and aligns with the intellectual mindsets and technical skills that geoscientists are trained in. Applying this Earth Science toolkit to the challenges of long-term sustainability will require the global geoscience community to repurpose its principles and practices. In particular: (1) better communicating what geoscientists know and do, and how that is socially useful; (2) reaching out to other disciplines more engaged in sustainability issues; and (3) re-designing Earth science education and training programs to place sustainability and human wellbeing at the heart of a 21<sup>st</sup>-century geoscientist’s professional purpose.

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**Keywords:** Geoscience; Sustainability; Sustainable Development Goals; Human wellbeing

## 1. Introduction

In his opening address to 2020: "Climate Change in the Eastern Mediterranean and the Middle East" Symposium organized by the Jordanian Atomic Energy Commission. HRH Prince El-Hassan bin Talal called for a strengthening of scientific and technological cooperation in the Middle East and the eastern Mediterranean basin to face the climate change challenge. As part of that strategic planning, Prince El Hassan stressed the importance of an integrated approach to human and natural resources management, considering the triangle of geography, geology, and geophysics.

It is welcome but rare to hear a global public figure highlight the critical role of geoscience in sustainable development. As acknowledged in Prince El Hassan’s remarks, the ‘3Gs’ of (physical) geography, geology and geophysics remain underrepresented concerning other disciplines in contributing knowledge and expertise to regional and global concerns over planetary health and human wellbeing (Mora 2013, Stewart & Gill 2017). This ‘invisibility’ of geoscience in sustainable development discourse is surprising because the social mission of human advancement exists deep in the historical roots of contemporary geoscience. Two centuries ago, distilled by socially progressive Enlightenment thinking, James Hutton (Hutton 1788) placed the ‘physiology’ of the planet at the heart of a new integrated and holistic Earth Science amid the technological birth of Britain’s industrial revolution. His seminal 1788 opus ‘Theory of the Earth’ opened with the remark: ‘This globe of the earth is a habitable world, and on its fitness for this purpose, our sense of wisdom in its formation must depend’ (Hutton 1788). The subsequent refinement of modern Earth Science has only served to

reinforce its intellectual credentials as a science that ‘looks forwards backward’ to advance human progress (Lucchesi 2017, Rajendran 2019).



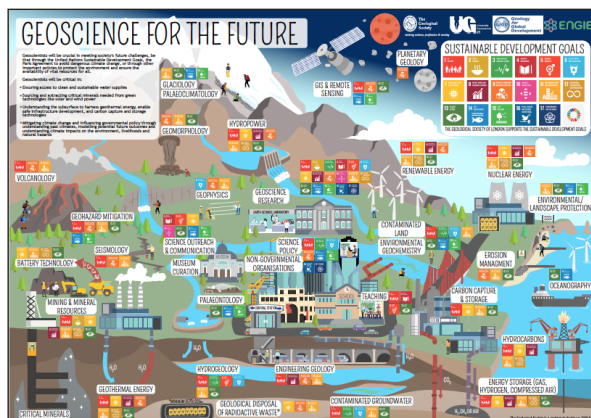
**Figure 1.** The 2015-2030 United Nations Sustainable Development Goals

This article sets out the contextual background to Prince El Hassan’s provocation and examines the contributions that geoscience and geoscientists might bring to the principles and practices of sustainable development. In doing that, it advances several key challenges that the geoscience community will need to address on the global sustainability agenda.

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## 2. The Challenges Ahead

Our planet, or more specifically those living on it, will face a gathering storm of ‘grand challenges in the 21<sup>st</sup> century. Those challenges arise from global socio-economic drivers of international trade, industrialization, and urbanization, as a growing human population consumes its natural resource base at an ever-accelerating pace and tackles a consequent climatic and ecological crisis that imperils humanity’s ultimate survival. Geoscience - the study of our planet’s 4.5-billion-year-old history, how it works, and what it means for those living on it – potentially offers important knowledge, experience, and guidance on how to confront many of these critical challenges (Schlosser & Pfirman 2012, Gill 2017, Stewart & Gill 2017) (Figure 1). Despite its traditional focus on looking backward into ‘deep time’, geological input now seems essential for forward-looking sustainable stewardship of the planet (Beer et al. 2018). Geoscientific expertise is needed for ensuring the material supply for the ‘energy transition’ to renewable technologies and supporting the wider ‘clean, green economy’ that major countries are moving towards. In addition, geoscientists can contribute important knowledge for responding to increasing water and food insecurity crises in regions suffering the effects of climate change, tackling the ecological ravages of habitat destruction and biodiversity loss, and reducing the risk of disasters in the world’s swelling urban centers (Figure 2).



**Figure 2.** A promotional poster from the Geological Society of London, available in multiple languages, highlighting the diversity of contributions that geoscientists can make to society.

The urgent imperative for Earth Science to help address society’s growing unsustainability gains deeper motivation from the perversity that humans themselves have become a dominant geological force, now sufficient in intensity to warrant our bespoke era: The Anthropocene (Steffen et al. 2011, Crutzen 2016, Zalasiewicz et al. 2019). Although the conceptual space for creating the modern Anthropocene was carved during the nineteenth-century foundation of geology (Davis 2011), geoscientific methods designed to unravel ‘deep time’ now track the environmental and ecological fallout from present-day human actions. The Huttonian science in which ‘the present is the key to the past’ now looks forwards to guiding planetary boundaries, earth system tipping points, and a safe operating space for humanity’ (Rockstrom et al. 2009). The fact that some of the cumulative impacts of our anthropogenic changes are now significant enough to be able

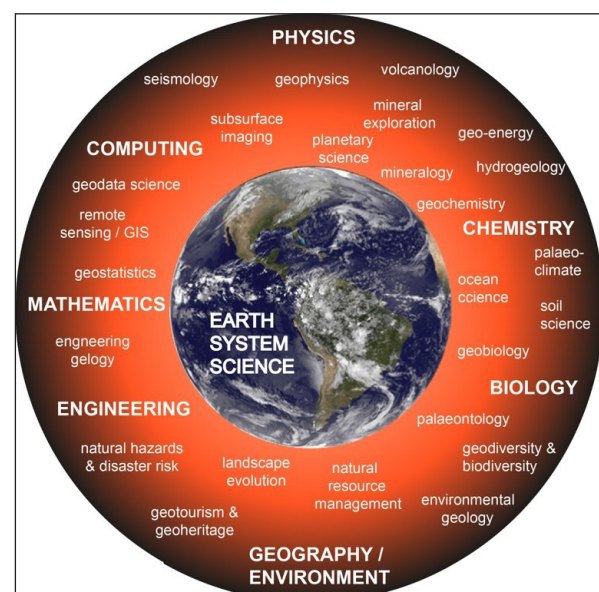
to be compared with natural analogs in the geological past (Burke et al. 2018) means that now, more than ever before, the central tenets of ‘palaeoscience’ bear directly on future society (Mills & Jones 2021).

Entering this new ‘human age’, geoscience’s direction of travel seems clear. Although ‘discovery science’ about our planet’s distant geological past will continue, ‘...Earth Sciences research needs to be more focused on problem-solving rather than refining our knowledge of the problems that face the Earth system’ (Ludden 2020, p.69). Traditional applied geological and geophysical fields (economic geology, petroleum geology, engineering geology, hydrogeology, and geohazards) will assume even greater importance, alongside the more geographical facets of climate science, land management, and disaster risk reduction. Increasingly, society will look to the geosciences not only for sustainably providing its resource demands (Lambert 2001) but for also resolving the impact of developmental projects on the environment, the severity of natural hazards, and human health. Even very basic geological and environmental knowledge can help transform resource-poor communities and tackle development barriers in many regions (Gill et al. 2019), and economic livelihoods can be improved directly through geo-heritage and geo-tourism, such as UNESCO Geo-parks (Catana & Brilha 2020).

In countless ways, sustainable stewardship of the planet will benefit from a more explicit acknowledgment of the critical importance of the natural world’s underpinning ‘geodiversity’ (Schrodt et al. 2019). So, with that mission in mind, what are the specific key skillsets and mindsets that geoscientists can bring to the global sustainability agenda?

## 3. The Sustainable Geoscience Toolkit

Geoscientists are Earth Scientists, meaning that their core concern is the fundamental working of the planet. They do that through a multidisciplinary science that integrates physics, chemistry, and biology, draws from engineering, computing, and mathematics, and spills over into the geographical and environmental sciences (Figure 3).



**Figure 3.** The multidisciplinary nature of geoscience, integrating physics, chemistry, and biology and drawing from engineering, mathematics, and geography

Blending and balancing these disparate disciplines develops high-level competency across a broad portfolio of technical specialists, notably:

- Geophysics – deploys a wide array of techniques that image inside the planet's depths and monitor the action of earthquakes (seismology) and volcanoes (volcanology).
- Geochemistry – where the tools and principles of chemistry are used to forensically characterize the materials, minerals, and rocks that make up our physical world (mineralogy and petrology).
- Geobiology - reveals the intimate relations between environments and ecosystems, past and present, and charts the evolution of life as preserved in the rock record (paleontology).
- Engineering geology - uses our understanding of soil and rock properties to solve practical problems for infrastructure and the built environment whilst hydrogeology examines the flow of groundwater in the subsurface.
- Geodata science uses probability and statistics to measure Earth variables over time and space, and high-level mathematical modeling and computation tools alongside Artificial Intelligence and Machine Learning to solve and visualize complex planetary problems.

In combining these disparate disciplines into a coherent model of planetary inquiry, geoscience manages to balance and blend a suite of complementary methodological mindsets (Frodeman 1995, Clelland 2001, Baker 2014). These are:

- Geoscience as an interpretative science: indirect, ambiguous, enigmatic, and subjective clues in the rock record or the deep subsurface need to be deciphered to shed light on Earth processes (Curtis 2012)
- Geoscience is an observational science: observations play a central role in geoscientists' reasoning and testing of new ideas and theories (Rogers 1989, Kastens et al. 2009)
- Geoscience is a historical science: observations of present-day phenomena and environments are used to infer conditions in the past (Frodeman 1995, Dodick & Orion 2003)
- Geoscience as a 'big data science: vast volumes of data have informed geological inquiry but the 'digital revolution' promises a new era of data-driven geoscientific discovery (Pennington et al. 2020, Stephenson et al. 2020, Wang et al 2020)
- Geoscience as systems science: recognizing the dynamic interconnections that maintain a habitable planet (Clark et al. 2004, Stillings 2006)

Geoscientists understand that the Earth is a system integrating the solid earth (lithosphere) and the other 'spheres' (atmos, hydro, cryo, and bio) and that feedback between these constituent parts is critical for sustainability (Clark et al. 2004). Earth systems are "complex" in the technical sense: exhibiting nonlinear interactions, multiple stable states, fractal and chaotic behavior, self-organized criticality, and non-Gaussian distributions of outputs. However, they

are also "complicated" in the ordinary sense of the word; multiple processes (mechanical, chemical, biological, and anthropogenic) may operate and interact at the same time and place. Although geoscientists are not the only scientists who work with complicated, complex systems, their ability and propensity to apply a systems approach to understanding the Earth across multiple scales is an important expertise that geoscientists offer society. As Gosselin et al. (2013) note, 'As a historical and interpretative science, geology can inform society about interactions in coupled human-environmental systems because our skills and proficiencies allow us to recognize the varying manifestations of phenomena at different spatial and temporal scales.

These intellectual and technical competencies are well known and accepted within the geoscience community (though much less so beyond), but arguably it is our lesser appreciated conceptual and creative thinking skills that may be the most valuable to sustainable development. As the pioneering petroleum geologist, Wallace Pratt pointed out decades ago "Where oil is first found, in the final analysis, is in the minds of men" (Pratt, 1952). The human mind is arguably the geoscientist's most important tool (Rajendran 2019). It is the geoscience mind that '...converts colors and textures of dirt, or blotches on a satellite image, or wiggles on a seismogram, into explanatory narratives about the formation and migration of oil, the rise, and fall of mountain ranges, the opening and closing of oceans' (Kastens et al. 2009, p.265).

Geoscientists also take a long view of time, appreciating the relative brevity of human history within the vastness of the age of the Earth (Orion 2006). This perspective is unusual: short time frames, of the order of days to years, drive most decisions in business, politics, and media news cycles. If widely adopted, geoscientists' more attenuated view of time might provide a crucial counterweight, and support decision making with a time horizon of decades to centuries. What's more, in their guise as time travelers, geoscientists can envision Earth in states drastically different from the planet that currently exists, a perceptive skill that in turn draws on other key conceptual skillsets (Manduca & Mowk 2006, Kastens 2009, and Kastens & Manduca 2012):

- Interdisciplinary problem-solving geoscientists solve problems in the context of an open and dynamic system of interacting parts and processes
- Managing uncertainty: geoscientists revel in incomplete data and subjectivity, probability and uncertainty are integral to all geoscience interpretations
- 3D & 4D thinking being able to visualize and solve problems in three dimensions and across time requires geoscientists to have considerable intellectual flexibility, imagination, and creativity (Reynolds 2012)
- Multi-scalar levels of inquiry: geoscientists span from the nanoscale to the planetary scale to understand how the Earthworks
- Geoscience reasoning and synthesis: geoscientists apply a very particular form of scientific reasoning,



recognizing that most geological problems have no clear, unambiguous answers and working by analogy and inference to make predictions with limited data (Frodeman 1995, 2014, Clelland 2001, Baker 2014)

- Working in the real-world 'laboratory': field-based learning helps geoscientists develop a feel for Earth processes and a sense of scale, and strengthens their ability to integrate messy, fragmentary information, reason spatially and temporally, and comment on the quality of observational data.

Although much modern geoscientific analysis is undertaken in the laboratory or imaged from space, 21<sup>st</sup>-century geoscience remains at its traditional core a field-based science. In undertaking reconnaissance geological mapping and geophysical exploration, geoscientists are often the first 'boots on the ground'. They are, therefore, generally the initial interface between their organizations and local neighborhoods and communities, and with securing the 'social license to operate a critical part of the publically contested infrastructure, minerals, and energy development projects, communication is an implicit geoscience skill (Stewart & Lewis 2017). Although generally a 'soft skill' in which they are rarely formally trained, geoscientists find themselves daily explaining their science to other technical specialists and other professionals, translating partial and obscure data and observations into coherent narratives that link past, present and future. In that regard, geoscientists are natural storytellers, routinely developing compelling narratives to explain our often-abstract ideas about the deep Earth or ancient worlds (Stewart & Nield 2013).

None of these technical, conceptual, and social skills, taken individually, is unique to geoscience. Nor does every individual geoscientist have every one of these skills or apply them in their work. Nevertheless, taken collectively, this combination of attributes provides a powerful toolkit for addressing the uncertain and untested problems of sustainable development. With that recognition, many national geological surveys are already reformulating their strategies around sustainable geosciences principles and practices (Smelror 2020, Ludden 2021). At the same time, the key professional sectors that geoscience serves are also rapidly adjusting, with the construction, minerals extraction, and energy sectors increasingly projecting themselves, their practices, and their people through the lens of sustainability and the Sustainable Development Goals framework (Capella et al. 2017, Calas et al. 2017, Mudd 2021) (Figure 4).

Whether geoscientists like it or not, a brave new world is rapidly coming. Yet, despite the signs that a new Earth sciences revolution is underway, the academic geoscience community in universities and research institutes around the world still appears to remain wedded to traditional 20<sup>th</sup>-century Earth science pedagogies and practices. So, what needs to change?

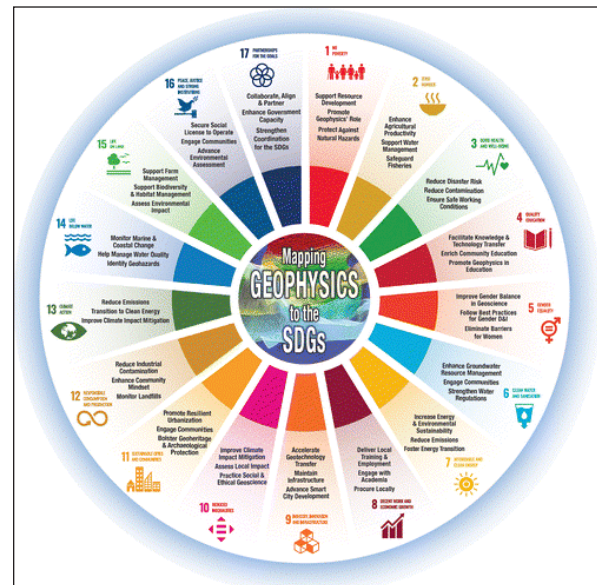


Figure 4. The Geophysics Sustainability Wheel (Capella et al. 2017)

#### 4. Looking Forward Backwards

The challenge from Prince El Hassan about how the triangle of geography, geology, and geophysics can be integrated effectively into national and regional sustainability agendas presents a critical question for modern geoscience. Currently, too few geoscientists have direct involvement in the growing societal shift towards achieving the 2030 UN Sustainable Development Goals (Schlosser & Pfirman 2012, Mora et al. 2013, and Stewart 2016). 'Sustainability' and 'sustainable development' are rarely featured in many universities' geoscience courses or professional geoscientific training, and the topic is largely absent from Earth science research in specialist journals or academic conferences (Stewart & Gill 2017). At the individual level, many geoscientists can (and do) make more contributions that are directly relevant to sustainable development. However, at the strategic level of the global geoscience community, three 'missions' seem paramount:

1. Geoscience needs to better communicate what it knows, what it does, and why it is useful.
2. Geoscience needs to reach out to other disciplines more engaged in sustainability issues
3. Geoscience needs to re-design its education and training programs to place sustainability and human wellbeing at the core of its professional purpose.

##### 4.1 The Communication Challenge

Outside of long-suffering wives, husbands, and partners, few non-geologists know what geoscience is. There is a general sense that geology is rocks ('stones') and fossils ('dinosaurs'), but the harsh reality is that beyond that ordinary people pay little attention to and have no interest in the wider Earth sciences realm (Stewart & Nield 2013). Therefore, if the average person in the street has little or no grasp of what a geologist is or does, then why should a local government official, business executive, or policy maker have any better idea?

Traditionally, there has been an academic disinterest and an institutional lack of incentive to encourage scientists to translate their technical science for non-technical audiences (Stewart & Lewis 2017). That, however, is no longer the case. More and more, national governments, through their funding agencies, are demanding public accountability for research funds, and the response has been a dramatic increase in university support for science communication training and academics taking part in associated public engagement and educational outreach activity. As part of that sector-wide academic mind-shift, geoscientists around the world are being expected not just to undertake geological investigations but to justify why their work is important and tell end-users what it means for them. It is a change that geoscientists should embrace because, as highlighted above, most are natural storytellers, and the subject of the Earth, its extraordinary history, and its present-day impact on those living on it provide a rich diet for popular science consumption (Stewart & Nield 2013). But 'selling planet earth' to the public and policymakers will require more than just strengthening our geoscience outreach activity, but rather will require the systemic embedding of the science (and art) of science communication into our graduate, postgraduate, and early-career training programs (Stewart & Hurth 2021).

#### 4.2 The Interdisciplinary Challenge

Addressing complex and contested sustainability issues demands integrated solutions from multiple disciplines. Although geoscience is already a multidisciplinary field of inquiry (Figure 5) wider cross-disciplinary collaborations are required. In the first comprehensive overview of geology for sustainable development, the Geological Survey of India stressed the need for geologists, geochemists, geophysicists, geomorphologists, and the like to work together in integrated projects with engineers and planners (GSI 2010). Such collaborations are now fairly commonplace, and there are encouraging signs of research partnerships with allied disciplines such as biology, zoology, ecology, agronomy, and environmental science, such as in the emerging

interdisciplinary field of 'critical zone science' (Anderson et al. 2010, Banwart et al. 2013, and Brantley et al. 2016). However, if the geoscience community is to meaningfully address global sustainability issues. Then even more ambitious and challenging collaborations will be needed, extending to the social sciences and humanities - human geography, anthropology, psychology, sociology, political science, and law - which are concerned with the human dimensions and societal institutions whose values underlie our currently unsustainable ways of living (Stewart 2016, Stewart & Gill 20217).



**Figure 5.** Each of the main technical specialisms within geoscience has applications to help tackle the challenges of sustainable development.

#### 4.3 The Education Challenge

Geoscience's emboldened interdisciplinary inquiry will need to be rooted in teaching and learning that emphasizes the interactions of geological, biological, chemical, and physical processes and environments, in combination with their social, economic, political, and cultural dimensions – the realm of 'sustainability science' (Gosselin et al. 2020). By more directly addressing the formidable challenges of global unsustainability, traditional geoscience has the potential to be revitalized, at a time when recruitment to university geology and earth science courses around the world is struggling. The promise is of a refreshed discipline – 'human geoscience' (Himiyama et al. 2020) – that is a better fit for purpose in managing the pressing social and environmental concerns of sustainable development (Gill & Smith 2021).

Group Definitions				Geological Sciences										Notes	
Earth Materials, Processes & Management		Understanding of 'Earth Materials, Processes & Management' is important to one or more targets/means of implementation relating to the given SDG.	Colour	Earth Materials, Processes & Management								Skills & Practice		Abbreviated SDG titles from Global Goals (2015). Full SDGs from United Nations (2015a).  * (Abbreviated) Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.  * Education and Capacity Building are important to some degree within every goal.  [a] Promoting equality of opportunities to all (including access to geoscience education). Eliminating all forms of violence and discrimination against women and girls in public and private spheres.  [b] Supporting research and development.  [c] Promoting equality of opportunity, and ending discrimination.  [d] Shared responsibility to improve sustainable practice, particularly in the private sector.  [e] Increased international cooperation on marine protection and research.  [f] Transparency of payments and contracts, helping to fight corruption.	
Skills & Practice		Sharing of and/or changes to geological 'skills and Practices' is important to one or more targets/means of implementation relating to the given SDG.	Grey	Agrogeology	Climate Change	Energy	Engineering Geology	Geohazards	Geohazards & Geotourism	Hydrogeology & Contaminant Geology	Minerals & Rock Materials	Education*	Capacity building*		Miscellaneous
Sustainable Development Goals (SDGs)	1	No Poverty	End poverty in all its forms everywhere.												
	2	No Hunger	End hunger, achieve food security and improved nutrition, and promote sustainable agriculture.												
	3	Good Health	Ensure healthy lives and promote well-being for all at all ages.												
	4	Quality Education	Ensure inclusive and equitable quality education and promote life-long learning opportunities for all.												
	5	Gender Equality	Achieve gender equality and empower all women and girls.											[a]	Miscellaneous
	6	Clean Water & Sanitation	Ensure availability and sustainable management of water and sanitation for all.												
	7	Clean Energy	Ensure access to affordable, reliable, sustainable, and modern energy for all.												
	8	Good Jobs & Economic Growth	Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.												
	9	Innovation & Infrastructure	Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation.												[b]
	10	Reduced Inequalities	Reduce inequality within and among countries.												[c]
	11	Sustainable Cities & Communities	Make cities and human settlements inclusive, safe, resilient and sustainable.												
	12	Responsible Consumption	Ensure sustainable consumption and production patterns.												[d]
	13	Protect the Planet	Take urgent action to combat climate change and its impacts.												
	14	Life Below Water	Conserve and sustainably use the oceans, seas and marine resources for sustainable development.												[e]
	15	Life on Land	Protect, restore and promote sustainable use of terrestrial ecosystems...*												
	16	Peace & Justice	Promote peaceful and inclusive societies for sustainable development, provide access to justice for all and build effective, accountable and inclusive institutions at all levels.												[f]
	17	Partnerships for the Goals	Strengthen the means of implementation and revitalize the global partnership for sustainable development.												

**Figure 6.** A matrix to visualize the role of geologists in helping to achieve the internationally agreed Sustainable Development Goals (from Gill 2017)

Quite how this new pedagogic model of ‘sustainable geoscience’ can best be embedded into or grafted onto university geoscience courses and programs will vary from country to country. In the USA, there is a long tradition in which ‘sustainability is promoted as a strong organizing principle for modern liberal arts and technical education programs, requiring systems thinking, synthesis, and contributions from all disciplines - geoscientists, natural/physical scientists, social scientists, human and behavioral scientists, and engineers’ (Gosselin et al. 2013). Here and elsewhere, geoscience courses are being restructured around the framework of the UN Sustainable Development Goals, the traditional emphasis on fossil fuel extraction rebadged as geo-energy or energy transition science, and, in the UK, the first chair in Sustainable Geoscience has been appointed. In many universities, an introductory undergraduate course on ‘Geology and Society’ is a simple and obvious first step in helping students appreciate the relevance of their geoscientific training in the broad arena of sustainable development (Figure 6). At a more advanced level, and whilst maintaining the technical rigor and academic integrity of conventional geoscience training, applied courses on economic geology, petroleum geology, and engineering geology can be reframed through a sustainability lens (e.g., natural resource management, geo-energy, urban geoscience). However, arguably the most transformative way for geoscience to integrate into sustainability science will be in developing bespoke postgraduate courses in sustainable geoscience that take advantage of interdisciplinary alliances within universities to establish Masters and Ph.D. level training in a new holistic 21st century Earth science thinking.

There are broader win-wins to building sustainability into geology curricula and professional development training. It promises to develop a new generation of geo-professionals well versed in understanding and addressing sustainability issues (Mora 2013) and more able to effectively work with other scientists, businesspeople, and politicians to develop viable solutions to current and future environmental and resource challenges. Graduate employability prospects will be further improved by stronger academic engagement on local environmental issues with external community-based stakeholders and the wider public. Finally, engaging with socially contested issues means dealing with ethical dimensions of sustainability (Metzger & Curren 2017), which provides much needed ways to introduce geoscience students to the growing awareness of the principles and practices of geoscience, which are increasingly regarded as a vital component of professional geoscience practice (Peppoloni & Di Capua 2016, 2021, Wyss & Peppoloni 2014, Bohle & Marone 2021).

## 5. Concluding Remarks

Reframing geoscience – and university geoscience education - around the grand challenges of the 21<sup>st</sup> century would appear to be essential if Prince El Hassan’s ‘3G’ triangle of geography, geology, and geophysics is to help guide the wise stewardship of the planet.

For geoscientists, sustainable geoscience has the potential to revitalize Earth science and re-connect it with its distant Huttonian roots. That wider re-enchantment

could help reverse the current decline in geoscience student numbers at many universities around the world, and perhaps ameliorate the damaging association that the subject has with those vocational sectors that are now publically rejected as environmentally destructive, notably the fossil fuel and mineral extraction industries.

The inclusion of socially relevant modules or content in university courses could make geoscience more relevant to students who are fascinated by the planet but who do not pursue it, possibly because they see it as less salient, prestigious, or scientific than other disciplines, viewing it simply as ‘the study of rocks’ (Mora 2013).

Whether this re-purposing is for young students or senior decision-makers, redefining James Hutton’s social mission for the modern age will help society deliver its ambitious, enduring and motivating over-arching goal of long-term wellbeing for all (Stewart & Hurth 2021), and in doing so show that 21<sup>st</sup> century geoscience is more than simply the study of old stones.

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