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Views & Comments

The SDG Project: A Long-Term Project under Technological Uncertainty

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1. Introduction

A second "Warning to Humanity" issued by 15 000 scientists from across the globe [1], the "disappointing" COP25 meeting (25th Conference of the Parties to the United Nations Framework Convention on Climate Change) [2], and a "grim" United Nations report [3] imply that the ability of Earth's environment to support human life will persist for a much shorter time than the 200 years predicted by physicist Stephen Hawking.

This essay urges engineers to bend their project management and technical skills to the tasks that could best save us. It describes the unique characteristics of the Sustainable Development Goals (SDGs) project, making a comparison to the long-term projects under uncertainty that are dealt with by particle physicists. It identifies some leverage points that deserve engineering and policy attention, and describes an open-science program for attacking the technical portions.

2. SDGs: The good news and the bad

The United Nations has set 17 SDGs, with 169 sub-goals known as "targets." Unlike the earlier Millennium Development Goals, which were widely regarded as too "top-down" and authoritarian, the SDGs emerged from wide-ranging dialogs with multiple constituencies.

The goals and the 2030 target date for their fulfillment are agreed upon. There is, however, no agreement on how to achieve the SDGs. It is also (quietly) agreed that the SDGs cannot be achieved using today's technologies. Future innovations in waste reduction, emission scrubbing, recycling, geo-engineering, ecosystem restoration, cleanup technologies, and energy efficiency will make the difference to our future, and are essential for fulfilling the SDGs.

Some engineering projects extend over many years, or even over more than a decade. Their successful completion depends on technologies that do not exist on the date of the project launch. Managing such projects typically depends on agility—that is, constant adjustment of the project plan—or on keeping alternate designs in reserve, in case the technologies needed for the primary design do not emerge. As for the technologies themselves, the project leader must decide whether to passively scan for the needed advances or to proactively support their development. These kinds of projects, of which the SDGs are an example, are quite different from traditional short-term product-development projects conducted under fixed technology.

The target date for fulfilling the SDGs is, in fact, just a decade from now. The European Union has further committed to "net-zero" carbon dioxide (CO_2) emissions by 2050. *The Economist* [4] states that "ingenious new techniques" for CO_2 recapture will be needed in order to make the latter goal a reality.

The path to 2030 and onward to 2050 is paved with uncertainties surrounding the timing of the needed green technologies; costs and the sources of funds; producer and consumer acceptance; and many other social, political, and humanitarian factors.

3. Long-term projects under technological uncertainty: How is fulfilling the SDGs like building a next-generation particle accelerator or detector?

Physicists engaged in "atom smashing" and detecting particles from space face project difficulties that are remarkably parallel to those we face in achieving the SDGs. This section lists the instructive similarities and differences.

First, there are clear similarities between building a next-generation particle accelerator and meeting sustainability goals. Particle physics facilities take a long time to plan and build. For example, CERN's (Conseil Européenn pour la Recherche Nucléaire, or European Organization for Nuclear Research) planned Future Circular Collider (FCC) will require at least 30 years to complete [5]. "Such a gargantuan project," writes Lucibella [6], "faces a variety of technical, economic and political challenges, some likely easily surmountable, others less so." This is comparable to the (optimistic) ten years given to achieve the SDGs, which face similar challenges.

Like climate change initiatives, designing next-generation particle accelerators or underground particle detectors is a multinational endeavor. Gilchriese et al. [7] mention cooperating sites for contemporary detector projects in Canada, China, Spain, United States, Japan, France, India, and Italy.

Both particle physics and SDG projects involve multiple constituent classes. For the SDGs, these include every population, government, and business affected by climate change. For the FCC, which is to have a 100 km circumference, constituents include landowners, archaeologists, construction companies, government funding agencies, instrument developers, and physicists of several

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varieties. "The FCC study, hosted by CERN, is an international collaboration of 135 research institutes and universities and 25 industrial partners from all over the world" [8].

Future technologies critical for environmental remediation are noted above. For particle detection, "The next-generation dark matter and [particle] decay experiments require unprecedented levels of radiopurity in their detector, target, and shielding materials .... For the most sensitive applications, R&D in ultra-sensitive high-purity germanium gamma ray spectroscopy (HPGe)" is needed [7]. On the accelerator side, "Engineering challenges [include] designing strong enough magnets for the giant particle accelerator's storage ring, ... containing the synchrotron radiation emitted by the particle beam, [and] extrapolating computer technology twenty years into the future" [6] (see also Ref [9]). There will be little point in constructing detection facilities if these technologies do not eventuate within the project planning horizon.

Both kinds of projects feature high costs. The FCC will ultimately cost 24 billion EUR [5,10], although this is still "peanuts" compared with the trillions the SDG project may absorb.

Funding uncertainty is also high for both. Physicists fear that politicians cannot sustain a 30-year funding interest in what is essentially a big, circular hole in the ground. Key personnel whose expertise is essential for project success may resign, retire, die, or transfer to a more immediately rewarding project. On the SDG side, business economies can offer perverse incentives, often favoring pollution over remediation expenditure.

Physicists and environmentalists alike deal with trade-offs and synergies among project elements. Gilchriese et al. [7] note that particle detectors may prove "synergistic ... with nuclear non-proliferation activities," and "the same large underground detectors built for neutrino physics can be used for baryon number violation searches." Each design alternative for an accelerator or detector can offer specific advantages and disadvantages relative to the other designs. One specific trade-off is that "Next-generation ("tonne scale") neutrinoless double-beta-decay experiments ... may face competition for space from G2/G3-scale dark matter experiments" [7]. (The next section of this paper focuses on similar trade-offs and synergies among the SDG targets.)

Optimal organizational structures are a challenge for both SDGs and particle physics. "Increased U.S. assay capability is best achieved by organizing the existing underground facilities under a single umbrella organization" [7]. Influential organizations addressing the SDGs—but not yet playing well together—include provincial governments, the Business Roundtable, the World Economic Forum, and signatories to the Paris Accords. There is no single SDG project manager, and it is debatable whether there should be.

Finally, for SDG and accelerator projects alike, even questions of human survival arise. Physicists had considered whether the Large Hadron Collider, searching for the Higgs boson, carried the risk of creating an Earth-eating black hole [11], but ultimately decided it would not. (In hindsight, it did not.)

The similarities between SDG planning and particle research planning are striking. Nonetheless, there are important differences between the two. One of these differences involves the idea of design alternatives. "The final design for the FCC is up against a parallel effort to design the Compact Linear Collider, or CLIC," notes Lucibella [6]. "Once both designs are completed, CERN administrators will recommend one of the two options." Similarly, according to Gilchriese et al. [7], "[Underground] depth requirements for tonne-scale $0\nu\beta\beta$ experiments depend on the choice of technology and are not yet entirely known."

Although we may say that we have only one planet, and thus have no design alternatives, our planet does offer much geographic and cultural diversity. This makes experimentation possible. Phillips et al. [12] articulated a philosophical basis for such experimentation. Its practical implication is explored later in this article.

The required particle physics-related technologies are mostly well identified, needing incremental advances in engineering and production. With regard to the SDGs, although we can ask the questions, we do not know what specific future technologies will answer the questions—and we hope for fundamental scientific breakthroughs.

An accelerator design will be a well-defined "spec," with a clear scientific objective (and, to some extent, an ancillary political or defense benefit). The SDGs remain rather ill-defined, although progress indicators have been proposed, and the SDGs span social, economic, environmental, and political objectives.

Any measure taken toward the climate goals of the SDGs will cause economic harm to some entrenched interests. The FCC collider plan draws opposition from scientists because it may not open sufficient new horizons in physics, and from citizens who believe its cost should be better spent on social programs. Table 1 presents a summary comparison of the SDG and particle projects.

Technology roadmapping, the usual tool for planning that involves yet-to-come technologies [13], does not seem applicable to the SDG situation, as the SDGs involve multiple stakeholders of equal status but with disparate situations and agendas, and as-yet-unimagined technologies. There is, however, a "ten-year roadmap for future high-energy physics projects" [6].

4. Suggested actions for the SDG project

Gilchriese et al. [7] identify "pinch points" (their term) for particle detectors. These are "the limited assay infrastructure worldwide, and space for the future G3 dark matter experiments which can probe the irreducible neutrino background." Note that these pinch points are not future technologies, nor are they resources that can be acquired quickly, for any amount of money.

Pinch points for the SDGs include changing the minds and hearts of politicians and businesspeople, and the agricultural, consumption, and other habits of populations. More amenable to engineering solutions, however, are the pinch points represented by the SDG trade-offs.

There is now a sizeable body of literature detailing the synergies and trade-offs among the SDG targets, although it offers

Table 1
Comparison of SDG and particle projects.

Dimension	SDG project	Current collider/ detector projects
Time span	Ten years SDG target; 30 years decarbonization target	30 years (estimated)
Cost	Trillions of USD	24 billion EUR
Geography of participants	Global	International
Constituents	Everyone	Varied professionals and institutions
Technology requirements	Not yet developed; mostly unspecified	Not yet developed; mostly specified
Funding prospects	Not known where the money will come from.	Government-funded, but continuity of funding is uncertain.
Subject to trade-offs and synergies among project elements	Yes	Yes
Organizational structure	Currently completely decentralized	Possibly trending toward centralization
Alternate designs?	No	Yes
Goals	Social, environmental; economic; ill-defined, ambiguous; controversial	Technical, political, scientific, military; controversial

little advice on what to do about them. Lusseau and Mancini's [14] mapping of these +/– interactions shows, happily, that most of the pairwise interactions are of a positive nature—that is, that making progress toward target *x* also advances target *y*. A substantial minority of the interactions are negative, however. Some of the latter trade-offs are local—more jobs in location A means more pollution in location A—while others are non-local, meaning, for example, that greater use of information technology in location A's schools (which advances SDG 4, "Quality Education") means more child labor on the other side of the planet (setting back SDG 8, "Decent Work"), as it is known that children mine the metals used in e-tablets [15].

5. Geographic and cultural diversity

> *There could be some trade-offs among the target of ending hunger (T2.1) and energy production, especially in countries that rely on biofuel to expand energy access (T7.1, T7.2) . . . . Innovative and sustainable agriculture practices could help to increase agriculture productivity (T2.3) as well as produce renewable energy resources (T7.2). For example, in Sri Lanka, practices of intercropping Gliricidia (a fast-growing, nitrogen-fixing leguminous tree) with coconut are substantially improving agricultural yields as well as providing sustainable bioenergy feedstock.* [16]

In the above excerpt, Mainali et al. [16] identify what was an SDG trade-off in Sri Lanka (using e.g. T7.1 to denote the first target under SDG# 7). They show that the trade-off was reduced by changing an agricultural practice. They imply that the same solution might be helpful in other regions of the world, where climate, soil conditions, and dietary habits permit it.

Focusing on such local SDG trade-offs, we may ask: What proportion of all SDG trade-offs are indeed local? Is a particular trade-off really multi-local—that is, does it hold true throughout most of the world? If so, are there locations where it does not hold true, or is of lesser magnitude? If such anomalous locations (e.g., Sri Lanka in the example above) are found, why does the anomaly exist? Is it because of local geological conditions, or local human practices? If the causative conditions or practices of the anomalous region can be identified, can they be exported to other regions, in order to slow worldwide climate change?

I am leading a United States–Europe–China research consortium that hopes to answer these questions. The consortium now consists of the Chinese Academy of Sciences, the University of New Mexico, and Europe's OKRE Observatory. The proof-of-concept phase will use text mining and machine-learning tools to identify and try to explain "anomalies," as defined above. It is hoped that a fuller project will develop further artificial intelligence tools and supplement them with a worldwide network of human informants—students enrolled in SDG studies, and indigenous peoples—to leverage anomalies for minimizing SDG trade-offs.

6. Technology forecasting

Consider a matrix, with entries representing the magnitudes—positive, negative, zero, or unknown—of the interactions between pairs of SDG targets, measured at the present moment. Consider also the logistic (or similarly sigmoidal) curve representing the growth of patents (or other progress indicators) in technological areas pertinent to a particular SDG trade-off pair. The curve's parameters may indicate fast or slow technological progress, but, in any case, will change the interaction matrix in each succeeding time period.

Within an adjudged range of s-curve parameters, we can ask from a theoretical perspective: Will iterations converge to a matrix with no negative entries? Will it do so in time to achieve the SDGs? If not, what aspects of the matrix's structure are preventing timely convergence?

Having answered these questions, we may move to practical implementation, monitoring and selectively encouraging "technologies to reduce negative SDG interactions" (TRNIs).

7. Engineering and policy implications

By comparing the work toward the SDGs with the planning of particle physics facilities, this essay highlighted the special features of the "project" of achieving the SDGs. Prominent among these special features are high cost, long time horizons, and technological uncertainty. SDG researchers and policymakers would do well to converse with physicists, who have "done this before."

The essay went on to suggest a high-leverage strategy for pursuing the SDG project: namely, by focusing on the trade-offs among the SDG targets. Resources are not available to attack all the SDGs simultaneously, but the attack must start somewhere. Because the SDGs were formulated through dialog with multiple constituent groups, and because each of the SDGs is of top importance to at least some of these groups, any arbitrary prioritization of work on the SDGs will meet with constituent resistance. Focusing first on the most severe trade-offs is scientifically defensible, and is thus likely to be more acceptable to all stakeholders.

"SDGs 3 and 12 are identified as a top trade-off pair in 121 countries" [17]. As there are approximately 200 countries in the world, this statement implies that the 3 and 12 trade-off is lesser in about 80 of them. This means that anomalies, as I have defined them, do exist. Finding and explaining such anomalies is grist for research in engineering, artificial intelligence, agronomy, anthropology, and other disciplines.

When SDG *x* shows a negative interaction with SDG *y*, it seems sensible to forecast *x*–*y* TRNIs by the growth of patents co-citing keywords associated with both of these SDGs. This is a signal that engineering work in areas surrounding such patents can have a real impact on SDG fulfillment.

From a policy viewpoint, this essay's logic implies that a nation or province should not adopt a single SDG as a key strategy—or focus too single-mindedly on its "nationally determined contribution" [18] to decarbonization—as doing so ignores possible negative impacts on other goals. Rather, at least equal policy emphasis should be on reducing SDG trade-offs (and, of course, on enhancing SDG synergies).

Emergent TRNIs deserve policy priority, with subsidies or incentives as preferred by each responsible government.

Saving the planet should supersede first-to-publish considerations. Thus we welcome the sharing of thoughts, data, partial results, and collaborations, in an open-science format. A website will appear shortly for this purpose. Meanwhile, interested collaborators may contact me at phillipsf@unm.edu.

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