The Value and Urgency of Transportation Forestry

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Abstract

The community and ecological benefits of trees and forests along roadways and other transportation infrastructutrre are important. Historically, the dialogue surrounding trees in transportation systems has focused on safety and crash reduction. We propose the sub-field of "Transportation Forestry" to maximize the benefits and minimize the risks of trees and supporting green infrastructure along transportation corridors. Transportation Forestry intersects urban/community forestry, landscape architecture, transportation and urban planning, civil/automotive engineering, and environmental/public health. These disciplines and fields collectively enable appropriate siting, selecting, planting, and maintaining green infrastructure proximal to transportation infrastructure while emphasizing prevention and remedy of injustices. We describe the value of establishing this sub-field and call for action that promotes a Transportation Forestry workforce. Essential research questions are provided to build a foundation of evidence for best practices. We demonstrate that this sub-field can advance healthy transportation development and climate change adaptation/mitigation.

1. Introduction

Transportation systems, composed of interconnected roads, bicycling and pedestrian paths, and transit areas, have shaped the form and function of modern cities. It is estimated that a third to half of any U.S. city's footprint is taken up by road and paved parking areas[1]. Across urban areas globally, 25 million more kilometers of roads are expected to be built by 2050[2].

Transportation systems (also called transport in Europe and elsewhere) include roads of different service scales, from highways that span regions to intracity arterials to neighborhood-level collectors. Associated land includes rights-of-way buffers, roadside sidewalks, and parking areas. Transportation systems include transit (i.e., light rail and bus), bicycle, and pedestrian systems. All mobility corridors and lands can generate positive and negative outcomes for human health, ecosystems, climate change adaptation and mitigation, and environmental and health justice[3].

As humanity grapples with the rapidly escalating and inequitable effects of the triple planetary crisis of pollution, biodiversity loss, and climate change - nature-based solutions that comprehensively address interlinked crises are more important than ever. Urban and community forests and other forms of green infrastructure are promising solutions with many benefits, from harm-reducing effects of carbon sequestration, heat and noise amelioration, and air filtration to health promotion through stress reduction and restoration, mental health support and facilitation of physical activity[4,5].

Urban and community forestry (U&CF) emerged in the 1960s in response to defining forestry management in urban locations and the demand by urban residents for dedicated city foresters and programs due to tree loss from development and disease[6]. U&CF is now widely recognized as a profession and a major driver of urban green infrastructure. Its science and practice are not limited in scope to specific areas of cities but also encompass the management of tree stands and supporting green infrastructure (i.e., natural and seminatural environmental features designed to deliver a wide range of ecosystem services) across public and private areas of cities, suburbs, and rural communities[7]. A critical U&CF action is addressing longstanding environmental injustices[8]. The U.S. Forest Service is distributing $1.5B to promote stewardship and planting in disadvantaged communities. Increasing numbers of cities in Europe and elsewhere seek to improve equitable access to trees through the 3-30-300 “rule” – requiring residents to have three visible trees, 30% canopy cover, and urban greenspace within 300 meters[9,10].

Practicing U&CF requires advanced practitioner knowledge and consideration of the diverse values and functions of greenspaces[11]. Trees near healthcare facilities may necessitate a deep understanding of therapeutic landscapes and the socioeconomic and psychological benefits of green spaces. Trees around schools may be optimized to provide educational opportunities, engaging students in environmental stewardship and creating experiential and conducive learning environments. Trees in commercial districts may warrant prioritizing shade and aesthetics to increase walkability and patronage behavior. Ultimately, any given place represents a unique situation to consider when best realizing the multimodal benefits and risks of trees to optimize green infrastructure benefits.

U&CF practice along roadways and other forms of transportation infrastructure (i.e., parking areas, transit) presents a particularly complex and uniquely promising landscape and/or situation.

Specialized expertise is needed in traffic management and safety, considering root structures to avoid pavement and utility damage[12], species selection that thrive in harsh conditions[13] and can provide air quality benefits[14], visibility in sight lines, and vehicle crashes into vegetation[15]. While public urban tree plantings are often concentrated along smaller streets[16], research on the benefits and selection of woody species has historically not been integrated within transportation engineering and planning[17]. Yet trees and green infrastructure can protect nearby communities from the large, often inequitably distributed, public health burdens of transportation, such as urban heat, air and noise pollution, visual blight, and driver aggression. Considering these benefits, rapid increases in financial investments are being allocated through federal transportation departments and for transportation-related projects[18–20].

This perspective highlights the need for a sub-field within U&CF focused on planning and managing trees and other green infrastructure associated with transportation and transit systems. We define this sub-field and propose the research and professional collaborations necessary for its success. We further describe the value of establishing this sub-field and provide calls for action that promote a Transportation Forestry workforce. Essential research questions are provided to build a foundation of evidence for best practices.

2. Defining Transportation Forestry

Broadly defined, a transportation system is a spatial network of connected physical infrastructures at multiple scales that permit the flow of people and commodities[3]. In addition to streets and parking, facilities may include limited access highways, viaducts, principal arterials, corridors such as transit lines, sidewalks, greenway trails, rail lines, rail yards, pipelines, airports, and related distribution facilities. Transportation facilities can create barriers to community connectivity, including obstacles to mobility, access, or economic development, due to high speeds and grade separations acting as physical barriers and other design factors[21]. Additionally, ongoing road construction can negatively impact existing trees and green infrastructure if not properly addressed in the planning process[22].

Meanwhile, the environmental burdens of transportation systems are extensive. Roadway traffic is the top source of air pollution in most cities and communities[23]. Air and road traffic emit noise levels and frequencies that harm health and wellbeing[24]. Roadways constitute the largest impervious surface area in many cities and neighborhoods, a leading cause of the urban heat island effect and stormwater runoff[25]. While the benefits of transportation facilities are essential to modern society, they can come at a high cost to the environment and health of many communities, particularly those that are most vulnerable or socioeconomically disadvantaged[3]. Transportation-related politics and policies have created and perpetuated disadvantages across many communities, ranging from the externalities of road placement (such as economic and community decline) to direct environmental harms, often reinforcing longstanding social and environmental inequalities[26]. Therefore, Transportation Forestry could improve the pathways linking transportation with human and environmental health while also promoting equity[3].

Transportation Forestry is an amalgam of disciplines, fields, and approaches that carefully consider the siting, selecting, and maintaining trees and supporting green infrastructure proximal to transportation infrastructure, emphasizing collaboration with communities to prevent and overcome injustices (Figure 1). U&CF, landscape architecture, air quality scientists, and environmental psychology offer insights into which species are best suited for specific climates and environments, how they affect local ecosystems and communities, how to encourage ownership and stewardship on behalf of residents, how to promote proper alignment and support of city tree ordinances and policies, and how to endorse management for long-term survivability and sustainability of trees, people, and cities. Utility arboriculture focuses on the pruning, regulation, compliance, and monitoring related to overhead lines and right-of-way safety[27]. Transportation and urban planning provide a framework for incorporating green spaces into existing and future roadways and transit, walking and bicycling corridors and safe travel speeds. Civil and transportation engineering ensures trees and supporting green infrastructure minimize safety concerns, such as sight lines, clear zones, and vegetative material falling on roadways, as well as provide effective designs for facility designs such as stormwater flow, air pollution filtration, and noise abatement.

Rapidly expanding relevant research and expertise in environmental and public health identifies how trees and supporting green infrastructure can offer maximum net health benefits in the context of local conditions and avoid unintended consequences from a confluence of health-promoting and harm-reducing ecosystem services. Community development assures authentic dialog and design participation with residents living near transportation corridors to reveal their needs and interests in community revitalization. Environmental sociology, justice and inclusion scholarship offer perspectives on how social inequity affects green infrastructure and the phenomenon of concentrated disadvantage, wherein low-income and ethnic minorities suffer from intersecting and compounding socioeconomic disparities and environmental stressors and are often subject to displacement during gentrification. These factors contribute to a unique social context that may influence the effectiveness and reception of green infrastructure projects. This interdisciplinarity creates an integrated approach to what might otherwise be isolated challenges, uniquely positioning the field to provide comprehensive solutions to concurrent transportation burdens.

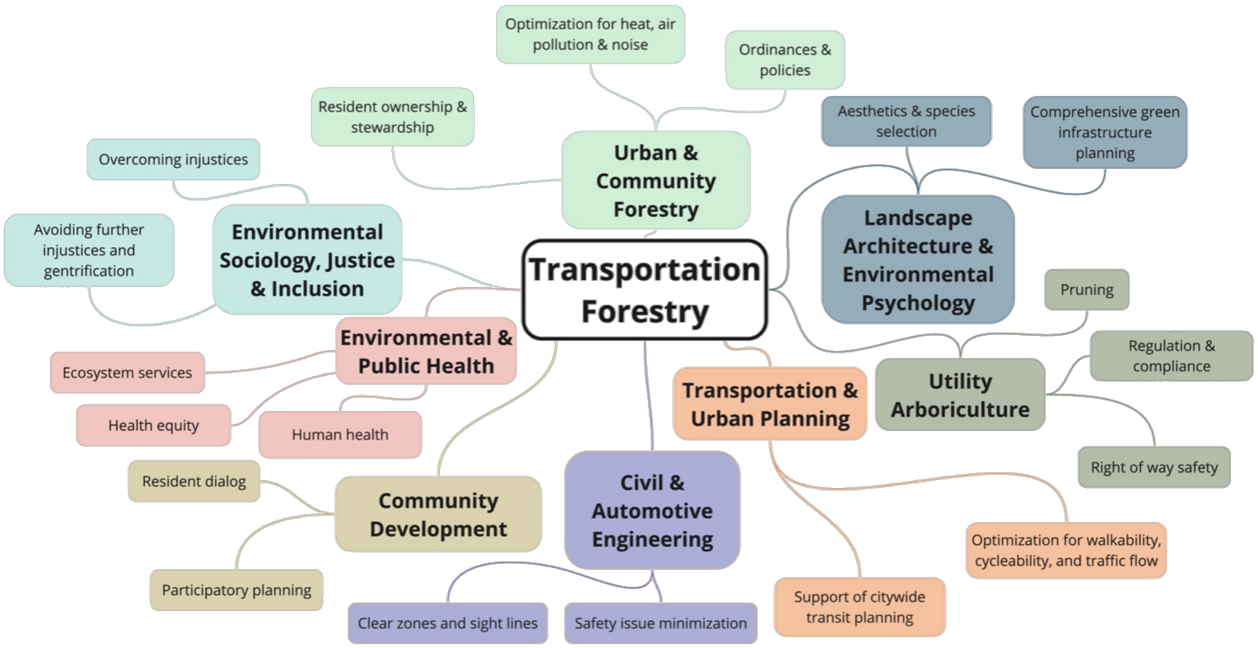

Figure 1. Examples of disciplines, fields, and approaches that contribute to the sub-field of Transportation Forestry. Areas of expertise overlap but are not visualized here for simplicity.

3. Trees and Traffic Safety

Safety is of the utmost importance in mobility design, and engineering has essential implications for the success of Transportation Forestry. More than 1.3 million people are killed each year on the roads around the world, and millions are seriously injured[28,29]. Crashes on roadways are among the top ten causes of death globally, with car crashes being the leading cause of death in the U.S. for people ages 1 to 54[29]. Vision Zero policies recognize that traffic deaths are preventable if the infrastructure is designed to ensure inevitable driving mistakes do not result in severe injuries or fatalities.

3.1. Current Approaches to Traffic Safety

Improving safety across the complexity of transportation systems involves the review of current best practices and exploring innovation opportunities. The widely referenced Green Book *(A Policy on Geometric Design of Highways and Streets)* contains highway and street design guidance, such as traffic lane width, intersections and curve radii at different speeds[30]. It has historically emphasized the importance of clear zones, meaning roadsides free of fixed objects, including trees. Fixed objects (including utility poles and signage) are of particular concern as they are inflexible on impact, heightening the risk of severe injury and death. Transportation leadership often understands the benefits of trees and supporting green infrastructure, but this understanding may not be sufficient to counteract perceived safety issues[31,32]. Many typical engineering countermeasures intend to "forgive" driver error, such as wide travel lanes and roadside clear zones[33]. In addition, maintenance staff who manage the long-term sustainability of roadsides may be more motivated by budgets or contracts than research or policy guidance[31]. Ultimately, removing trees can have the unintended consequence of increasing traffic speeds, exacerbating driver error, reducing safety, and increasing injuries or deaths[34,35].

3.2. Improving Safety through Transportation Forestry

Despite the current approaches and perspectives, there are still opportunities for utilizing trees and supporting green infrastructure for traffic safety. A study in Denver, Colorado, U.S., reported that the expected safety benefit of tree exclusion in urban roadside clear zones may be overstated[36,37]. Impact speed is profoundly important as the fatality risk at speeds of approximately 60 km/h is five times higher than 30 km/h[38], and roadside vegetation has been correlated with traffic-calming and reduced speeds that may result from the perception of roadway restrictions[34,35]. In addition, the U.S. national crash data for urban settings indicates lower death and injury rates due to slower vehicle speeds when trees are present[37].

More broadly, investigators are exploring the role of urban design and cognitive interpretations of the built environment that contribute to driver error and crash behaviors[39]. Better reaction times reduce crash incidence and severity; during highway driving simulations, driver attention levels increased with roadside greening and shorter reaction times during emergencies[40]. Vehicle position within the travel lane is influenced as drivers move farther away from the road edge (reducing crash risk) if trees are spaced closer together[41]. The Green Book and other design guidelines, such as the Urban Street Design Guide, increasingly acknowledge the importance of pedestrian and bicycling mobilities for health and climate benefits[42], and for these modes to take off, increases in safety are required.

4. Other Benefits of Transportation Forestry

Beyond the potential safety benefits of Transportation Forestry, urban and community forests benefit residents and ecosystems in other ways[43–45]. Appropriately selected, designed and maintained trees and supporting green infrastructure can represent a viable and cost-effective strategy to reduce ambient air pollution from traffic emissions[13]. Vegetation can simultaneously block pollutants from reaching residential areas, filter air pollutants, and disperse pollutants to reduce community exposure. Specific roadside vegetation characteristics can impede air mixing and lead to wind stagnation, causing increases in downwind pollutant concentrations[46]. For street canyons, vertical objects, including buildings and trees, can entrap air pollutants in a re-circulatory system that inhibits wind ventilation, reducing opportunities for escape[47]. Thus, Transportation Forestry requires understanding and engineering/design solutions that maximize air pollution reductions and avoid unintended consequences from designs that can increase local air pollution levels. Trees and supporting green infrastructure can also be a relatively inexpensive and aesthetically acceptable option to reduce roadway noise[48]. As with pollution, the noise reduction capacity of vegetative belts can be multiplied with deliberate design, placement, and species selection[49].

Transportation Forestry also requires the selection of seats and species to provide shade for pedestrians, cycling, and public transit while minimizing safety concerns along transportation corridors. Impervious surfaces drive the formation of urban heat islands, and vegetation represents a uniquely efficacious and cost-effective intervention to reduce urban heat[50]. Urban heat is responsible for the highest number of deaths due to climate change, with urban heat islands disproportionately exacerbating the exposure of residents living in underserved communities[51]. Through shading and evapotranspiration, vegetation can counter this effect and mitigate climate change-driven morbidity and mortality. Trees and green infrastructure can also be cost-effective approaches to reduce the burdens of flooding and stormwater runoff related to the extensive paved surfaces of transportation networks[52]. In cities around the U.S., billions of dollars are spent to address stormwater runoff and combined sewer overflows, with needs growing due to climate change[53]. As a partially cost-effective solution with extensive co-benefits, trees intercept rainfall before reaching the ground level, improving water infiltration and preventing soil erosion[54].

While forestry has many direct benefits to surrounding communities, the potential for additional combined co-benefits to improve health and well-being is extensive. Greened vacant lots near roadways have been associated with reductions in heart rate and self-reported improvements in mental health[55]. Engaging residents in urban forestry initiatives can reduce the prevalence of factors contributing to urban blight, such as littering, leading to overall improvements in blighted communities[56]. Urban green infrastructure can promote social cohesion and pride, increased social interactions, and community attachment[57]. Living in areas with high tree canopy and vegetation cover has also been associated with improved sleep quality, birth outcomes, and physical activity levels, reducing the incidence of chronic conditions, diseases, and all-cause mortality[58]. Notably, green neighborhoods are associated with lower blood pressure and cardiovascular diseases, major risk factors and causes of mortality worldwide[58]. Further, green streetscapes provide comfortable shopping environments and improve merchants' relationships with shoppers, resulting in improved revenues[59,60]. Additionally, flowering trees and plants support local pollinator populations, which impacts economic stability in agricultural areas[61].

Realizing these direct and indirect benefits while avoiding unintended negative consequences requires a nuanced understanding of Transportation Forestry. For instance, improperly designed green walls can bounce soundwaves back to pedestrians, creating effects opposite to those intended. Plantings in areas prone to extreme heat must be designed to maximize cooling effects while minimizing restrictions in airflow. Safety aspects must be maintained, including sight lines on crest vertical curves (the tops of hills) and curves, clear zones commensurate with the speed limit, minimal overhanging limbs that could fall onto roadways, and vegetative structures that do not promote concerns about crime or wildlife that may increase risk of roadway crashes. Shade can promote icy road conditions or slippery vegetative litter in wintertime, increasing crashes; thus, locating plantings to minimize falling debris and considering shade in colder climates is important. Natural areas can also support unsheltered individuals. Expanding the availability of these areas along transportation corridors could increase hazardous exposures and perpetuate health inequities if structural dimensions of homelessness are not addressed.

5. Calls for Action

We propose calls to action to grow the nascent sub-field of Transportation Forestry. First, we call for concentrated establishment and practice of Transportation Forestry in disadvantaged communities. Social and environmental justice are essential to Transportation Forestry, as areas with the lowest tree canopy and vegetation cover tend to have the lowest socioeconomic status[62]. For example, the U.S. Climate & Economic Justice Screening Tool (CEJST) reveals exceptionally high transportation-related hazards (i.e., diesel particulate matter and traffic proximity or volume) in communities facing socioeconomic stressors and environmental burdens. Disadvantaged communities, often located next to major transportation corridors and interchanges, may benefit more from nature-based interventions than other communities; residents in lower-SES communities may spend more time in their communities, suffer more from transportation and other environmental burdens, and have lower baseline health status[63]. Greening initiatives in disadvantaged communities often experience low adoption, maintenance, and tree survival rates yet represent areas with the greatest potential benefits of investment[64–66]. Establishing and practicing Transportation Forestry in disadvantaged communities will allocate the resources to areas with the greatest potential for trees and supporting green infrastructure.

Second, we call for developing interdisciplinary professional education and workforce programs to promote crosstalk and knowledge transfer between relevant disciplines and fields. Experts from relevant disciplines and fields could co-develop training modules to ensure trainees learn from each of these critical sectors. Coordinated learning materials and case study development will allow discussion of disciplinary-specific challenges and opportunities related to planting along transportation corridors. Integrated curricula can be offered across undergraduate and graduate-level courses, with cross-listing across departments at universities and community colleges. Certificates can be provided to distance education students and professionals seeking continuing education credits. Professional organizations in relevant disciplines and fields may pursue longer-term accreditation standards. Simultaneously, we recommend greater interaction between researchers and policymakers in forestry, equity, sustainability, public health, housing, civil engineering, urban planning, and transportation. These fields may be siloed within their disciplinary focus, such as U&CF experts in U.S. Forest Service projects and civil engineering experts in U.S. Department of Transportation projects. Collaboration between fields to address air pollution, noise, stormwater runoff, safety, and urban heat along transportation corridors can jointly design and implement Transportation Forestry to maximize the net benefits of available resources. Yet, leadership in Transportation Forestry is needed to develop the interdisciplinary expertise and collaborations to realize this potential. Increased awareness of the value of this sub-field will encourage more conversations and collaborations between disciplines and fields and governmental agencies. For instance, city departments that work on forestry, transportation and public health are often separated and may not always work collaboratively. Tree planting, underground utilities, and pedestrian/cycling routes can be better coordinated with crosstalk and restructuring of how agencies and professions work together.

Third, we call for increased research on evidence-based best practices in Transportation Forestry. A steadily growing research base supports the best practices of U&CF. In contrast, research about trees and transportation is limited. Select topics that are essential to support evidence-based practices of Transportation Forestry are:

- **Data on safety, crashes, and trees.** Few articles emphasize ensuring road safety when discussing the benefits of streets, sidewalks, and shade trees[43]. Conversely, transportation industry research on crash circumstances (such as road geometries) and driver behavior (such as safe speed response) emphasize trees as fixed objects with serious safety risks. Rectifying and validating these perspectives across geographies and urban/rural community contexts is critical. Current crash report data are primarily from federal sources and may not fully reflect the conditions faced by local governments[37]. For instance, a Seattle, Washington, U.S., study found no correlation between trees and crashes, while larger scale and rural road-centered studies found positive correlations[67]. Research should prioritize understanding clear zone sizes and vegetation options related to urban road types and configurations (e.g., intersections and curves). Developing a "Safe System" approach may balance physical constraints with driver cognitive responses, such as attentiveness and posted speed compliance[39,68], while "crash taxonomies" could inform best practices for crash avoidance and countermeasures[69]. Determining crash incidence and severity are dually important questions; one study in New York City found that crashes on smaller, more enclosed streetscapes were less likely to result in injury or death than those on larger, more open streetscapes[70]. Such gaps in knowledge regarding effective and safe planting will hinder the adoption and effective implementation of Transportation Forestry until they are filled.

- **Innovations for multiple transportation modes.** The opportunities for trees and green infrastructure to support diverse forms of transportation would benefit from various community perspectives and mobility type considerations. Some examples are becoming available, such as "Context Sensitive Solutions" and "Complete Streets" policies in the U.S.; "Woonerf" design in the Netherlands; "shared space" strategies in Belgium; and The Manual for Streets and Duty of Care in the United Kingdom Evaluation. Integration of these strategies beyond pioneering and innovative communities would serve communities broadly, particularly as cities attempt to adapt to climate change while promoting active transportation. Further, the emerging capability and use of assisted- and self-driving vehicles have the potential to fundamentally change considerations of roadways, with possible implications for near-road vegetation (e.g., increased need for clearer sight lines for precise navigation and sensor systems, while at the same time, decreased road widths in traffic flow efficiency are increased, potentially allow more space for roadway plantings).

- **Intersections between greening, equity, climate, and safety.** Disparities in tree canopy and park distribution have been noted across many cities, and the trend appears to extend to roadsides. Green injustice research and policies could render more knowledge about urban green spaces and street greening[71,72]. Aside from reduced access, little is known about equity specific to roadside greenery and its implications on driver behavior. One study found that the number of street trees per mile (within clear zones) was associated with fewer crashes in wealthier neighborhoods and more crashes in lower-income neighborhoods[36]. Research on the design of transportation corridors as "Safe Systems" rather than solely the behavior of individual drivers may reduce crash rates while reducing the potential for racially charged exchanges between the police and the public[73]. Meanwhile, research on quantities and qualities of green infrastructure along roadways could inform balancing acts between the climate, environment, active and vehicle transportation, and policy or utility constraints to improve Transportation Forestry's efficiency. Technologies like self-driving cars with LiDAR or machine learning algorithms applied to 360-degree images may assist with real-time monitoring of urban forests along transportation corridors. Tradeoffs between solar microgrids limiting the availability of tree planting spaces may increase as transportation and renewable infrastructure investments continue to be made.

- **Growing challenges in roadside conditions.** Arboriculture technologies continually expand recommendations for adequate soil volumes for roots, nutrient needs, water and irrigation management and pruning. The interaction of sub-surface root growth with paving can result in potential hazards and increased maintenance costs. Applied technologies may be used in forensic evaluations, such as using ground penetrating radar to evaluate root architecture and implement repairs before hazards become serious.

- **Effective collaboration between U&CF and Departments of Transportation (DOTs).** It will be necessary to update best management practices, training certificates, ordinances, and policies to establish Transportation Forestry. This will require input from many fields related to this sub-field, notably U&CF and DOTs. Focus groups and case studies where these groups have effectively collaborated would highlight techniques to facilitate more effective collaboration and communication. Results from this and other topics above can be integrated into standards of practice, such as the American National Standards Institute (ANSI) A3000 Tree Care standards for integrated vegetation management.

6. Conclusion

Transportation Forestry is an important and urgent new sub-field, poised to equitably address many pressing challenges of our time - from climate change and pollution to biodiversity loss and public health. Developing evidence, collaborations, dialogue, tools, and a workforce of Transportation Forestry experts will create a more sustainable and health-promoting transportation infrastructure that benefits communities, particularly those disproportionately affected by transportation-related stressors. Interdisciplinary collaboration will enable maximal impacts from significant investments into transportation and health. This new sub-field can equip cities with powerful tools in the fight against climate change and toward a more equitable, resilient, and sustainable future.

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