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REVIEW ARTICLE

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A review of sustainability metrics for the construction and operation of airport and roadway infrastructure

Abstract Sustainability has become increasingly important, however, relatively little attention has focused on metrics for the construction and operation of airport and roadway infrastructure. Most attention has focused on buildings, with high profile BREEAM and LEED projects taking center stage. Sustainability is also important in airport and roadway infrastructure projects, which have significant public impact but have a much lower profile than vertical construction when it comes to sustainability. Sustainable infrastructure is important in China and India where new infrastructure is under construction to meet growing and developing economies, and in the US, where infrastructure is in substandard condition and requires reconstruction. The purpose of this paper is to provide an overview and discussion of sustainability rating systems for airport and roadway infrastructure, including both construction and operation. Specific projects that highlight both proven and innovative sustainable practices are included to illustrate the application of these concepts. Finally, the relationship between sustainable transportation infrastructure and resilient transportation infrastructure is addressed since resiliency is of growing interest and there is overlap between these concepts.

Keywords sustainable construction, infrastructure, airport, roadway, resiliency, sustainability

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1 Introduction

Infrastructure investment is a critical component for the economic and social livelihood of a nation and its citizens. Efficient transportation infrastructure provides benefits such as supporting market accessibility and productivity, facilitating economic development for regions within a country, stimulating employment and labor mobility, and connecting communities for economic and social benefits (OECD, 2019). The importance of transportation infrastructure has been documented by research that confirms the positive impact of transportation investments to support growth in both labor productivity and total factor productivity (Farhadi, 2015).

Sustainability or sustainable development is not a new idea, and it reflects that the needs of future generations must be balanced with the present needs. Increasing interest in sustainability has affected every industry and sector, including construction. Although much attention was initially focused on buildings, sustainable practices are also increasingly employed in the construction and operation of transportation infrastructure. Recognition of the importance of sustainable transportation infrastructure is well placed, since the projected investments in infrastructure are significant and continue to grow. Infrastructure is critical not only to mobility, it is also critical to ensure economic development, productivity, and competitiveness; despite its critical role, investment in infrastructure has not always kept pace with needs, and in many countries, investments have actually been declining (UNECE, 2016).

The importance of sustainability for transportation infrastructure construction and operation is significant and was addressed by world leaders in the United Nation's (UN) 2030 Agenda for Sustainable Development. UN Sustainable Development Goals address the need to build resilient infrastructure (Goal 9), and the need to make cities inclusive, safe, resilient, and sustainable (Goal 11). Attainment of both of these goals is supported by sustainable transportation infrastructure (United Nations, 2015). These goals are consistent with previous global priorities, such as designation Sustainable Buildings and Construction as one of five priority programs by the UN in 2014 (United Nations Environment Programme, 2014).

The projected investment in transportation infrastructure is significant. To meet the demands of 2030, global infrastructure requirements, including transportation infrastructure, are projected to be almost $90 trillion (Global Commission on the Economy and Climate, 2016). One estimate suggests that transportation infrastructure investments in Asia will be $8.4 trillion by 2030 (Asian Development Bank, 2017). In many countries, roadways and airports represent a significant component of the projected transportation infrastructure. In the US, surface transportation and airports represent over 90 percent of the transportation needs projected until 2025, as shown in Fig. 1 (American Society of Civil Engineers, 2017). In Europe, investment in roadway and air sectors have also been significant, representing approximately 60% to 70% of transportation infrastructure expenditures in the last two decades (European Environmental Agency, 2016). In Australia, infrastructure accounts for just under 25 percent of the GDP (Leviäkangas et al., 2018).

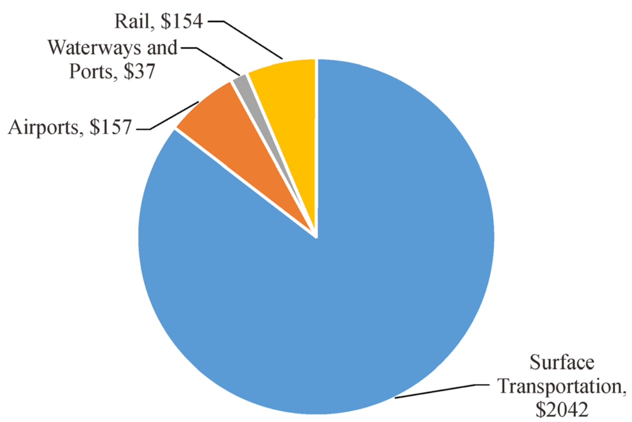

Fig. 1 Estimated annual transportation infrastructure needs in the US ($B) (American Society of Civil Engineers, 2017).

Investment in infrastructure not only provides mobility and enhances quality of life, but also ensures economic vitality and growth. It is estimated that globally, air passenger travel may double in 15 years, and air freight may triple in 20 years (Organisation for Economic Co-operation and Development, 2011). The current infrastructure is not adequate to handle the volume projected for 2030. Roadways also provide a critical component in mobility and accessibility. The roadway sector represents the largest area of need in the US (American Society of Civil Engineers, 2017), globally, roadways connect major cities and serve rural villages in Asian countries such as India (Curran and Yap, 2017).

Previous literature has addressed a variety of topics related to the construction and operation of transportation infrastructure projects, but there is limited scholarly investigation of sustainability metrics for the construction and operation of transportation infrastructure. Ugwu et al. (2006) recognized the difficulty of assessing sustainability at the project level, and developed a methodology, as well as key performance indicators, to translate sustainability goals to project level metrics. Zeng et al. (2018) explored the importance of supplier development for the construction of mega-projects for transportation infrastructure. Zeng et al. (2015) defined Megaproject Social Responsibility (MSR), and Lin et al. (2017) developed a structured methodology to assess MSR with 46 indicators at the project level and 25 indicators at the organizational level to balance the interests of all stakeholders. Findings suggest that project quality and safety is important in the construction phase, government plays an important role in management, and social responsibility is integrated into the operational activities (Lin et al., 2017).

Construction delivery method has an impact on metrics such as delays, and performance (Zhang et al., 2018), and it is reasonable that delivery method may also impact sustainability. This is an important consideration since delivery methods such as public private partnerships (PPP) have become increasingly common since they can often effectively leverage the strengths of the public and private sector (Ng et al., 2017). Private investment in infrastructure (e.g., through PPP) and decisions based on project financial viability may not ensure that economic and social considerations are adequately addressed (Leviäkangas et al., 2018). Scheepbouwer et al. (2017) also investigated the challenges associated with different procurement methods, and findings suggest that a more holistic assessment of value is appropriate. Recent research suggests that a broad framework such as systems thinking, including an understanding of the linkages and interactions between components, is needed to develop strategies to improve performance (Love and Luo, 2018); although applied to cost overruns, schedule overruns and poor productivity, this perspective could also be applied to ensure sustainability.

Mai et al. (2018) researched innovative management frameworks for complex systems during the construction of transportation infrastructure. He and Wang (2015) investigated the use of lean construction to support sustainable construction. Zhu et al. (2018) researched sustainable development and green environmental protection as one component in the construction of a very large bridge crossing. Sustainability has been addressed in other infrastructure contexts, such as power infrastructure (e.g., Martinot, 2010). Innovative concepts, such as sustainable roadways with self-healing asphalt that use inductive power to charge electric vehicles (Venugopal et al., 2018), may inspire the future, but may not support sustainable transportation infrastructure in the near term. Sarsam (2015) investigated sustainability metrics for roads, and noted that many of the metrics (e.g., Green LITES, Greenroads, ILAST and INVEST) all consider the same categories of environment, water, energy, materials, and strategic innovation, and recommended that rating systems should focus on providing transportation choices that include walking, transit and cycling, and ensure safety and an adequate level of service. Despite significant expenditures on infrastructure and growing focus on sustainability, there is limited investigation of alternative metrics for different transportation sectors. This paper presents the most widely recognized and used sustainability metrics for roadway and airport infrastructure, which are the two largest sectors in terms of current and projected investments.

Sustainability can be interpreted in a number of ways, and often includes a focus on both construction and operations. The triple bottom line approach suggests that a sustainable organization or project must be financially secure, must minimize environmental impacts, and conform with societal expectations (Elkington, 1994). This concept has been further developed by others, as illustrated in Fig. 2(a), which emphasizes the importance of the overlap areas to ensure that investments provide sustainability and support social, economic, and environmental needs. Some refer to this as weak sustainability, since it implies that the environmental, social, and economic realms are separate (albeit intersection) parts of a system. An updated model that has been put forth is shown in Fig. 2(b); this model for strong sustainability reflects that the environmental realm is the foundation for strong sustainability because the environment provides natural resources that cannot be obtained in any other way, including air, water, food, energy, and raw materials (United States Department of Agriculture, 2011). The authors suggest that often sustainability is a higher order concern, and although it is ideally always addressed, in many cases it is only addressed once a community is assured that basic operational functions, as well as safety and security are met. This is consistent with Maslow's hierarchy of needs, and is shown in Fig. 2(c). This philosophy is consistent with the evolution of sustainability in developed nations, and the fact that many developing countries do not prioritize sustainability for infrastructure until the basic operational and then safety needs are met.

This paper provides an overview of methods for assessing the sustainability of infrastructure investments in the roadway and aviation sectors, including a discussion of metrics, often referred to as rating systems. Rating systems provide a number of benefits, and are important for both measuring the current status quo as well as providing a mechanism to measure progress and meet future goals. In some cases, sustainability metrics can also be an important means to ensure other system benefits, such as reducing lifetime expenses, which encompass capital, operating and decommissioning expenses. Rating systems may also be useful by facilitating comparison with peer projects and peer institutions. In many cases, an airport authority is responsible for only one airport, which limits the opportunity to compare facilities in a single organization; however, benchmarking with other facilities desirable. Finally, the use of rating systems, sometimes applied by an independent third party, may ensure public and transparent accountability.

2 Methods to assess sustainability of infrastructure

Methods for assessing the sustainability of infrastructure investments include the internationally recognized Building Research Establishment's Environmental Assessment Method (BREEAM) and Civil Engineering Environmental Quality Assessment and Award (CEEQUAL) Scheme, Leadership in Energy and Environmental Design (LEED), Envision, Global Reporting Initiative (GRI) Standards, and the International Organization for Standardization (ISO) rating systems. The next section reviews these internationally recognized sustainability standards; the following

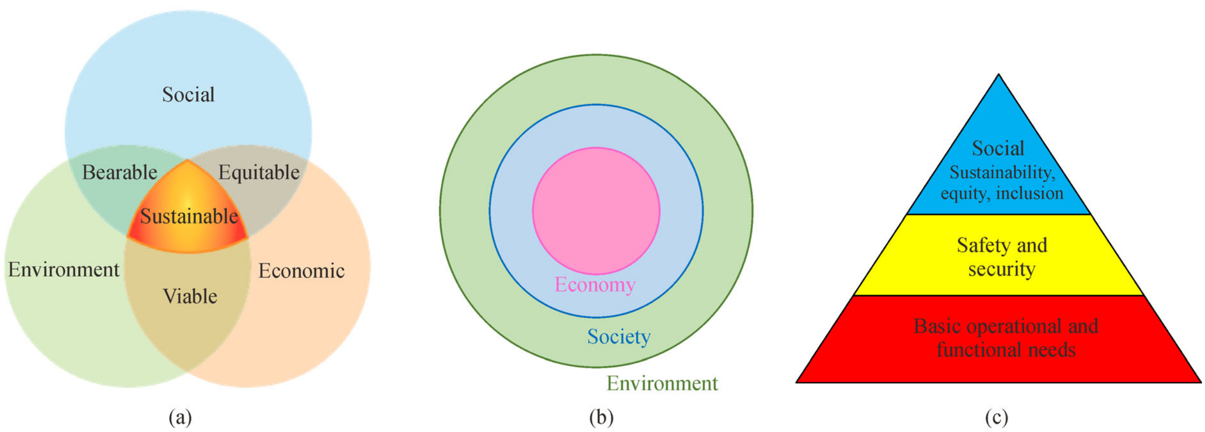

Fig. 2 Sustainability concepts. (a) Triple bottom line (Adams, 2006); (b) Strong sustainability (Maureen Hart. Sustainable Measures as referensed by USDA, 2011); (c) Adaptation of Maslow's hierarchy of needs (2006).

two sections address rating systems that have been developed specifically for airports and roadways.

2.1 BREEAM and CEEQUAL

Building Research Establishment's Environmental Assessment Method (BREEAM) was one of the first methods for the assessment, rating, and certification for sustainability in the built environment. Developed by the Building Research Establishment (BRE) in 1990, it was originally a United Kingdom (UK) organization that provided sustainability assessment for buildings. Sustainability assessment for buildings can have significant impacts at airports. For example, in the US, 46.9% of airport infrastructure needs are terminal buildings (considering airports of all sizes), and terminal buildings represent over half of the development costs at large hub airports (Europe ACI, 2017b).

BREEAM was subsequently expanded to include master planning and infrastructure, as well as application in other countries. This expansion in scope and application was facilitated by the transition of the organization to a private entity in 1997. By 2017, BREEAM had become the most widely used rating system in Europe and with applications in over 70 countries (BREEAM, 2019). Assessments are certified at five levels: Pass, Good, Very Good, Excellent, and Outstanding.

In December 2015, a technical manual was published to pilot a BREEAM program for infrastructure, expanding the scope of the program which also includes buildings (new construction, refurbished and retrofit facilities, and facilities currently in-use) and master planning for communities. BREEAM infrastructure currently is structured around the following categories:

- Integrated design (includes lifetime costing and environmental impacts),
- Stakeholders,
- Land use and ecology,
- Resilience,
- Local wellbeing (economic and social),
- Transport,
- Landscape and heritage,
- Pollution,
- Carbon and energy,
- Materials,
- Waste,
- Water.

The BREEAM infrastructure method is currently being integrated with CEEQUAL (and will be called CEEQUAL 6). CEEQUAL is a sustainability assessment and award system that began in 2003 as an environmental assessment system, has been used for a variety of projects, including airports and roads, as well as bridges, tunnels, buildings, utilities, and water projects; CEEQUAL was acquired by BRE in 2015. CEEQUAL considers the following project impacts (CEEQUAL Ltd., 2017a):

- Project/contract management,
- People and communities,
- Land use and landscape,
- Historic environment,
- Ecology and biodiversity,
- Water environment,
- Physical resources use and management,
- Transport.

Sample airport and roadway infrastructure projects certified through CEEQUAL are shown in Table 1; since BREEAM infrastructure program is currently being piloted, there are no case studies to present. Costs for CEEQUAL are based on the value of the project. Awards may be assessed for the Whole Team (sometimes mandated as a contractual requirement by the client) or for the Delivery Team. For a Whole Team award for an international project, the cost would be £4900 for a project less than £1M and £11200 for a £20M project (CEEQUAL Ltd., 2017b). CEEQUAL can also be used through a term contract (Maintenance and/or Construction), which may be appropriate if an agency has numerous smaller projects.

2.2 LEED

Leadership in Energy and Environmental Design, more widely recognized by its acronym LEED, represents a design framework and certification process sponsored by the U.S. Green Building Council. Since the first pilot in 1998, LEED has expanded from one standard for new building construction to five rating systems and four levels of certification. The rating systems now encompass interior design, operations and maintenance, homes and neighborhood development in addition to design and construction. Certification levels include Certified, Silver, Gold, and Platinum (best) based on a credit system. LEED certification or principles of LEED is often pursued for new airport terminal building construction; it has also been obtained for airport campuses (e.g., Indianapolis International Airport), as shown in Table 2. Although LEED Neighborhood Development does encompass infrastructure at the local level, the emphasis is primarily design rather than construction focused, with an emphasis on site location, design features, a community centered environment, multimodal transportation and conservation. Credits directly affecting construction practices are minimal, and include required credits for Construction Activity Pollution Prevention, and optional credits for Historic Resource Preservation and Adaptive Reuse (2 credits), Minimized Site Disturbance (1 credit) and Recycled and Reused Infrastructure (1 credit), which collectively represent only a small fraction of the possible credits for the total project (4 of 110 credits). Costs include documentation and fees based on project size, with an estimated cost of \$0.05 to \$0.07 per square foot for design and construction review of new construction (U.S. Green Building Council, 2019a).

Table 1 Sample projects certified through BREEAM and CEEQUAL

Facility	Certification	Project	Notable Components
Waddington Runway Refurbishment	CEEQUAL Excellent	Refurbishment of runway and lighting	• Whole Team Award (75.5%) on this secure RAF defense site • First runway project to incorporate major recycling in UK • Pavement refurbishment ranged from overlay (1.2 m) to full reconstruction on runway, thresholds, and taxiways • Project lighting included ground lighting and taxiway lighting
Trafikplats Jung, Kvänum, Sweden	CEEQUAL Very Good	Replacement of intersection with grade-separated interchange (65.48 million SEK)	• Construction Only Award, award was not a contract requirement • Reduced need for lime-cement injections as evidenced by the results of geotechnical survey expedited project schedule (by 10 months) and reduced environmental impact (21% reduction) • Carbon footprint was 21% below original design (saving 487 tons CO_2) due to fewer lime-cement injections and use of grass to prevent erosion rather than gravel • No waste sent to landfill; surplus clay was used to protect groundwater and excavated material was used for community sled run
M1 Widening	CEEQUAL Very Good	Roadway widening and improvements on 10-mile section of M1 (£250 m)	• Whole Team Award on this project to improve safety and reduce congestion on a historic and strategic connection in London • 35-month project resulted in four lanes with continuous shoulder • Included replacement and widening of 18 bridges, utility diversions, and overhead power cables • Noise impacts were reduced through noise barriers and low noise pavement surface • Recycled aggregate was used for pavement (92%) and drainage (40%) • Stormwater plan includes 20% increase in storage capacity (ponds) to accommodate future climate change • Project photo study documented changes and extensive archeological investigation was conducted prior to project

Note: CEEQUAL Ltd., 2017c.

Table 2 Sample projects certified through LEED

Facility	Certification	Project	Notable Components
San Diego Airport[a)]	LEED Platinum, 2014	460000 sf expansion of terminal, 1.3M sf apron and taxiway	• Energy efficient high performance glazed glass and natural lighting, efficient baggage management • Materials selection • Construction waste reduction (> 90% reduced waste) • Energy use monitoring for future operation
Indianapolis International Airport[b)]	LEED Certified, 2012	1.2M sf campus including terminal, concourses, transportation center, parking garage	• Natural lighting, energy efficient HVAC, building controls and water fixtures • Recycling for construction material and terminal operations • Low impact construction including recycled and regional construction materials • Reduction in aircraft taxi times
Santa Barbara[c)]	LEED Gold, 2013	72000 sf included aircraft parking ramp, parking, roadway, and relocation and rehabilitation of terminal	• Recycled concrete and asphalt for new terminal road and parking lot • High efficiency water fixtures (30% reduction) • Bike racks and lockers for alternative transportation • Renewable energy photovoltaic system • Recycled materials for wood
LAX Midfield Satellite Concourse (MSC)[d)]	Designed for LEED Sliver and LAGBC Tier 1	$1.6B five level 750000 sf concourse	• Energy and water conservation • Recycled material use including steel and wood from former Quantas Hangar • Heat island reduction through cool roofs and pavements • Natural daylight in public spaces
Beijing Daxing Intl Airport[e)]	LEED Platinum	Total planned land area of up to 50 sq km	• First project in the world to use LEED for cities: planning and design • Developer of the Beijing New Aerotropolis will use an indicator system to track performance of airport area development
Delhi Indira Gandhi Terminal 3[f)]	LEED Gold including Arc	> 3000000 sf terminal	• Arc provides daily metrics (energy, water, waste, transportation, and passenger experience) for the airport and vendors are based on sensor data and analytics

Note: a) Green Building Elements, 2014; b) Indianapolis Airport Authority, 2012; c) Johns, 2013; d) LAWA, 2016; e) Crea, 2018; f) Crea, 2017.

2.3 Envision

Whereas the focus of LEED is typically buildings, the focus of the Envision rating system is horizontal infrastructure. It was developed by the Institute for Sustainable Infrastructure and the Zofnass Program for Sustainable Infrastructure at Harvard University, and quantifies credits in the categories such as quality of life, leadership, resource allocation, natural world, and climate and risk. The Envision tools can be used at any project stage. As a relatively new tool, over 60 projects have earned Envision awards to date, and there are only a few airports, bridges or roadways. There are, however, hundreds of other projects that may use the Envision program as a tool without completing the verification process. Envision recognizes five achievement levels: Improved, Enhanced, Superior, Conserving, and Restorative (optimal), and includes both quantitative and qualitative assessments for credits.

The Envision system is designed to cover all civil infrastructure including roads, bridges, airports, railways, dams, pipelines, and parks. There is a fee for certification, based on the project size, ranging from $9000 for a smaller project (less than $5M) to $35000 for a larger project (up to $500M) (Institute for Sustainable Infrastructure, 2014). The rating system focuses on design, construction, and operation of the project to ensure continued sustainable operation throughout the life of the asset. The Envision program is centered around five categories (Zofnass Program, 2016):

- Quality of life (physical, economic, and social impact on individuals and communities),
- Leadership (collaboration with stakeholders, management and planning),
- Resource allocation (construction and operations for materials, energy, and water),
- Natural world (siting, land and water, and biodiversity),
- Climate and risk (minimize emissions and resilience to short-term risks such as floods or fires and adaptability to long-term conditions such as changing weather patterns).

In addition to the projects shown in Table 3, Istanbul's new airport was the first airport outside North America to obtain sustainability verification through Envision. The

Table 3 Sample projects certified through Envision

Facility	Certification	Project	Notable Components
Detroit Metropolitan Airport	Envision Silver	Runway 4L/22R and associated taxiway reconstruction	• 6.5 miles of runway (10000 ft long and 150 ft wide) and taxiway • Low-energy LED lighting and signage • Stormwater management, including stormwater re-use for dust control (10M + gallons to date) • Re-use of excavated materials on site • Holistic decision-making and resilient design • Improved long-term durability of runway will reduce maintenance needs and costs and increase operational efficiency
T.F. Green Airport (PVD) in Providence, RI	Envision Gold	Runway 5 extension to enhance safety and accommodate more aircraft	• Sustainability was identified as a main objective during the design phase • Quality of life benefits include job creation and regional accessibility, as well as partnerships with local schools • A taxiway connector and hold bay were eliminated from the design to reduce both capital and maintenance costs (including lighting, signage, and pavement costs as well as reduced stormwater runoff)
I-4 in central Florida	Envision Platinum	21-mile corridor reconstruction (design and construction cost $2.32B)	• Public-private partnership (P3) with 40-year P3 concession agreement • Relocated protected wildlife • Used efficient machinery • Controlled stormwater runoff and prevents construction pollutants from contaminating soils, surface water, and groundwater • Four underground storage tanks and petroleum impacted soils (145 tons) removed from project site • Removed 99% of concrete and steel from roads and bridges • Integrated rail projects, bike trails, and pedestrian projects • Project will ease congestion and increase connectivity among communities • Variable toll express lanes
San Diego Intl Airport Parking Plaza	Envision Gold	Three level parking garage with 3000 parking spaces	• 11 acres and 1M sq ft • Includes reservation, assist to locate vacant parking space, and streamlined payment • Increased safety with reduced visual obstructions • Efficient access and egress for special events • Utilizes advanced technologies such as automated vehicle identification and payment via cell phone • Improved public spaces that incorporate public art • Solar panels provide renewable energy

Note: Envision, 2017; 2019.

airport also completed a sustainability assessment using the International Finance Corporation (IFC) Standards and the Equator Principles in 2015. These principles support sustainable development by shifting financial capital to projects that utilize sustainable practices and support an inclusive economy (Weber and Acheta, 2016). This illustrates that some airports use multiple sustainability metrics to quantify their activities.

2.4 GRI Standards

The Global Reporting Initiative, more commonly known by the acronym GRI, is an internationally recognized framework for sustainability reporting that was formed with the support of the United Nations. The GRI Standards are very different than rating systems such as LEED, CEEQUAL, Greenroads and Envision. The GRI Standards provide guidelines for an organization to report its sustainability efforts (such as in a corporate sustainability report or an annual report for a public organization such as an airport). Rating systems such as LEED, CEEQUAL and Greenroads provide a certification from an independent entity for a specific facility. Although there are important differences, both the GRI Standards and rating systems may have an important role for airports.

The first guidelines were published in 2000. The original sustainability standards were the G4 Guidelines, which will be recognized until July 2018, although they have been superseded by the more recently developed GRI Standards (aka the GRI Sustainability Reporting Standards) (GRI, 2018). Both the G4 Guidelines and the GRI Standards provide a tool for organizations to articulate sustainability goals with stakeholders and quantify achievements. Since the GRI Sustainability Reporting Guidelines are relatively new, and there is more historic information regarding the G4 Guidelines, the G4 Guidelines are discussed in this paper. Additional guidance relevant for roads and airport includes construction and real estate supplements, as well as airport operator supplements. The construction and real estate sector supplements encompass buildings, as well as roads, tunnels, bridges, and airports. These supplements disclose information related to economic (e.g., procurement practices), environmental (e.g., materials, energy, water, emissions, transport, noise), and social (e.g., labor practices, human rights, and society) considerations. Airport operator information may be relevant not only for airport operators, but also for contractors who provide construction services at airports, including on-going services for activities such as pavement maintenance. Due to the high standards and tight tolerances for runways, pavement maintenance is an important on-going activity for many large airports. Although internationally airports are increasingly utilizing this reporting system, US airports have historically been slower to do so, and may be more likely to use metrics developed specifically for airports. There are exceptions, for example, the Indianapolis International Airport included GRI indicators in the 2013 IAA Sustainability Report (White et al., 2013). The most recent compilation of top ten airports based on sustainability using the G4 Guidelines included airports in New Zealand, Asia, and Europe (Jordao, 2009). The airport operators sector supplement addresses six major areas (GRI, 2009):

- Economic,
- Environmental (materials, energy, water, biodiversity, emissions, and noise),
- Labor practices and decent work (employment, worker safety and injuries, and equal opportunities),
- Human rights (procurement practices, non-discrimination, and child labor),
- Society (local communities, anti-corruption, and fair competition),
- Product responsibility (consumer satisfaction, fair marketing, consumer privacy, emergency preparedness, and services for those with special needs).

Topics of greatest interest based on a review of sustainability reporting in the airports sector include (GRI, 2009):

- Air quality,
- Energy,
- Solid waste reduction and recycling,
- Noise abatement,
- Health and safety,
- Water conservation and management.

Airports may evaluate their sustainability independently in accordance with the GRI G4 Guidelines (and now the GRI Sustainability Guidelines), and self-report to the GRI. Results are available in a combined database called the GRI sustainability disclosure database; 37 organizations have reported results to this database (based on a search with the keyword airport, in the aviation sector). The 33 organizations reporting results during the years 2014 through 2018 are shown in Table 4. These results illustrate that some airports may conduct sustainability assessment with multiple systems. For example, Dallas Fort Worth (DFW) has utilized both the GRI G4 and the ACI Airport Carbon Accreditation rating systems, and San Diego has utilized GRI and LEED. Other airports may utilize one rating system one year and another rating system in subsequent years. For example, the Indianapolis Airport utilized the G4 in 2014 and began using the ACI Airport Carbon Accreditation in 2016 (IIA, 2017).

2.5 ISO 14001

ISO 14000 provides an internationally recognized framework for the establishment and implementation of an environmental management system (EMS) by the International Organization for Standardization (ISO). ISO 14000 is different than a rating system for a building system (e.g., LEED) or a road system (e.g., Greenroads) or a reporting

Table 4 Organizations in aviation sector (keyword airport) in GRI sustainability database

Organization	Years	Region
Airport Authority Hong Kong (China)	2014, 2015, 2016	Asia
Beijing Capital Intl Airport	2017	
Hong Kong (China) Airport Services	2014, 2015, 2017	
Airports of Thailand	2014, 2015, 2016, 2017	
Incheon Airport	2014, 2015, 2016	
Korea Airports Corporation	2014	
Kaohsiung Intl Airport	2016	
Malaysia Airports	2014, 2015, 2016, 2017	
Mumbai Intl Airport	2014, 2016, 2018	
Sheremetyevo Intl Airport	2018	
Tallinn Airport	2018	
Athens Intl Airport	2014, 2015, 2016, 2017	Europe
Brussels Airport	2014, 2015, 2016, 2017	
Dortmund Airport	2018	
Heathrow Airport	2014, 2015, 2016, 2017, 2018	
Krakow	2018	
Malta Intl Airport	2016, 2017	
Manchester Airports Group	2014, 2015, 2016	
Munich Airport	2014, 2015, 2016	
Sheremetyevo Intl Airport	2017	
Tallinn Airport	2014, 2015, 2016, 2017	
Vienna International Airport	2015	
Auckland Intl Airport	2015, 2016, 2017	Oceania
Brisbane Airport Corporation	2016	
Christchurch Intl Airport	2017	
Sydney Airport	2015, 2016	
Austin-Bergstrom Intl Airport	2014, 2015, 2017, 2018	Northern America
Dallas/Fort Worth Intl Airport	2014, 2016	
Edmonton Intl Airport	2015, 2016, 2017, 2018	
Indianapolis Airport Authority	2014	
Metropolitan Airports Commission (MSP)	2016	
San Diego Intl Airport	2014	
Lima Airport Partners	2015, 2016, 2017	Latin America & Caribbean

Note: GRI, 2016.

standard (e.g., GRI). ISO 14000 specifies criteria for an effective environmental management system (EMS).

While ISO was originally founded in 1947, the environmental management system 14000 series was initiated in 1996 as a framework for voluntary regulation rather than certification. The ISO 14000 series can be used for internal information, as well as to communicate an environmental commitment to the public, customers, and clients. ISO 14001 provides a framework to improve resource efficiency, reduce waste, and control costs. Organizations set their own targets, and then use the tools provided by ISO 14001 to implement environmental control processes, perform monitoring, compare results with objectives to evaluate performance, and change tactics to renew or modify plans and goals, as needed (ISO, 2015).

The number of construction firms that have implemented ISO 14001 is limited, largely because it is not always economically feasible, has not been demanded by clients, and has not been demonstrated to result in significant environmental benefits (Valdez and Chini, 2002); however, internationally, it has been recognized as a potential catalyst for improvement (Zeng et al., 2003).

Air cargo operators, who typically work at multiple airports, have implemented ISO 14001 in recent years for operations at selected airports. Examples include Scandinavian Airlines in Norway and Denmark in 2010 (SAS, 2010); China Airlines in Songshan in 2013 (China Airlines, 2014); Lufthansa Cargo in Singapore, Tokyo, and Delhi in 2015 (Cargo Trends, 2015); and LAN Cargo in Miami in 2016 (Air Cargo News, 2016). International Air Transport Aviation (IATA) also has a voluntary Environmental Assessment (IEnvA) tailored for use by companies focused on air operations, however since its focus is primarily operations rather than infrastructure, it is not included in this paper.

Larger airports such as Toronto Pearson Intl Airport, Miami Intl Airport, and Denver Intl Airport, were early adopters of ISO 14001 certification in North America (Miami International Airport, 2007). European airports may have embraced this certification earlier, as exemplified by Brussels Airport Company, which has been certified since 2000 (Payload Asia, 2017). More recently, India's Indira Gandhi Intl Airport in New Delhi uses ISO 14001 to support assessment for activities (Indira Gandhi International Airport, 2019). Smaller airports, such as the Westchester County Airport (north of New York City), which was recognized in 2004 for its progressive environmental practices, may also be certified. Airports may use the Environmental Management System (EMS, also called Airport Environmental Management Systems or AEMS), which is a certification through ISO 14001 and provides a mechanism not only for monitoring environmental performance and management practices, but other important activities such as employee training. Additional guidance for airports in the US is provided in Advisory Circular (AC) 150/5050-8, Environmental Management Systems for Airport Sponsors. This provides a frame of reference, but does not provide a lot of detail, although it does reference the ISO 14000 series. This AC, which affects large and medium hub airports that choose to develop and complete an EMS at the airport, is only six pages of narrative, was developed in 2007, and has not been updated since then (FAA, 2007).

3 Airport sustainability practices and tools

In addition to the internationally recognized sustainability rating systems and tools discussed in the previous section that are broadly used in the built environment, there have been a number of sustainability rating systems developed specifically for the airport sector. Top sustainable construction practices in the airport industry include: reuse and recycling of construction aggregate, implementation of energy efficient products, use of local materials, LEED certification, life-cycle analysis, equipment requirements such as anti-idling campaigns, and minimizing site disturbance for erosion and stormwater control. Incentives for sustainable practices include cost considerations, compliance with local zoning, permitting, and local government sustainability requirements. Possible impediments to sustainable practices include the need for compliance with strict requirements for airports, including Federal Aviation Administration (FAA) and International Civil Aviation Organization (ICAO) regulations. For example, warm-mix asphalt (WMA) requires a lower temperature than hot mix asphalt (HMA), saving fuel and reducing emissions. It is increasingly used in roadway applications. However, it is not widely used in airport applications. Although WMA was used in 2009 on a runway at Boston's Logan Airport, and in 2012 on a taxiway at O'Hare Airport, applications are limited since FAA does not have a specification for WMA and FAA. Previous research for airport applications indicates that WMA may have a lower lifespan, and a lower tolerance for high summer temperatures (Ricondo et al., 2011). More recent trends in WMA include a variety of additives to reduce the viscosity of the binder at lower temperatures (e.g., some additives create foaming effect in binder and others provide better dispersal). While these technologies may hold promise for the future, as recently as 2017 FHWA suggests they should be considered experimental, and typically airport applications lag highway applications (FHWA, 2017a).

Material reuse includes recycled aggregate and vegetation. Although there are limits related to FAA specifications for runway and taxiway use of recycled materials, recycled aggregate can be used as backfill, and on the landside at airports. The FAA provides strict regulations regarding construction and standards on the airside of airports (the airside includes runways, taxiways, ramps, and other facilities for aircraft). There is much more latitude for utilization of recycled and alternative materials for construction on the landside of airports, which includes the terminals and facilities for passengers and ground access to the airport. In the $300M Terminal Oakland International Airport Improvement Program, three on-airport sites were established to facilitate reuse of asphalt and concrete, and also vegetation and soil (Ricondo et al., 2011). It is estimated that over 500000 cy of construction materials will be recycled in the next five years, saving $5M (Port of Oakland, 2007).

There are a number of sustainability metrics developed specifically for airports. Examples include the Airport Carbon Accreditation program developed by the Airports Council International (ACI), and rating systems developed by airport sponsors such as the Chicago Department of Aviation and Los Angeles World Airports. These tools are targeted specifically for airport infrastructure and are applicable for implementation by other airports. Other airports have also developed self-assessment programs. However, this discussion is limited to the programs developed by Chicago and Los Angeles, which illustrate the possibilities.

3.1 Airport Carbon Accreditation

The Airports Council International (ACI) developed the Airport Carbon Accreditation program to encourage airports to reduce their carbon dioxide emissions and to provide a mechanism to measure their carbon footprint; accreditation is based on assessment of airport activities practices, in combination with an independent verification of carbon monoxide measurements taken in compliance with ISO 14064 (greenhouse gas emissions). There are four levels of certification with the Airport Carbon Accreditation program: Mapping, Reduction, Optimization, and Neutrality (best). ACI refers to airports that are certified at any of the four levels as accredited airports. This highlights the fact terminology may vary from one rating system to another. The first airport was accredited in 2009 (Frankfurt) and within 5 years over one hundred airports were accredited, representing airports that serve over a quarter of the world's air passenger traffic (Europe ACI, 2017a). By 2017, there were almost 200 airports in the program, representing almost 40% of the world's passenger traffic. By 2019, the ten-year anniversary of the program, there were 264 airports involved, with 49 airport operators designated as carbon neutral (Europe ACI, 2019). The program has been revised over time to adapt to airport needs, with changes such as the incorporation of emissions from construction activities at the airport. Sample airports that use the ACI Airport Carbon Accreditation Program are shown in Table 5. A summary of the airports that use the ACI Airport Carbon Accreditation Program are shown in Table 6. Use of the Airport Carbon Accreditation program is most common in Europe, where 139 airports utilize this rating system, followed 54 accredited airports by Asia, 39 airports in North America, and 20 airports in Latin America and the Caribbean (Europe ACI, 2009).

3.2 Chicago Department of Aviation

The Chicago Department of Aviation (CDA) developed the Sustainable Airport Manual to support activities at both O'Hare and Midway airports, as well as for use by other airports (CDA, 2014). The manual covers administrative procedures, planning, design and construction, operations and maintenance, and concessions and tenants. A substantial portion of the manual is devoted to design and construction, and encompasses a range of topics including sustainable sites, materials, resources, and construction practices, as shown in Table 7. The manual provides a comprehensive means for assessing sustainability using checklists and points to assess proposed plans and ongoing progress toward organizational goals. Activities at O'Hare and Midway must comply with all the sustainability requirements of the City of Chicago, since the airports are owned by the city. The manual and associated rating system is available online, and may be used by other airports for self-assessment (CDA, 2014).

3.3 Los Angeles World Airports

Los Angeles World Airports (LAWA) developed Sustainability Vision and Principles in 2007, and has confirmed their commitment to sustainability in subsequent documents such as the Sustainable Airport Planning, Design and Construction Guidelines in 2010, which focused on an economic, environmental, and social framework for sustainability and encompasses culture change, stakeholder engagement, and awareness building. The manual provided a point system for the categories Planning and Design and Construction to attain the three sustainable levels: Sustainable, Business Class, and First Class (best). In addition to planning and design guidelines, there was a list of construction performance standards, a construction checklist, and a certification statement to support sustainable construction. Sample categories for the construction checklist included: project logistics, contractor sustainability, stormwater management and erosion control, construction water conservation, construction air quality, construction waste management construction vehicles and equipment, noise control, lighting, landscape maintenance, health and safety. An excerpt of the checklist is shown in Fig. 3.

In 2017, LAWA developed a Sustainable Design and Construction Policy (LAWA, 2017a) and Sustainable Design and Construction Requirements (LAWA, 2017b). The overarching theme of the policy and design and construction requirements is environmental responsibility throughout the life-cycle, and environmental responsibility and resource efficiency for all facets from siting and design, through construction, operation and maintenance, as well as renovation. Reference standards are based on other sources, plans and documents. Most new buildings and building renovation projects must achieve a minimum of LEED Silver certification. Runways, taxiways and other

Table 5 Sample airports using ACI Airport Carbon Accreditation Program

Facility	Certification	Notable Activities
Sea-Tac[a)]	Optimization	• Use of carbon free hydro-electric power eliminates carbon emissions for electricity • Carbon emissions due to natural gas used to power buses, boilers and provide hot water • Use of biofuels being studied in conjunction with Alaska Airlines and Boeing • Clean taxi program assures use of alternative fuels or high efficiency vehicles • One of the fastest growing airports in the US
London-Heathrow[b)]	Optimization	• Replaced 70000 airport lights with LED • Reduction of 540000 tonnes of carbon monoxide in 16 months • The busiest airport in Europe and the busiest airport in the world in terms of passenger traffic • Other sustainability initiatives include composting food waste and replacement of Terminal 1 restroom and pipe system to reduce water use
Indianapolis Airport[c)]	Reduction	• In 2016, IND achieved the Mapping level; in 2017, IND received the Reduction Accreditation
Chengdu Shuangliu Intl Airport[d)]	Mapping	• In 2019, China's Chengdu Shuangliu Intl Airport (CTU) and Zhengzhou Xinzheng Intl Airport (CGO) became two of the 54 airports accredited through ACI in Asia

Note: a) Europe ACI, 2011; b) Heathrow, 2016 and Europe ACI, 2010; c) Europe ACI, 2017c; d) Europe ACI, 2019.

Table 6 Worldwide use of ACI Airport Carbon Accreditation Program

Region	Certification Level	Number of Airports	Number of Countries	Passenger Traffic (in region)	Example Airport
Asia Pacific	Mapping	12	4	5.3%	Chengdu Shuangliu
54 total	Reduction	17	9	9%	Abu Dhabi
	Optimization	19	10	18.3%	Hong Kong (China)
	Neutrality	6	3	4.8%	Indira Gandhi (Delhi)
Europe	Mapping	42	12	4.0%	Malta
139	Reduction	33	14	14.3%	Tel Aviv Ben Gurion
	Optimization	24	11	21.3%	Frankfurt
	Neutrality	40	13	24.2%	London Gatwick
Africa	Mapping	7	4	14%	Port Elizabeth
12 total	Reduction	4	3	17.2%	Cape Town
	Optimization	0	1	1.1%	Felix Houphouet-Boigny
	Neutrality	1			Abidjan
North America	Mapping	11	2	2.5%	Winnipeg Richardson
39 total	Reduction	16	2	13.2%	Phoenix Sky Harbor, IND
	Optimization	11	2	21.9%	Toronto Pearson, LAX
	Neutrality	1	1	3.6%	Dallas Fort Worth
Latin America &	Mapping	14	8	14.6%	San Jose Juan Santamaria
Caribbean	Reduction	4	4	1.9%	Puerto Vallarta
20 total	Optimization	1	1	0.8%	Quito
	Neutrality	1	1	0.1%	Galapagos Ecological

Note: Europe ACI, 2009.

Table 7 Selected Construction Components in CDA Sustainable Airport Manual

Sustainable Sites	Materials and Resources	Construction Practices
Construction activity pollution prevention	Building and infrastructure reuse	Clean fuel and low-emission construction vehicles
Adopt CDA Best Management Practices	Construction waste management	Construction equipment maintenance
(BMP)	Balanced earthwork	Construction activity pollution prevention
Brownfield redevelopment	Aggregate and material reuse	Construction waste management
Stormwater Design	Recycled content	Construction material conveying
	Local/regional content	Construction noise
	Equipment salvage and reuse	Sustainable temporary construction materials

Yes	Maybe	No	Possible Points	Performance Standard
Construction Indoor Air Quality				
			1	Construction IAQ During Construction
			1	Construction IAQ After Construction
			2	Total
Construction Waste Management				
			1	Recycle & Reuse of Construction Materials
			1	Recycle & Reuse of Construction Materials
			2	Salvage Materials & Resources
			4	Total

Fig. 3 Excerpt from LAWA Sustainable Airport Checklist (LAWA, 2010).

non-building projects must incorporate concepts from LEED, as well as Envision, and other airport sustainability guidelines, specifically the Chicago Department of Aviation Sustainable Airport Manual and the Port Authority of New York and New Jersey (PANYNJ) Sustainable Building Guidelines (2017) and PANYNJ Sustainable Infrastructure Guidelines (2011). California and local standards are also referenced, including the Los Angeles Green Building Code (LAGBC) and CALGreen, as is the LAX Landside Access Modernization Program, which provides a plan for a new ground transportation network.

3.4 Sustainable practices in airport construction and operation

Sustainability is an important and growing consideration for airports. Many airports have utilized a variety of metrics to assess their sustainability. For example, the Austin-Bergstrom International Airport has LEED Silver certification for its taxi staging area, participates in the GRI, as well as the ACI Airport Carbon Accreditation program. A proactive approach to sustainability reflects the fact that many airports strive to be a strong partner in their communities, quantifying and communicating the role of sustainability at airports is often very valuable both for internal airport assessments, and for communicating the value of airport activities to community stakeholders.

4 Surface transportation sustainability practices and rating systems

There are a number of sustainability rating systems for roads, however, the results of these rating systems are less widely reported. Even though sustainable practices such as warm mix asphalt and recycled aggregate are increasingly used by roadway agencies, there may be less demand for associated rating systems. While sustainability metrics for roads may rarely make headlines, a number of systems have been developed. Example sustainability reporting systems discussed in this paper include: Infrastructure Voluntary Evaluation Sustainability Tool (INVEST), Greenroads, GreenLITES (Leadership in Transportation Environmental Sustainability) program, and the Illinois-Livable and Sustainable Transportation rating system (I-LAST). GreenLITES and I-LAST illustrate that the development of a rating systems is merely the first step; although both systems have technical merit, neither was ever widely implemented. The inclusion of these rating systems highlights the fact that a rating system does not have an impact unless it is implemented.

4.1 INVEST

Infrastructure Voluntary Evaluation Sustainability Tool (INVEST) is a sustainability metric that was developed by the Federal Highway Administration (FHWA). It was piloted in 2012 and released in 2015 (Federal Highway Administration, 2019); the current version is INVEST Version 1.3. INVEST has modules for system planning at the state and regional level, project development and operations and maintenance. Each module has different criteria, and all are intended for self-evaluation. INVEST has been used by 15 states for statewide planning and 23 organizations for regional planning (e.g., metropolitan planning organizations). INVEST has also been used for project development, and considers 33 criteria that reflect planning and design, as well as construction. There are separate scorecards that can be used depending on the type of project (e.g., paving vs. recreational) and the location (urban vs. rural), and scoring can be customized for the application. One example of a case study that used the INVEST rating system for a roadway project is the Cleveland Innerbelt Corridor and George V. Voinovich Bridge. This project, which had to balance the needs of an interstate highway with those of a historic district. The project earned a gold rating for Phase I. The project saved 22M gallons of water, saved 100000 gallons of diesel fuel, prevented more than 125000 cubic yards of waste from entering landfills and utilized LED lighting to reduce energy use by 57%. The project also reused a significant amount of material including over 2000 tons of rebar, 13000 tons of concrete, and 5.6M pounds of steel (Ohio Department of Transportation (ODOT) and Trumbull Great Lakes-Ruhlin, 2017). A second example of an INVEST project is a bridge in Arizona that used recycled steel from a building for rebar in a freeway project. In addition to saving 24000 tons of iron ore, 13000 tons of coal, and 1000 tons of limestone through recycling, this project kept materials out of landfills, reduced the need to mine virgin materials, and utilized local Disadvantage Business Enterprise partners (Fluor, 2017). Arizona DOT (ADOT) has institutionalized the use of INVEST and has incorporated its concepts into a variety of projects (repaving projects, corridor planning, vegetation management, lighting projects, and context sensitive solutions) as well as manuals and guidance documents. ADOT has developed a Sustainable Transportation Program that institutionalizes sustainability into planning, design, construction, operation, and maintenance activities, as well as administrative activities (ADOT, 2019). ADOT also has a Sustainable Pavement Program and a Resilience Program to ensure safety, efficiency, and cost factor in heat extremes and natural disasters such as wildfires, flooding, and landslides (ADOT, 2019).

4.2 Greenroads

Greenroads is a rating and certification system for sustainability on transportation projects. A Greenroads Rating (also called an Assessment) is a score that is based on project compliance with mandatory requirements and voluntary core and extra credit points. Projects that meet all mandatory requirements and score a minimum number of points in the Assessment are eligible to pursue a Greenroads Certification Award, which is a more formal, rigorous, and lengthy process. The certification process tracks progress throughout the project, and eligible projects may be awarded a bronze, silver, gold, or evergreen (best) Certification Award if Greenroads International determines that all project requirements have been met (Greenroads International, 2016). Projects can also be designated as pilot projects. The designation of Pilot Project is less formal than Certification, but it follows the same basic process, and provides an opportunity for project sponsors to learn about Greenroads; Pilot Project designation is typically most appropriate for projects that are well underway and serves as a resource for future projects

(Greenroads Foundation, 2017a).

Every Greenroads project must meet requirements addressing the following 12 areas: ecological impact, energy and carbon footprint, low impact development, social impact, community, lifecycle cost, quality control, pollution prevention, waste management, noise and glare, utility conflict, and asset management. Points can be scored by activities that address the core areas of environment and water, construction, materials and design, utilities and controls, and access and livability. Construction Activities are included for items such as workzone health and safety, equipment fuel efficiency, and accelerated construction schedule. Materials and design include items such as recycled and recovered content, local materials, and long-life design (Greenroads Foundation, 2017b).

Over 120 projects are registered around the world (Greenroads Foundation, 2016). Fees vary; there are costs to register a project (which provides access to the rating system), for educational support, to obtain a rating, and to complete certification. For an active project with less than one year before notice to proceed, registration for the first year is approximately $5000, with subsequent years costing $500 per year (Greenroads Foundation, 2017c). Sample Greenroads projects are shown in Table 8.

Construction of the 183 South project reflects the addition of new toll lanes in an existing corridor, in conjunction with improvements to the existing lanes and enhanced facilities for bikes and pedestrians. This project, which provides a connection to the Austin Bergstrom International Airport, is a design/build project that is currently underway, and the Greenroads status is Pilot Project. Construction of Bagby Street represents a reconstruction and the project was successfully completed with a Greenroads Silver Certification (Greenroads Foundation, 2016).

4.3 GreenLITES

New York State Department of Transportation (NYSDOT) has also been a leader in the area of sustainability, with the development of the GreenLITES (Leadership in Transportation Environmental Sustainability) program, a self-certification program with four levels: certified, silver, gold, and evergreen (best). One guiding principle of GreenLITES is to increase the awareness of sustainability, and the self-certification framework is flexible to accommodate local and regional priorities. It reflects five categories: sustainable sites, water quality, materials and resources, energy and atmosphere, and innovation. The innovation category can encompass construction, including (NYSDOT, 2011):

- Avoiding trees and established vegetation,
- Sound erosions and sediment control,
- Designation of a qualified environmental construction monitor to oversee sensitive environmental areas,
- Seeding clear zones to reduce the need for future maintenance and increase carbon sequestration,
- Reuse of trees,
- Removal of contaminated soil beyond project requirements,
- Specification of local seed stock and plants.

4.4 I-LAST

Illinois Department of Transportation (IDOT) has developed a sustainability program called the Illinois-Livable and Sustainable Transportation rating system (I-LAST), a tool to evaluate the use of sustainable practices and the impact of these projects on the livability, sustainability, and the environment. I-LAST is a scorecard for self-assessment that addresses 153 items in the areas of planning, design, environmental, water quality, transportation, lighting, materials, and innovation. The program was developed in conjunction with Illinois builders and engineers associations (Illinois Department of Transportation and Illinois Joint Sustainability Group, 2012).

The impact of sustainability efforts for road construction can be substantial. In Illinois, it is estimated that the amount of recycled material in highway projects has increased 4-fold in the four years from 2009 to 2013. One innovative total recycle asphalt process utilizes 97% recycled material, including recycled concrete and slag for aggregate, recycled asphalt pavement (RAP) and shingles (RAS). The remaining 3% of new material is asphalt binder. Another sustainable initiative is the

Table 8 Sample Greenroads certified and registered projects

Facility	Status	Project	Notable Components
183 South Bergstrom Expressway, Austin TX[a)]	Pilot Project	Widen 8 miles of US 183, adding toll lanes, improving existing lanes, and adding bike and pedestrian paths, sidewalks, and cross-street connections	• Community tree planning near project corridor • Reduced construction noise, light, and emissions • Restoration of historic Montopolis Bridge will serve bikes and pedestrians • New trailhead and park at Colorado River will be constructed • Protect wildlife and their habitats • Reduce noise impacts and minimize air quality impacts (including emissions and dust control)
Bagby Street Reconstruction, Houston TX[b)]	Greenroads Silver Certified, 2013	0.62 mi of reconstruction on a collector for $9.6M	• Cool pavement: reduce impact on air temperature due to pavement reflectance and minimize stormwater runoff temperatures by using porous pavement • Regional and recycled materials

Note: a) Central Texas Regional Mobility Authority, 2019; b) Greenroads Foundation, 2016.

replacement of cement with fly ash and blast furnace slag in concrete (Lippert et al., 2013).

4.5 Sustainable practices in roadway construction

One of the ways agencies support sustainable roadway construction is to utilize recycled materials such as WMA. Use of recycled materials and WMA not only supports sustainability but also reduces overall project costs. As these practices become more widely used, they are included in standard specifications for state roadway construction. States are not only using a wider variety of recycled materials, but are also finding ways to increase the percent of recycled materials. As demonstration and early projects mature, the longevity of construction methods can be more accurately evaluated. Although many sustainable practices such as use of recycled aggregate have become incorporated into standard policies, it is less common for agencies to quantify the impacts of these and other activities in sustainability metrics. FHWA has developed the INVEST rating scheme, but it is voluntary. The impact of FHWA's leadership in sustainable design and construction cannot be underestimated since FHWA provides funding (and associated constraints) for both state and local projects. Historically, FHWA provided guidance that recycling initiatives must be cost effective, environmentally responsible, and provide adequate performance (FHWA, 2017b).

It is likely that sustainability metrics will become increasingly important for projects in the future, although it is not currently a required component by funding agencies, or the public. Although some agencies, such as Caltrans, may utilize practices that exceed environmental mitigation requirements, these practices are not always recognized or collectively referenced into a sustainability framework (Sousa and Way, 2013). For example, an analysis of the widening and realignment of State Route 76 in San Diego suggested that the project would be eligible for a Greenroads Silver rating and an INVEST gold rating, however, no rating system was explicitly used during the design or construction of the project, other than the practices typically used by the District 11 office (Sousa and Way, 2013).

5 Discussions

The most successful sustainability initiatives are cost effective, and provide adequate performance in addition to reducing negative environmental impacts, and supporting a community's social and economic development goals. In some cases, sustainable practices often become the de facto design standard and are written into standard construction specifications (e.g., Iowa DOT, 2010; ODOT, 2015; ADOT, 2019). Sustainability is also supported by an increased focus at the federal level, as evidenced by increasing requirements for asset management and life cycle cost analysis, as well as development of the INVEST tool. A comparison of the different sustainability metrics discussed in this paper is provided in Table 9.

Sustainability metrics include legacy and newer systems that require independent, third-party certification (e.g., BREEM, CEEQUAL, LEED, and Greenroads). A number of metrics have been developed to support independent self-assessment; many of these have been developed by government agencies rather than non-profit agencies. These self-assessment tools often provide a structure that allows an organization to tailor the tools to meet their specific objectives and needs. The capability to self-assess also provides significant advantages in terms of lower cost. The lower cost reflects elimination of the cost for certification, as well as reduced cost for internal staff time devoted to providing the documentation required by the certifying agency.

For roadway and surface transportation projects, perhaps the most notable impact of sustainability practice is the synergistic effect that occurs when state and local agencies take a leadership role in sustainability. For example, the sustainability efforts at the state level in Illinois, Washington State, and New York State have created a framework that supports local efforts to implement sustainability. Many local agencies utilize state specifications, both for convenience and to assure eligibility for state funded local projects. As a result, incorporating sustainable practices at the state level can have a multiplier effect. For example, once a plant is set up for the use of RAS, it will continue to use mixes that utilize RAS, and local agency projects may use as much or more than state projects (Lippert et al., 2013). The resulting multiplier effect can be dramatic since there are approximately four times as many miles of local roads as state roads in the US (US Census, 2008). There is no completely analogous framework for airports, since airport oversight and funding are often at the local and national level, with less impact at the state level. If an airport authority has jurisdiction over multiple airports, the smaller airports (perhaps reliever airports) may benefit from policies developed for the larger airport.

In another example of multi-agency and multi-modal synergy, the implementation of WMA on taxiways in the O'Hare modernization project was supported by research conducted at the University of Illinois, in support of sustainability research funded by IDOT. Without the support of IDOT and the University of Illinois, O'Hare may not have been the first airport in the Great Lakes Region (and among the first in the US) to utilize WMA on a new taxiway (Ande, 2012). The synergistic effect of sustainability is also seen in a multimodal context at O'Hare. Because there are limitations regarding the use RAP in runway pavements, there is substantial RAP available when runways are reconstructed. In Chicago, the excess RAP is utilized in nearby roadway projects that do not have RAP limitations associated with them. In this

Table 9 Comparison of sustainability metrics

Method	Traditional Application or Developer	Scope	Awards and Notable Components
BREEAM	Buildings in Europe	Certification for buildings, master planning, and infrastructure	• Pass, Good, Very Good, Excellent, and Outstanding
CEEQUAL	Infrastructure in Europe	Certification for civil engineering, infrastructure, landscaping, and public projects Topic areas: project management, land use, landscape, ecology and biodiversity, historic environment, water resources, energy and carbon, material use, waste management, transport, neighbors, community relations	• Whole Team (formerly whole project), Interim Client & Design, Client & Design, Design (if client and contractor do not wish to participate), Design & Construction, Construction • Being integrated with BREEAM in future
LEED	Buildings in the United States	Certification for design and construction, interior design, operations and maintenance, homes and neighborhood development	• Certified, Silver, Gold, Platinum
Envision	Horizontal infrastructure	Certification for design, construction and operation of all civil infrastructure including roads, bridges, airports, railways, dams, pipelines, and parks Design categories include: quality of life, leadership, resource allocation, natural world, climate and risk	• Improved, Enhanced, Superior, Conserving, and Restorative • Program may also be used without formal certification
GRI	Organizational reporting	Guidelines for organization to self-report sustainability efforts Special supplements for construction, real estate, and airport operators	• Previously referred to as G4 Guidelines • Organizations develop their own sustainability goals and can use GRI to quantify achievements
ISO 14001	Environmental Management Systems	Supports internal information and communication with public, customers, and clients Provides framework to increase resource efficiency, reduce waste, and control costs	• Framework for voluntary regulation rather than certification • Tools support environmental control processes, monitoring, comparison of objectives and results, and continuous improvement
Airport Carbon Accreditation	Developed by Airport Council International	Mechanism to measure airport carbon footprint	• Mapping, Reduction, Optimization, and Neutrality • Accreditation is based on practices and independent verification of CO measurements
CDA Sustainable Airport Manual	Developed for O'Hare and Midway	Includes administrative procedures, planning, design and construction, operations and maintenance, and concessions and tenants	• Supports self-assessment based on checklists and points • Best management practices are identified
LAWA Sustainable Design	Developed for Los Angeles World Airports	Includes economic, environmental, and social framework for sustainability and provides point system for planning, design, and construction	• Sustainable, Business Class, and First Class Supports self-assessment based on checklists, design guidelines, and performance standards

case, although the RAP is not utilized on site, overall transportation costs are minimized by using it locally and regionally, landfill costs are reduced, and less new material is required.

An examination of certification tools for sustainability and the application of these tools in the transportation sector highlights interesting similarities and differences between the aviation and roadway sectors. In terms of similarities, both sectors are increasingly integrating sustainable practices into planning, design, construction, and operation. In terms of differences, the aviation sector seems more likely to utilize third-party certification criteria (e.g., ACI Carbon Accreditation, LEED and ISO). 264 airports participate in the ACI Carbon Accreditation program, representing 43.7% of the global air passenger traffic (Europe ACI, 2017b) utilizing a program that is only ten years old. Similarly, airports often utilize LEED certification: a search of projects in the USGBC library with the keyword airport identified in 472 LEED projects (USGBC, 2019a). LEED projects in the airport environment reflect a wide variety of projects including air traffic control towers, rental car facilities, terminals and airport campuses. The collective interest in sustainability in aviation may reflect the fact that airports are often a symbol of their community. Similarly, public interest in sustainability may differ for buildings as compared to infrastructure. This difference includes a different interest in sustainability and a different willingness to pay for sustainability. Buildings are often iconic for the organization or the community, and as a result there is associated personal, organizational, and civic pride. This may translate to a desire to brand the building with a sustainability rating that reflects community goals and priorities. Roadway infrastructure, on the other hand, is often viewed as a utilitarian investment that should meet functional needs but should consume the least possible

Table 10 Comparison of sustainability metrics (continued)

Method	Traditional Application or Developer	Scope	Awards and Notable Components
INVEST	Developed by FHWA	Modules for system planning at state, regional, and project level Addresses project development, operations, and maintenance	• Provides scorecard that can be used to advance better practices, foster sustainability, educate stakeholders, and promote communication • Considers 33 criteria that reflect planning, design, and construction and can be customized for the project
Greenroads	Roadway design and construction in US	Independent certification for roadway design and construction Rating system reflects water, environment, access, community impact, construction practices, and materials	• Projects can be designated as a pilot project or Certified project based on ratings Bronze, Silver, Gold, and Evergreen
GreenLITES	Developed by New York State DOT	Self-certification framework can accommodate local priorities and reflects the following categories: sustainable sites, water, materials and resources, energy and atmosphere, and innovation (which can encompass construction)	• Self-certification at levels Certified, Silver, Gold, and Evergreen
I-LAST	Developed by Illinois DOT	Tool to evaluate the use of sustainable practices and the impact of these projects on the livability, sustainability, and the environment	• Scorecard for self-certification that addresses planning, design, environment, water, transportation, lighting materials, and innovation

financial resources. Airport interest in sustainability may also be due to the strong role of worldwide aviation organizations that support for aviation sustainability, including not only ACI but also ICAO, which is an agency of the United Nations. ICAO has played an important role in aviation safety and standard practices for decades.

The roadway sector is more likely to integrate sustainability practices into their standard specifications, particularly when they have been proven in terms of technical performance and cost. Although there are international organizations to support road construction and operation (e.g., International Road Federation, and International Road Transport Union (IRU)), these organizations do not have the same role in terms of international influence on the design, construction, operation, and maintenance of roads. The focus of roads is often more functional, and less iconic, which may be why sustainability for roads tends to focus on performance and cost considerations.

It is also important to note that for both roads and airports, there are numerous and other local, state, and federal and even international requirements to sustainability. For example, in the US, both roadways and airports must conduct an environmental impact statement (EIS) in order to use federal funds. An EIS considers a variety of environmental impacts including threatened and endangered species, air and water quality impacts, impacts on historic and cultural resources, social and economic impacts, and cost considerations. ICAO, as well as national regulators such as FAA and EASA (European Aviation Safety Agency), have provided guidance and regulations for airport and aircraft noise for decades. In addition to funding noise compatibility plans for decades, FAA also now supports Airport Sustainability Plans through the Airport Improvement Program, the largest sources of federal funds for airports in the US, and also provides project funding through Voluntary Airport Low Emissions Program (VALE) for airports in non-attainment areas where the air pollutants exceed allowable levels.

There are numerous similarities between the sustainability programs for airports and roadways. In both sectors, there is support for the use of local materials, and local labor, which provides social benefits as well as environmental benefits. In both sectors, there is an increasing focus on a holistic approach that measures not just the impact of construction and operation, but also the impact of planning, design, and even administration. Both sectors are also increasingly leveraging advanced technologies to support sustainability. In aviation, this is seen in the use of Arc for real-time data at the Intl Airport in the roadway sector, this is seen in programs for real-time congestion pricing and programs that focus on mobility and mode choices rather than quantifying mobility by vehicle miles driven.

In both sectors, there are challenges to the successful integration of sustainability metrics. Sustainability metrics often cannot adequately address the “hidden” costs and tradeoffs. For example, the lifecycle cost of an electric battery must include the environmental cost of harvesting rare metals and safety disposing of the battery when it is no longer useable. These lifecycle environmental costs are challenging to quantify, and as a result, it is difficult or impossible to include them in sustainability ratings. Similarly, it is hard to quantify trade-offs between competing goals. For instance, the sustainable practice of using locally sourced materials provided by local workers may put pressure on the overall cost and schedule adherence for the project. In another example, the benefits of reduced emissions due to electric power must be balanced with the cost of emissions due to the electric power generation hundreds of miles away. The methods may provide benefits but the lack of standard practices for the many intangible and hard to quantify costs and benefits inherently limits the effectiveness of sustainability metrics.

Some agencies may utilize several sustainability metrics. For example, an airport may use LEED for buildings, ACI for carbon accreditation for airport activities, ISO for environmental management and Envision for a runway project. This may provide benefits since each application can be tailored to the project, however, it may also unnecessarily increase costs associated with accreditation, and it may result in a piecemeal or fragmented approach to sustainability. One possible solution to this would be the development of an overarching sustainability plan for the agency, which would reflect local goals and needs, and identify the most appropriate role for sustainability metrics.

In many cases, sustainability practices for infrastructure that are successful reflect economic considerations, such as warm mix asphalt that will consume less fuel, and recycled aggregate that will reduce the need for new materials and reduce the need for landfill space for used materials. Practices that leverage financial incentives and mitigation credits may be most successful for increasing infrastructure sustainability. One example of this is the use of wetlands mitigation in the US, which developed a framework for the 1:1 replacement of wetlands that were removed due to infrastructure. This program has increased the prevalence of wetlands, ensuring biodiversity of plant life, as well as habitat and food sources for fish, reptiles, animals, and insects.

Given an increasing interest in climate change and its potential impact on infrastructure, a discussion of sustainability is not complete without including a discussion of resiliency. Resiliency is also becoming increasingly important for the construction and operation of infrastructure and facilities, including airport and roadway infrastructure. Resiliency is typically defined as the ability to withstand extreme (unusual) events, and the ability to adapt to changing conditions, including one-time events, such as hurricanes and earthquakes, and changing conditions brought about by climate change, financial crises, terrorism, and failures in global diplomacy (Hudson, 2012).

In some cases resiliency is included as one component of sustainability. This is evident in the INVEST rating system, since resiliency is a criterion included in both the project module and the planning modules for states and regions. This is also evident in the CEEQUAL, as demonstrated in the M1 Widening case study in Table 1, which recognizes a stormwater plan with a 20% increase in storage capacity to accommodate more severe future events. In some cases, resiliency is a relatively small component of the larger context for sustainability. Even if resilience is not explicitly included as a criterion in a sustainability metric, many practices in sustainability and resilience are complimentary. Both sustainability and resilience focus on combining facility needs with social and economic considerations, both utilize life-cycle analysis and both reflect a philosophy that an integrated and "big picture" vision is necessary for optimal decision making and management practices. The similarities and differences between sustainability and resilience has been studied and a unified approach has been developed (e.g., Bocchini et al., 2013), however, this kind of approach has not been widely embraced or applied. This may be partly due to the fact that, in some cases, resilience and sustainability are competing objectives (Bocchini et al., 2013), since a very resilient facility or system may require an excessive investment that may never be justified, due to the relatively small likelihood of a catastrophic event. While this paper does not aspire to resolve the issues that are raised by the discussion of sustainability and resiliency, it is important to acknowledge that both topics are becoming increasingly important and facility planning and design will at some point need to bring these two topics together.

6 Conclusions

The construction, maintenance, and operation of airport and roadway infrastructure has significant impacts and sponsor organizations are increasingly recognizing and quantifying these impacts through sustainability rating systems. This paper presents a review of the most commonly used tools that can be used to assess sustainability for the construction and operation of airports and roadways, and provides examples of rating systems and projects that have incorporated sustainability. As society becomes increasingly interested in sustainability, and as technologies make sustainable practices more viable, sustainability will be increasingly incorporated into projects and standard specifications for transportation infrastructure. One issue that will need to be addressed in the future is how resiliency criteria and metrics should be integrated with sustainability metrics. This is important so decision makers can evaluate the sometimes complimentary considerations, and sometimes contradictory considerations, that should be evaluated when designing for sustainability and resilience.

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