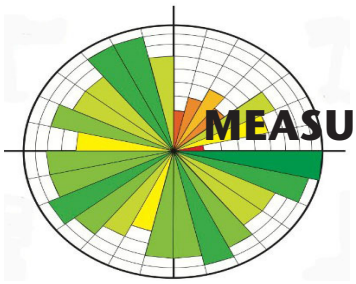
Roundtable on Science and Technology for Sustainability
Science and Technology for Sustainability Program
Policy and Global Affairs

November 12, 2015



MEASURING PROGRESS TOWARD SUSTAINABILITY

SOCIAL AND ECONOMIC INDICATORS AND METRICS FOR URBAN SUSTAINABILITY

Nearly 20 years ago, a landmark National Research Council report, Our Common Journey: A Transition Toward Sustainability, challenged the field of sustainability science to focus on developing a strong scientific basis for indicators and metrics, particularly given their importance in informing society about the extent to which "progress is being made in navigating a transition toward sustainability." The report noted that "there is no consensus on the appropriateness of the current sets of indicators or the scientific basis for choosing among them." Today, despite the widespread proliferation of sustainability indicators and metrics by a wide range of sectors, their selection and application remain challenging and there remains no consensus on what indicators are most useful for informing decision making.

To facilitate a discussion on these challenges, the Roundtable on Science and Technology for Sustainability convened three events focused on the indicators and metrics found to be the most effective in promoting sustainability. This is a summary of the second event, held on November 12, 2015, which featured discussions on social and economic indicators and metrics in the context of urban sustainability and on practical opportunities for strengthening and expanding indicators. Participants of the first event held on June 4, 2015, discussed sustainability indicators and metrics in the context of climate change and infrastructure vulnerability. The third event, to be held in June 2016, will examine the results of the June and November 2015 sessions on sustainability indicators and metrics to chart a path forward for sustainability science and technology activities.

Heather Tallis of The Nature Conservancy (TNC) opened the meeting with a keynote presentation on the importance of sustainability indicators and how they can be developed in an integrated way to address pressing global challenges. While there is a rich history of developing sustainability indicators to set environmental priorities and measure progress toward a goal, these indicators have not fully considered social consequences. Dr. Tallis provided two examples: early indicators of deforestation not considering conservation refugees excluded from their natural resource base, and early assessments of energy security focusing on the development of fossil fuels but not considering societal implications. These are examples, Dr. Tallis noted, where decision making and measuring progress led to unsustainable choices, and the question still remains about which indicators can truly measure progress toward sustainability goals.

Dr. Tallis said a major challenge for implementing sustainability is in understanding key issues that cut across sectors. There are 17 United Nations Sustainable Development Goals (SDGs) identified by the global community as major challenges; assessing which of those is truly the highest priority can be difficult, she said. TNC has begun to identify major challenges that can most effectively be addressed through conservation and environment-based solutions. Through a literature review and discussion with the global community, TNC identified key issues and developed a 5- to 10-year plan of how to address those issues. For example, the TNC analysis showed that sanitation is the largest single challenge in the SDGs. Almost 40 percent of the human population does not have access to sanitation. Another key challenge is water withdrawals, which is the single largest threat to freshwater biodiversity and habitat conservation. There is a nexus point, Dr. Tallis noted, between freshwater biodiversity and water security that intersects at water withdrawals. Identifying such interconnections can help establish collaborations to achieve the SDGs.

Dr. Tallis stated there is not enough data available to assess progress toward some of the most prevalent sustainability issues, such as a sustainable energy supply. For example, data are not consistently reported and tracked in a way that allows progress toward a sustainable energy supply to be assessed. There is also not enough regular reporting from development organizations, such as the World Bank, to assess how global drinking water supplies are changing. Dr. Tallis stated that the lack of data for significant global sustainability indicators should elevate the need to move quickly toward a consistent set of metrics that can be reported on regularly in order to advance the SDG goals.

Overview of Social and Economic Indicators and Metrics: Characterizing the Issue

Diane Pataki of the University of Utah discussed nonhuman biological metrics in cities and problems that arise in disentangling human from nonhuman components of cities, such as vegetation, wildlife, and biodiversity. There is a challenge in creating metrics that encapsulate specific attributes of the nonhuman environment of cities, which are quite different from rural and natural environments. For example, changes can be measured when tree canopies are added to cities, such as removing pollutants from the atmosphere or cooling air, but it is more difficult to measure cultural or psychological impacts. All these considerations contribute to difficulties in mapping an ecosystems framework onto a highly urbanized environment. While progress has been made in this area via measuring and mapping the amount of vegetation in cities, there remain notable knowledge gaps in surveys of urban biodiversity and in the development of ecosystem services valuation tools meant specifically for urban areas.

Urban landscapes present a unique environment that is challenging to measure using traditional metrics. There is a lack of knowledge of the interaction between non-native species and human well-being and a scarcity in studies that place ecosystem services in the context of urban metabolism. Urban metabolism constitutes quantifying material that flows into a city and all of the waste that comes out. Ecosystem services that are important at small scales may have little impact on a whole city. For example, the effect of urban plants and soils on carbon sequestration is small compared to all of the fossil fuels utilized in cities. Dr. Pataki concluded by indicating that one example of a successful urban ecological indicator was the development of tools for high-resolution mapping of the non-built environment in cities. On a final note, she identified urban metabolism, ecological footprints, and life-cycle accounting as a key set of potential metrics for urban systems.

Charles Redman of Arizona State University provided an overview of framing measurement systems. In terms of framing indicators, Dr. Redman provided alternative definitions of sustainability and resilience. He described sustainability as occurring when human well-being is enhanced, ecological integrity is maintained, and social justice is achieved. Resilience constitutes the capacity of a system to experience shocks while retaining the same function, structure, feedbacks, and therefore, identity. In developing indicators, however, Dr. Redman identified a series of intellectual misalignments that are a challenge to comprehensive metrics. For example, each discipline is defined by its own set of rules (e.g., vocabulary, research objectives). Systems have a distinctive logic, reflective of the dominant discipline behind them. These various domains then coalesce. For example, a number of "mixed" systems have appeared, such as social/technological (e.g., the Internet), ecological/technological (e.g., green infrastructure), or social/ecological (e.g., resource management) interactions. Dr. Redman stated that these various interactions need to be brought together in a way that respects their underlying concepts (see Figure 1).

In addressing resilience and sustainability frameworks, Dr. Redman and his colleagues created the Urban Resilience to Extremes Sustainability Research Network (UREx SRN), a network of 9 cities and 17 institutions which addresses risk management in the context of urban sustainability by working at the intersections of social, ecological, and technological domains (Figure 1). The network brings together social scientists, ecologists, engineers, designers, and urban planners in each city to grapple with risk management—a key element in making decisions for sustainability given uncertainty. Dr. Redman identified three issues needing to be resolved for more sustainable and resilient cities: (1) ensuring that resilient dynamics emerging from open, participatory approaches will lead to a more sustainable set of outcomes; (2) converting avoided future costs to current revenue streams; and (3) integrating long-term sensibilities and values into short-term management and decision making.

Robin Morris Collin of Willamette University College of Law highlighted community members as

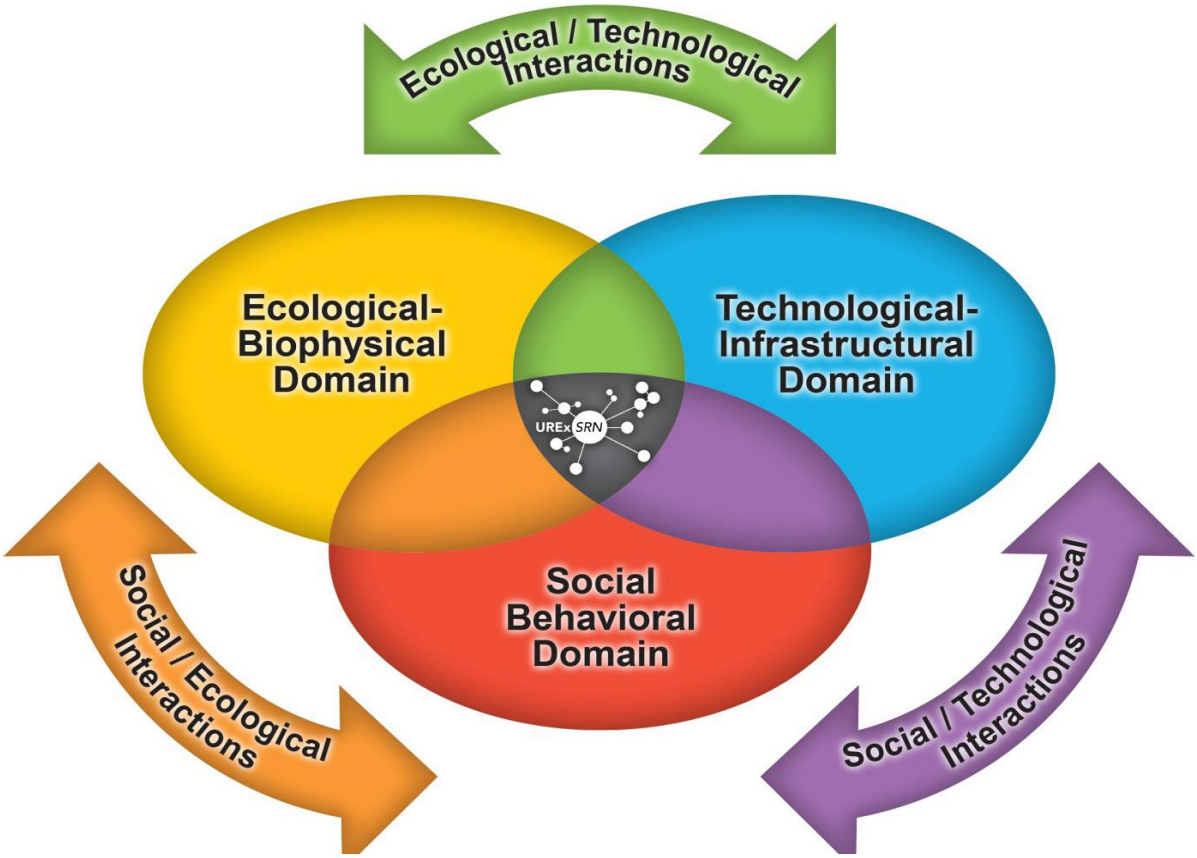


Figure 1 The Urban Resilience to Extremes Sustainability Research Network (UREx SRN).
Source: Charles Redman, presentation, November 12, 2015, Washington, D.C.

a key group of stakeholders for sustainability and as part of the scientific process for the collection of data. Local communities are the drivers behind sustainability indicators surrounding nature and people. Ms. Morris Collin said there can be an overreliance on data and indicators, considering the fact that poor people, children, and people of color are often excluded from sustainability metrics. Race needs to be included in framing and interpreting data for managing urban land use. The development of data and metrics should be an inclusive and open process that includes community voices. Technology plays a large role in facilitating the incorporation of communities in gathering data, and intergenerational equity plays a role in sustainability. Moreover, the government can be a powerful convener in framing and gathering information and in including community voices. Ms. Morris Collin concluded by saying the community has a role as a stakeholder and can offer local perspectives.

Examples of Innovative Public Sector Sustainability Indicators and Metrics

Duane Verner of Argonne National Laboratory discussed the use of climate data to inform critical infrastructure resilience and urban sustainability decision making. Mr. Verner said that decisions related to urban infrastructure often do not incorporate climate change data. There are barriers to climate change adaptation, including a lack of local-level modeling of temperature and precipitation changes, high-resolution climate scenario data, and a local framework for adaptation planning. Compounding these issues, he added, is the development of climate data for the atmospheric and oceanic science communities rather than for local decision makers. Urban planning and engineering design practices are currently not equipped to bridge the gap between climate model outputs and climate impact information necessary for adaptation; however, urban planners need to move to a mainstream use of climate data to inform urban sustainability decision making.

Regional climate models were developed to allow researchers to better account for topographic details while also improving the ability to simulate surface variables such as air temperature, precipitation, and wind. In addition, infrastructure models can be coupled to climate models to assess climate hazards and thereby inform decisions that result in more resilient infrastructure. Cities should reanalyze flood vulnerabilities in light of climate change, said Mr. Verner. Argonne is preparing a climate data user manual for the Department of Defense's Strategic Environmental Research and Development Program. The manual will provide a critical overview

of downscaling models, methodologies, and data; an assessment of each method; and uncertainties associated with the downscaling process and climate data in general.

Finally, Mr. Verner said Argonne is harnessing its expertise from various divisions, including climate science, environmental systems, engineering, infrastructure, socioeconomics, and security to develop a Regional Climate Assessment Framework (see Figure 2). Based on stakeholder needs and requirements, Argonne uses internal expertise, ongoing partnerships, climate data from many sources, and multiple models and tools to provide a range of products, including local climate data, simulation tools, and training programs. The framework will provide guidance on developing probability distribution curves to help understand uncertainty and will ultimately be used by communities to help adapt to climate change.

Gerardo Ruiz-Mercado of the U.S. Environmental Protection Agency (EPA) discussed the agency's work to develop chemical process indicators for sustainability assessment and design. In designing such process indicators, EPA assesses three dimensions of sustainability: environment, society, and economy. Based on this assessment, EPA proposed using the 4E's (environmental, efficiency, economics, and energy) in promoting and informing sustainability for chemical processes, particularly in an effort to integrate evaluation and decision making at the design level. The 4E's were used to inform the development of the GREENSCOPE Sustainability Framework (Gauging Reaction Effectiveness for Environmental Sustainability of Chemistries with a multi-Objective Process Evaluator).

The GREENSCOPE framework was designed to provide a clear approach for using sustainability indicators for assessing, monitoring, and predicting sustainability at any stage of the chemical process design. The tool calculates more than 139 different indicators, which stakeholders can choose, and decision makers can redefine, to fit different circumstances. The framework uses identification and selection of two reference states for each sustainability indicator, where the best target is 100 percent of sustainability and the worst-case is 0 percent of sustainability. For the environmental portion of the

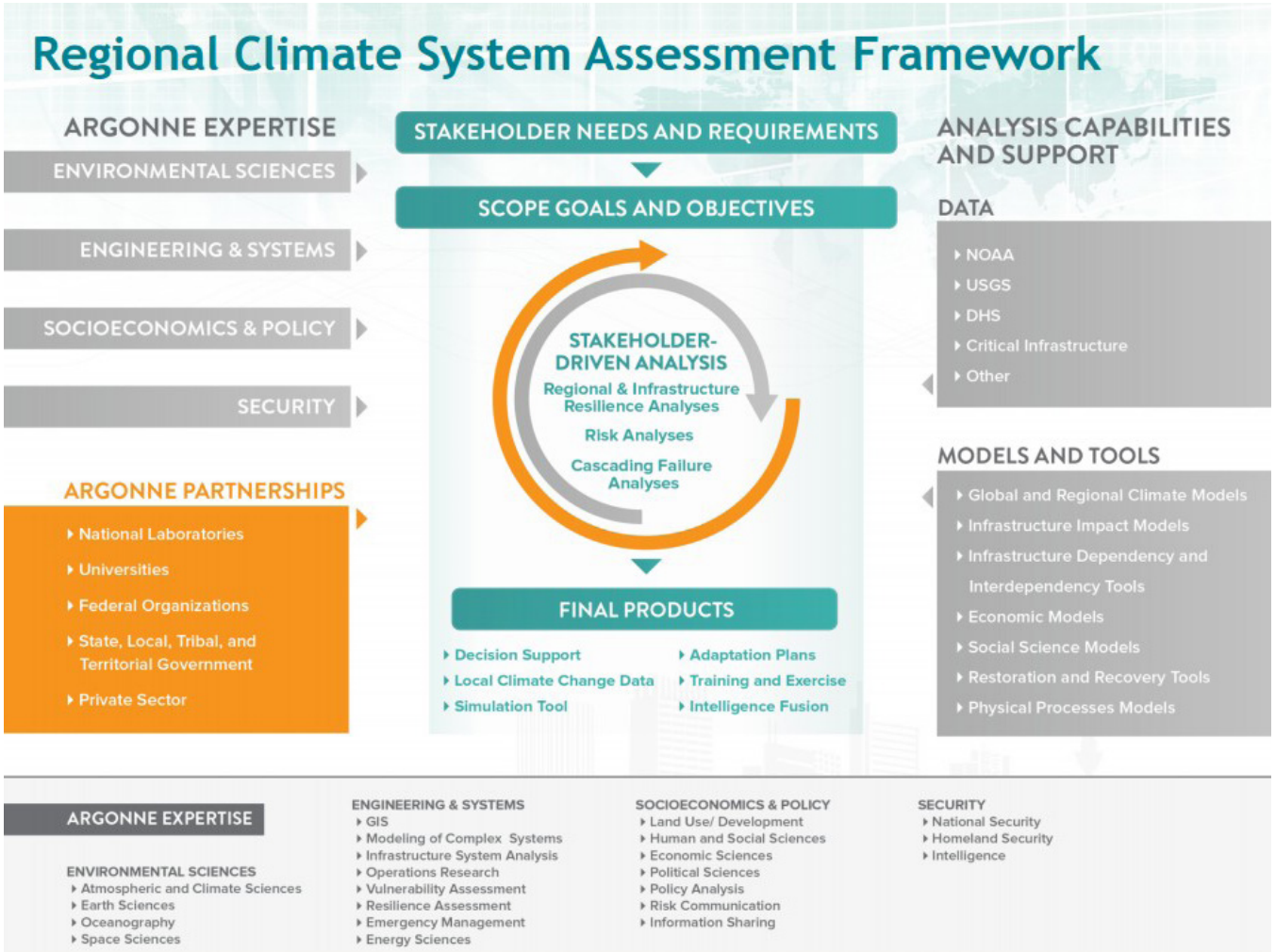


Figure 2 Regional Climate System Assessment Framework.
Source: Duane Verner, Argonne National Laboratory.

4Es, GREENSCOPE incorporates 66 indicators related to health and safety hazards, including releases, risk assessments, and ecosystem services evaluation.

There are 26 efficiency indicators that connect material input/output with a product or intermediate generated in a process, and EPA is proposing 33 economic indicators. These can be used to assess whether a sustainable economic outcome would be achieved for any process, technology, or modification and are supported in terms of cost criteria. The tool also includes 14 indicators that evaluate or analyze energy consumption, including different thermodynamic assessments for obtaining an energetic sustainability score. Dr. Ruiz-Mercado discussed challenges in advancing sustainability at a process level, including data availability for accurate calculations, development of quantitative social indicators, assessing multiproduct allocation for processes and facilities, and legal foundations and establishment of official methodologies and standards for the assessment of sustainability. It is also important to integrate life-cycle considerations at the process development level and for sustainability regulations to help drive these processes.

Michael Culp of the Federal Highway Administration (FHA) discussed efforts to develop a rating tool to assess sustainability decisions for the highway sector. The Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) was developed as part of a broader initiative titled the Sustainable Highways Initiative. The purpose of the initiative is to support programs and activities conducted across the FHA to facilitate balanced decision making among the environmental, economic, and social pillars. INVEST, released in October 2010, was designed to connect sustainability principles with action, measure sustainability for transportation, and ultimately to assist stakeholders in the industry to assess progress and make decisions that extend beyond meeting the requirements of transportation regulations. While the tool is voluntary, it was developed with privacy considerations in mind and to be a practical tool for use in planning processes. The tool is intended to be used throughout the life cycle of a project – planning, implementing, and operationalizing and maintaining a system.

Mr. Culp stated that there are many types of transportation entities currently using the tool, including state departments of transportation and metropolitan planning organizations. For example, the Utah Department of Transportation used the tool as it assessed sustainability decisions related to its highway system, and informed policy related to operations and maintenance, traffic monitoring, and coordination across the system. The key goals were to preserve infrastructure, optimize mobility, improve safety, and strengthen the economy. Budget pressures for the state were the driving need for more sustainable practices. INVEST was used to identify inexpensive ways to promote sustainability, such as better data about pavement conditions.

Another example Mr. Culp provided was the Illinois Department of Transportation using INVEST to develop a conceptual design for a Historic Route 66 corridor project showing locations for specific sustainability improvements. This included streetscape design, crosswalks, lighting, and bus stops. This effort demonstrated how improvements would enhance the level of sustainability of the project as measured against the national benchmark of INVEST. Mr. Culp concluded by noting that the FHA works on a broad spectrum of transportation issues and hopes that more communities will use INVEST for their transportation projects. Additional information and opportunities for training related to the tool can be found at www.sustainablehighways.org.

Innovative Private and NGO Sustainability Indicators and Metrics

Matthew Mehalik of Sustainable Pittsburgh discussed efforts to engage local governments, businesses, and other decision makers to embed sustainability throughout southwestern Pennsylvania. Sustainable Pittsburgh was founded in 1998 to accelerate the policy and practice of sustainability in the 10 counties of southwestern Pennsylvania. Two of Sustainable Pittsburgh's performance programs are the Pittsburgh Green Workplace Challenge and the Southwestern Pennsylvania Sustainable Business Compact. The Pittsburgh Green Workplace Challenge engages the region's business community with Pittsburgh's Climate Action Plan, which was launched in 2008. Although it started with the business community, it now engages the nonprofit sector, universities, local governments, and school systems. The competition tracks actions and impacts of competitors over a 1-year period and compares those metrics with baseline data. EPA's Portfolio Manager is used to assess energy and water reductions and the Waste Reduction Model is used to track waste management. CommuteInfo, a tool developed locally, tracks changes in commuting performance. Points are awarded to competitors for reducing energy, water, waste, and commuter footprints. Over the first 2 years of the competition, competitors saved more than 96 million gallons of water and 93 million kilowatt hours of electricity, which equates to approximately 23,000 metric tons of CO2 equivalent kept out of the atmosphere.

The Southwestern Pennsylvania Sustainable Business Compact engages the region's larger corporations in broader capacity-related issues and material sustainability. Bloomberg and other firms track how publicly traded companies address sustainability-related issues with indexes such as the Environmental, Social and Governance Index. The compact makes the business case for companies in southwestern Pennsylvania to better address regional sustainability challenges. Sustainable Pittsburgh started convening focus groups and conducting surveys in 2011, focusing on 12 major areas of sustainability using 170 indicators. The first tier of the assessment consists of

operational capacity-focused baseline indicators for a company. The second tier is composed of engaged-level indicators, which assess how much investment was put into practice within the company. The third tier consists of transformative indicators, which address engagement with the regional community. There are 21 businesses participating in the program, which completed more than 804 actions. The top 10 of the 170 indicators reported on fell into the following categories: diversity and inclusion (4), energy efficiency (2), financial performance, water efficiency, and waste reduction.

Fiona Cousins of Arup, a multidisciplinary engineering and consulting firm, discussed a holistic sustainability decision-making framework to support project development and communicate outcomes. Ms. Cousins stated that as a designer she is continually creating a plan of action to improve conditions, testing solutions and using metrics in their sustainability projects to test models. The first tool Ms. Cousins discussed was the Sustainable Project Appraisal Routine (SPeAR), which Arup developed in the late 1990s. It is a circular plot divided into major sectors representing environmental, social, and economic criteria. Within each of those major sectors are subindicators composed of tangible metrics, such as carbon pricing. Indicators are measured, quantitatively and qualitatively, and values closer to the center represent optimized values. The circular design provides a visualization of the trade-offs among social, environmental, and economic criteria within a system or solution being evaluated. The SPeAR approach, although it illustrates trade-offs, does not provide a single number for decision makers; however, it is useful for comparing different decisions for a single scenario. A more numerical tool developed by Apur is the Integrated Resource Management (IRM) model, which, similar to SPeAR, quantifies the social, environmental, and economic criteria of a system or solution. The IRM model was further developed by the Clinton Climate Initiative to become the Climate Positive Tool, which allows for the conversion of water and energy usage into carbon emissions.

Nancy Kete of the Rockefeller Foundation presented the City Resilience Index, a comprehensive and technically robust tool that enables cities to measure and monitor resilience in order to inform urban planning and investment patterns. It was important, Dr. Kete said, to have embedded in the tool criteria that would drive a city toward resilience, and especially criteria that a city may not already have or cannot yet measure. The index has 12 key indicators for resilience, 58 subindicators, and 156 prompt questions to guide quantitative and qualitative metrics. There are four dimensions to the City Resilience Index: knowledge, place, people, and organization. Dr. Kete said these dimensions can also be considered as health and well-being, economy and society, infrastructure and environment, and leadership and strategy.

An example of the nested structure of the index was shown with the Infrastructure and Environment Dimension, which addresses physical infrastructure and services within a city critical to resilience. The three main indicators within the Infrastructure and Environment Dimension are (1) reliable mobility and communications, (2) effective provision of critical services, and (3) reduced exposure and fragility. Within these indicators are 13 subindicators related to gray and green infrastructure, such as reliable communication technology and effective stewardship of ecosystems. The other three dimensions similarly had indicators and subindicators embedded within the index.

Dr. Kete said there are 156 guiding questions teed up against best- and worst-case scenarios. The questions are answered for all subindicators, and a score is accumulated with a justification for why a score was given. That justification, Dr. Kete said, over time will allow for an understanding of the path to resilience for cities and their relationships with all the variables in the index. Understanding those justifications from many cities over time will allow the index to be improved analytically and will make it more valuable to cities that continue to use it to improve their resilience. Dr. Kete said that aggregating data for many cities and conducting a cross-analysis

will be valuable for education and assessment purposes. In a pilot of the index, Hong Kong and Liverpool, two of the most developed cities in the pilot, were unable to respond to 50 percent of the variables. This was not viewed as a failure for the two cities, but instead, there are criteria related to urban resilience that were never before measured. This will induce cities to start measuring those criteria over time. Rockefeller's 100 Resilient Cities initiative built their whole program on the city resilience framework and will be an early adopter.

Maureen Hart of the International Society of Sustainability Professionals, discussed challenges communities face when implementing sustainability indicators. There is a lack of indicators that help with a long-term view, she said. Resonating with Dr. Redman's earlier comments, she said current indicators allow communities to be adaptive or transitional, but there needs to be a transformation in the approaches communities take for implementing sustainability. For example, there need to be improvements in systems thinking so that ecological, economic, and social indicators are better connected and more integrated.

Another challenge Ms. Hart sees is a lack of collaborative action and reporting. Often metrics are reported individually for a company or organization, but to aggregate reporting across many companies and organizations provides a more holistic picture of carbon reduction or energy savings in a region. Businesses may not be able to take on that role due to economic constraints of quarterly reporting, which also does not allow them to take a long-term view. Nongovernmental organizations, however, are more inclined to take a long-term view, but are limited by funding and grant cycles. A successful approach to a long-term view will require a collective responsibility within an urban region. Cities cannot be sustainable, she said, unless the entire metropolitan region and all the businesses and organizations within it are sustainable.

Not all indicators are used for the same purpose in reporting. For example, there are indicators for raising awareness, informing decision making, measuring progress, and communicating results. Often there is a lot of focus on indicators that measure progress or actions in great detail, when one that brings awareness and communities together is needed. For example, Ms. Hart said, an indicator for measuring an ecological footprint may have many technical challenges when used to track progress, but it is an excellent indicator when used for raising awareness. Having an indicator that helps people to understand carrying capacity or a social footprint would help to raise awareness and engage those not working toward sustainability goals.

David Dzombak of Carnegie Mellon University and Lynn Scarlett of The Nature Conservancy provided a summary of themes they heard during the panel presentations and discussions. Many participants noted that there has been substantial thought and investment in the development of indicators and metrics with increasing sophistication over the past 15 years. For those in the field, thinking about sustainability is deeper and more advanced, but at the same time, the full complexity of the challenges is becoming clearer. Several participants indicated the preferences and needs of stakeholders need to be incorporated into indicators broadly and inclusively. Communities that have adopted and maintained sustainability indicators have chosen metrics they care about and use in day-to-day management.

Many participants also discussed that when developing indicators, it is important to consider outcomes versus processes. A process-focused or an outcome-focused indicator will have different consequences for developing sustainable and resilient communities. For any indicator, the integration of processes and outcomes will be important. Some participants noted that disseminating and providing training on tools and metrics will help incentivize adoption of those tools. Establishing clear sustainability goals has been effective in the private sector and could be adopted by other organizations and communities.

Lastly, indicators can serve as a vision for a future state and not just as tools for driving designs or specific actions. Four key drivers to what is measured were discussed: (1) indicators with available data, (2) indicators that identify significant threats and/or drivers of the limitations of well-being, (3) indicators that represent what people care about, and (4) indicators that form a nexus—a collection of actions that drive multiple outcomes. ■

Presenters: **Fiona Cousins**, Arup**; Michael Culp**, Federal Highway Administration; **David Dzombak** (NAE), Carnegie Mellon University; **Maureen Hart**, International Society of Sustainability Professionals; **Nancy Kete**, Rockefeller Foundation; **Matthew Mehalik**, Sustainable Pittsburgh; **Robin Morris Collin**, Willamette University College of Law; **Diane Pataki**, University of Utah; **Charles Redman**, Arizona State University; **Gerardo J. Ruiz-Mercado**, U.S. Environmental Protection Agency; **Lynn Scarlett**, The Nature Conservancy, **Heather Tallis**, The Nature Conservancy; **Duane Verner**, Argonne National Laboratory.

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The summary was reviewed in draft form by **David Dornfeld**, University of California, Berkeley; **Melissa Kenney**, University of Maryland; and **Matthew Mehalik**, Sustainable Pittsburgh. The review comments and draft manuscript remain confidential to protect the integrity of the process.

About the Science and Technology for Sustainability (STS) Program

The long-term goal of the National Academies of Sciences, Engineering, and Medicine's Science and Technology for Sustainability (STS) Program is to contribute to sustainable improvements in human well-being by creating and strengthening the strategic connections between scientific research, technological development, and decision making. The program examines issues at the intersection of the three sustainability pillars—social, economic, and environmental—and aims to strengthen science for decision making related to sustainability. The program concentrates on activities that are crosscutting in nature; require expertise from multiple disciplines; are important in both the United States and internationally; and engage multiple sectors, including academia, government, industry, and nongovernmental organizations. The program's focus is on sustainability issues that have science and technology at their core, particularly those that would benefit substantially from more effective applications of science and technology.

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