# TOWARDS A HEALTHY PLANET

**Environmental Opportunities and Costs of the Clean Energy Transition**

December 2021

## Research Question

How will the "clean energy transition"—that is, the process of transitioning from traditional coal and gas generation to low-carbon or carbon-free generation—address legacy environmental impacts, today's environmental challenges, and advance society towards an environmentally just future?

## Key Points

- Addressing ongoing environmental impacts of fossil fuel generation is a central aspect of global climate change discussions and may inform decision-making at the country, state, and company levels. However, it may not be feasible to immediately remove fossil fuels from the generation mix until firm, dispatchable low-carbon resources can be deployed at scale.
- The use of existing financial cost-benefit analyses as primary policymaking and regulatory tools may not appropriately estimate the total costs and benefits of investments relating to clean energy, especially in regard to long-term environmental and human health impacts.
- Remediation of many legacy environmental damages has been largely successful, but there are remaining legacy impacts and emerging challenges as decarbonization accelerates to meet state, national, and international climate goals.
- The clean energy transition presents an opportunity to include affected communities and incorporate their input throughout all aspects of investment decision-making processes.

## Table of Contents



*This white paper was prepared by EPRI.*

## Context

Impacts on the environment due to "past and future greenhouse gas emissions are irreversible for centuries to millennia, especially changes in the ocean, ice sheets and global sea level" [117]. The recent International Governmental Panel on Climate Change (IPCC) Working Group I (WG1) report released in August 2021 stated it is "unequivocal that human influence has warmed the atmosphere, ocean and land," [119] and that it is no longer a question of whether or not climate change will impact global society but rather the severity of those impacts.

To mitigate and potentially avoid the worst impacts of global climate change, the electric power industry is entering a period of unprecedented transformation to a decarbonized system. This transformation presents the pervasive challenge of how to achieve extensive emissions reduction and low-carbon resources deployment while aiming to provide affordable, reliable, and environmentally sustainable energy. The process of transitioning from traditional coal and gas generation to low-carbon or carbon-free generation has been colloquially labeled the "clean energy transition," but what is clean energy, and how is it achieved? For many, the term clean energy can evoke images of renewable energy in the form of solar or wind generation. However, the changes occurring in the power system to facilitate the low- or no-carbon transition encompass much more than these two types of generation alone. Energy in this case refers to all technologies that will be deployed to meet decarbonization, the infrastructure needed for transmission and distribution, and all other aspects of the power system. The energy becomes "clean" when environmental impacts created by the system are avoided or mitigated in a way that balances the costs and benefits to support a healthy planet.

The power system includes not just the traditional aspects of generation, transmission, and distribution infrastructure and operators, but regulators and policymakers, customers, the environment, and society as a whole. All of these stakeholders must be involved in decarbonization to bring about the energy transition in a manner that enables affordable, reliable, and environmentally sustainable energy, while simultaneously prioritizing balanced distribution of the costs and benefits to natural systems.

The transition requires a holistic view of the opportunities and challenges, in addition to critically examining each facet, such that the full scope of tangible and intangible benefits and impacts might be considered *(Figure 1)*. As companies, states, and nations work to reduce their emissions, mindfulness of impacts on air, land, water, species, and people must be brought into the conversation.

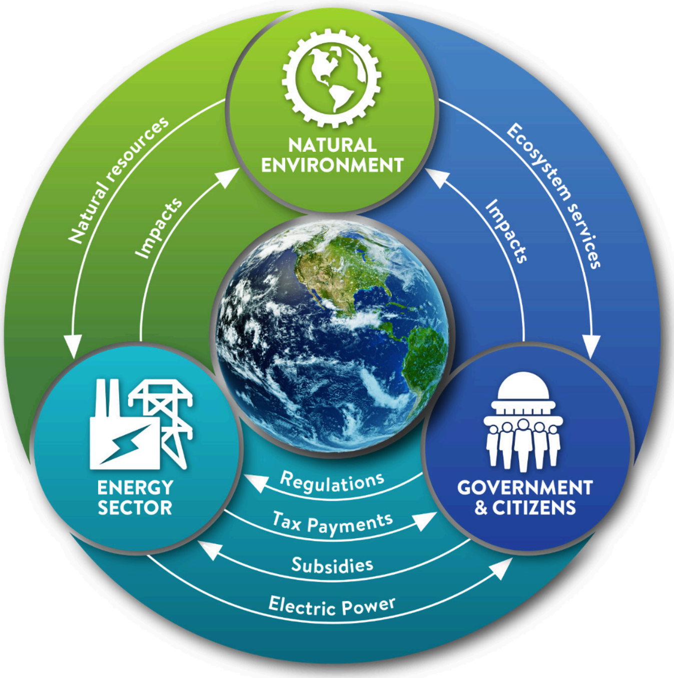


*Figure 1. Clean Energy and Environmental Interactions for a Healthy Planet*

Given the level of emerging global greenhouse gas (GHG) emissions reduction targets, along with state and federal policy changes, the clean energy transition will occur rapidly. However, there may be significant obstacles to achieving cost-benefit balance. GHG emissions reductions are not the only avenue through which the power system has impacted the environment. The industry continues to address legacy environmental issues while mitigating environmental challenges with current and future operations.

One pervasive and far-reaching legacy of the era of fossil-fueled generation is the mindset that minimum compliance at the lowest cost is the preferred end point of identifying, evaluating, remediating, and mitigating environmental impacts. When the only consideration is direct compliance for the lowest cost, evaluation of externalities beyond regulatory requirements is often ignored. While compliance with regulations is required and cost will always be a factor, considering the full impact of environmental concerns on human, natural, and economic systems could help mitigate or avoid similar impacts in the future. There are opportunities to create incentives, regulatory or otherwise, and to set precedents to encourage action in pursuit of a healthier planet [92, 95]. The inclusion of all lifecycle interactions of current and future technologies can provide an environmentally responsible foundation for clean energy.

EPRI's role in the transition is to perform an independent assessment of ways to potentially minimize negative impacts of energy generation, transmission, and distribution while maximizing beneficial aspects. EPRI will continue to assess the legacy impacts of the existing power system while also aiming to identify and mitigate potential future impacts. Understanding legacy issues and seeking out similar and new impacts that might occur during and after the transition may be the first step in addressing the challenges the energy sector is facing today with regard to new technologies, a changing policy and regulatory landscape, and the effects on environmental systems.

## Accelerating Solutions for Legacy Impacts

### *Introduction*

Balancing the benefits, impacts, and costs of decarbonization underlies the foundation of the equitable transition. Environmental impacts to land and water related to utility operations areas are typically concentrated near power generation and delivery infrastructure and locations where fossil fuels are extracted, while impacts to air range from local to regional to global in nature. Decisions made by electric power companies, regulators, and policymakers would benefit from quantification and prioritization of environmental impact avoidance and mitigation. This is particularly relevant as fossil generation may be needed for years to come to provide electric system reliability. The solutions developed to address legacy impacts can be applied to mitigate and/or prevent similar impacts until all fossil assets have been retired.

### *Remediation*

Legacy environmental impacts, or impacts that occurred before the promulgation of environmental regulation, have challenged the electric industry to identify new site investigation and remediation methods. One aspect of legacy remediation that can be applied to the energy transition is the use of risk evaluation to look for opportunities to improve both mitigation and remediation. EPRI has done extensive research in this area for impacts to soil, groundwater, air, species, and water [2, 6, 15, 34, 62, 63, 65, 89].

EPRI has worked to quantify the environmental risk of electric utility operations for several decades. Issues of particular concern in soil, water, and air have been addressed by EPRI research showing the actual versus perceived magnitude and location of risk. The risk of exposure from different media [2, 3, 5, 9, 16] related to power generation and delivery operations, in addition to the environmental risk [11, 12, 13, 18, 34] have been quantified and allowed remediation to be targeted where risk was highest. EPRI has also performed research that improved methods for remediating legacy contaminants in soil and water [1, 4, 7, 8, 22].

## Coal Combustion Products

One of the largest, and most costly, legacy issues for electric generating companies is coal combustion product management. The handling and disposal of coal ash in landfills and impoundments in the United States was inconsistently regulated at the state level prior to 2015, when the U.S. Environmental Protection Agency (EPA) propagated the Disposal of Coal Combustion Residuals from Electric Utilities regulation, commonly referred to as the "CCR Rule" [115]. The CCR Rule established a minimum federal standard for regulation of coal ash additional to state regulations. Many CCR impoundments did not meet all aspects of the minimum standard, and as a result, are now closing, accelerating a transition from management in impoundments to landfill management that had begun in the 1990s. Research from EPRI over the past 40 years provides a foundation for understanding the current and future risks of these facilities vis-à-vis CCR Rule compliance efforts. EPRI research such as the relative impact risk framework and Closure Option Assessment Tool (COAT) [22, 69] were developed specifically to assist companies with assessing ash pond closure options. These tools may aid utilities in weighing factors such as the long-term groundwater benefits of removing the ash compared to the short-term impacts from transporting the ash, air pollution generated by removal projects, and the potential for traffic accidents during transportation *(Figure 2)*.

Incorporating multiple short- and long-term factors into these frameworks may allow companies to identify solutions that provide the most benefits for the least impacts, rather than relying on a cost-driven approach. EPRI is also investigating the potential to harvest and beneficially use coal ash and flue gas desulfurization gypsum [10, 32, 44, 70]. By finding beneficial uses for these products, the legacy impact may be reduced and eventually mitigated while potentially reducing carbon emissions and impacts to other environmental media from the materials they are replacing [51].

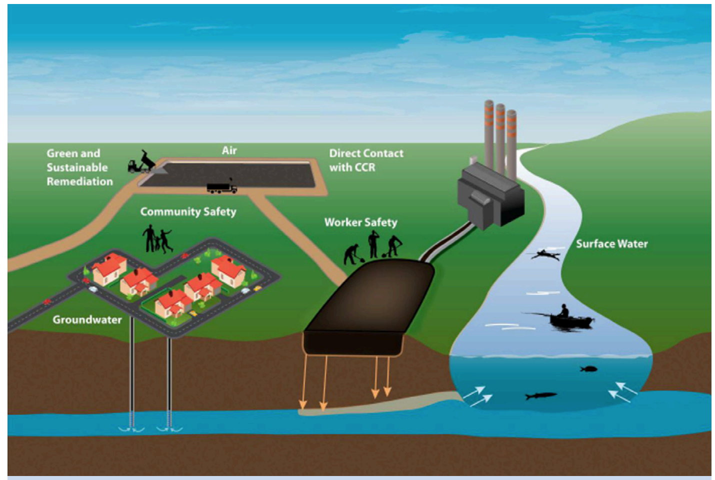


*Figure 2. Relative Risk Framework Pathways [22]*

## Land Use

Strategic Landholding Analysis (SLA) is another way EPRI is accelerating potential solutions to legacy impacts. SLA provides a framework utilities may utilize to assess their lands and identify natural resource assets that can be protected or improved to support natural systems, corporate sustainability, and conservation goals [85], both for normal operations and for sites slated to undergo decommissioning. This will be particularly important as efforts continue to build for conservation of species most impacted by utility operations, and for facilities slated to decommission. Utilities own or lease thousands of miles of transmission corridors and additional acres of landholdings. While historically managed with the goal to prevent the growth of non-compatible woody species that can cause outages, these transmission rights-of-way (ROWs) are increasingly being managed to improve biodiversity by providing habitat for pollinators, bats, and shrubland birds. In addition, some of these ROWs are including public activities such as walking, biking, and wildlife viewing.

## Air Quality

Air quality improvements measured to date have been driven largely by policy and regulation. At the federal level, the Clean Air Act (CAA) sets both emissions limits and ambient air quality standards [124]. States and localities may also develop their own air quality regulations and enforcement mechanisms, e.g., the California Clean Air Act (CCAA) [122], the South Coast Air Quality Management District [127], and the North Carolina Ambient Air Quality Standards [126]. The success of these programs can be quantified, as emissions of particulate matter ($PM_{2.5}$, $PM_{10}$), sulfur dioxide ($SO_2$), nitrogen oxides ($NO_X$), volatile organic compounds (VOCs), carbon monoxide (CO), and lead (Pb) have been reduced, on aggregate, by 78% since the CAA was passed in 1970 [118], leading to improved air quality [131]. These improvements have also ameliorated the environmental impacts of air emissions such as acid rain, nitrogen enrichment (e.g., eutrophication, or algae blooms in bodies of water with high nitrogen concentrations, due in part to nitrogen deposition), regional haze, and crop and forest damage [129]. As the energy sector pursues deep decarbonization, reduction of criteria and hazardous air pollutants can be considered to help maximize the air quality benefits of the future energy system. EPRI has been at the forefront of air quality research for decades, including recent research on air quality measurements, air toxics risk assessments, air modeling tool development, ecosystem impacts due to deposition, and human health effects [35, 39, 40, 52, 53, 54, 59, 61, 63, 68, 75, 76, 77, 78, 80, 81, 83, 86, 90, 94, 97, 101, 103, 104, 105, 106, 107, 108].

## Addressing Today's Challenges

### *Introduction*

The environmental challenges facing the electric power sector today may be categorized into three major areas:

1. Managing the continuing impacts of fossil generation during the transition
2. Determining incentives to shorten the transition period to low-carbon generation
3. Remediating and mitigating existing and future damages

Companies and governments are searching for solutions to these challenges through new technologies and policy or regulatory frameworks. The transition presents new opportunities to embrace the wide range of new potential benefits of clean energy, as solutions developed today may provide a framework for a more strategic and planned transition that considers human, financial, and environmental systems equally. Increased focus on environmental impacts of planning decisions may also carry into the future, as the change in generation assets and increase in transmission and distribution infrastructure provides numerous opportunities to capture and share both the costs and the benefits—monetary or otherwise—throughout the interdependent systems that comprise our society and our planet.

### *The Role of Fossil Fuels in the Clean Energy Transition*

Reliability and resilience are a priority of the entire power sector. Retiring firm and dispatchable generations resources such as coal and natural gas plants presents a challenge to a core tenet of energy, reliability. There are some ways in which renewable resources can be dispatchable [123]. However, renewable resources introduce high levels of variability into the system. The questions facing the industry are how to optimize reliability while undergoing efficient decarbonization, and what minimum fossil fuel capacity will be needed to maintain reliability during the transition. While fossil plants remain in operation, power generators may remain engaged in mitigating and minimizing the environmental impacts of these plants while working towards a future in which they will no longer serve as an energy source. There are pathways to remediating and mitigating existing damage today, and which may guide preventing additional damage in the future. Addressing environmental damage and continued greenhouse gas and air pollutant emissions reduction are expected to be primary aspects of private and public sector strategy going forward.

## Fossil Fuel Environmental Challenges

### *Ecosystems*

There are some current examples of ecosystem evaluations that have incorporated externalities beyond lowest cost compliance. One example is the voluntary preventive actions taken by utilities to slow or stop the declines in the populations of pollinator species, birds, and bats. Increasing the number of endangered species can impose additional operating costs and restrictions in areas where the species occur, while significantly impacting the natural ecosystems and food webs upon which humans depend [45, 62, 65, 96]. Taking steps prior to species being listed under the Endangered Species Act may add costs to operations but carries benefits that offset potential costs in the future.

Another example of incorporating externalities into ecosystem evaluations is the implementation guidance for §316(b) of the Clean Water Act that requires evaluation of the monetized, quantified, and qualitative social costs and social benefits of available entrainment controls, and rejection of any technology if the social costs are not justified by the social benefit [17, 19, 28, 31]. While the regulation is designed to protect aquatic ecosystems, it has been expanded to consider externalities beyond the waterbody under evaluation.

## Water

Water use for coal generation is increasingly challenged by the volume, quality, and temperature of available supplies and regulatory actions that seek to address these issues [24, 67]. EPRI has researched the costs and benefits associated with water use and provided frameworks that utilities may employ to evaluate and decrease their impact [20, 30, 33, 36, 43, 55, 66, 89] *(Figure 3)*. This framework shows how the common good can be considered to identify a potential path forward that best balances costs and benefits. Wastewater discharges have also come under increasing regulatory scrutiny, with the result that updated regulations have affected the operations at coal-fired generation facilities. EPRI has worked with utilities to help identify and implement wastewater management and treatment strategies for these waters [14, 23, 26].

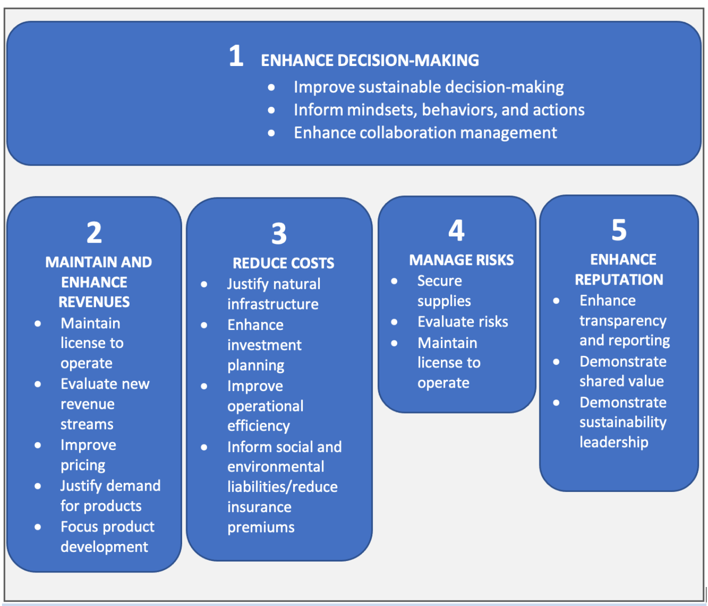


*Figure 3. The Business Case for Valuing Water [55]*

## Plant Decommissioning

Decommissioning fossil fuel plants can lead to improved air quality that further leads to improvements in public health and regional haze, and decreased atmospheric deposition that affects plant and water systems [34, 41, 50]. Decommissioning also presents opportunities for redevelopment that may provide jobs, tax base, and environmental improvements in local areas [58, 113]. Properties slated for decommissioning provide a unique opportunity to rebuild or protect natural areas that exist near many thermal generating assets. Conservation of these natural areas can provide a benefit to the public, and may be utilized by companies as possible mitigation banks for future low-carbon transition projects. Decommissioning and its associated costs may be delayed by implementing available mitigative and preventive technologies that allow fossil plants to continue operating, such as carbon capture and storage (CCS).

## Land Use

Transmission and distribution (T&D) of electricity also present opportunities to balance the benefits and costs of the clean energy transition while stacking land use benefits. Research performed during the fossil fuel era has led to advances in siting, construction, and maintenance practices that are bringing the industry to a time when increased resilience [49] and benefit stacking [33, 84] are recognized as goals that are worth more than the base cost of implementation. Improvements in integrated vegetation management are increasing the use of native plant species that benefit ecosystems and restore and protect native habitat [29, 62, 72, 73, 74, 91]. ROWs in many urban areas are being transformed to provide natural area access for humans to interact with nature. Infrastructure design and construction continue to develop and incorporate species protection in ways that protect both the asset and avian and animal populations that interact with the assets [21, 56, 71]. T&D infrastructure is also beginning to benefit from the use of drones and artificial intelligence, which, when combined, may identify hazards before they are visible to human inspectors [57, 82].

For both generation and T&D of electricity, one challenge that remains today is evaluating the system holistically while remembering that benefits and impacts are often localized. Finding a solution will become more important, and more challenging, as the electric system moves increasingly to distributed energy resources (DER). The change from large power plants and transmission infrastructure that primarily affect local areas, to many small generation assets with larger T&D systems will result in more distributed, but still local, benefits and impacts. More natural systems will be affected at the local level in a way that carries potentially negative consequences, while the benefits, such as reduced air emissions from fossil generation, may be distributed to systems that do not include those local areas. This is particularly true when siting renewables, as "wind and solar generation require at least 10 times as much land per unit of power produced than coal- or natural gas-fired power plants, including land disturbed to produce and transport the fossil fuels" [46, 125].

### Air Quality

Due to the increase in gas-fired power generation over coal-fired generation, the electric power sector overall has observed significant reductions in emissions, particularly significantly lower levels of $SO_2$, $NO_X$, and primary PM. Natural gas generation also does not contribute to mercury and other air toxics, further lowering their emissions beyond the effects of the Mercury and Air Toxics Standards (MATS). Despite these observed improvements, there are remaining challenges. As emission requirements for gas-fired power generators become more stringent globally, more accurate and reliable measurement and monitoring technologies will be needed for a variety of pollutants. In addition, there will be a continued need to measure and model ambient concentrations of pollutants, as well as to understand the human and environmental health impacts of emissions from natural gas generation, which may be utilized to inform the National Ambient Air Quality Standards (NAAQS). These quantitative needs will include (1) support of the development and evaluation of existing and novel ambient measurement technologies (e.g., low-cost sensors, satellite remote sensing); (2) continuing support of efforts to improve model mechanisms, testing and improvement of existing air quality modeling tools and evaluation of novel tools; (3) study of future contributions of natural gas generation to haze levels, nitrogen deposition, and primary and secondary fine particulate formation; (4) understanding the impact of ultrafine particles on human health, as well as low concentrations of $NO_X$ and PM in general; (5) examining the impact of PM components from natural gas generation on human health; and (6) evaluating the effects of ozone from NOx emissions on human health.

### Greenhouse Gas Emissions

GHG emissions are one of the top environmental issues of today. Emissions of $CO_2$, $CH_4$, and other GHGs have increased steadily since industrialization, and have intensified significantly since the end of World War II. A wealth of research performed since the 1980s has linked emissions of GHG to global warming and documented the detrimental effects of global warming upon the environment worldwide. For example, ozone formed from $NO_X$ and VOC emissions is driving the phenomena of arctic amplification [128], by which arctic regions are warming at a much faster rate than the rest of the planet; impacting species, speeding glacial melting, and declining permafrost conditions. Increased GHG emissions have also resulted in the increasing frequency, intensity, and duration of extreme events across the globe [130] *(Figure 4)*. The transition to clean energy is already lowering the energy generation sector's contribution to GHG emissions, and efforts are underway to decarbonize the transportation, industry, and buildings sectors as well.


*Figure 4. Cause and Effect: GHG Emissions, Global Warming, and Extreme Events*

## Advancing into the Future

As decades of research demonstrate that action is necessary to forestall unchecked global warming, much of the focus is on short-term challenges, such as the U.S. meeting the new Paris Agreement target of a 50% GHG emissions reduction by 2030. However, the implications of climate change are long-lasting. While achieving net-zero carbon emissions is a crucial aspect, more actions can be undertaken to achieve a healthy planet, with a number of challenges in air, water and land media to remain or emerge as renewables, energy storage, alternative energy carriers and other clean energy technologies are deployed. For example, while coal combustion residuals become less of a waste concern due to reduced mass and the presence of beneficial use options, the often-hazardous waste from battery or PV modules creates new risks until robust reuse and recycling processes and markets are established. The mass of wind turbine blades provides an attractive source of material available for future beneficial use products. Choices made throughout the life cycle of these technologies, from the point of procurement, during operations and through end-of-life management, can be made with consideration given to maximizing environmental and human health benefits, and minimizing negative externalities. However, this is only possible after examination of those interactions and quantification of their value. Emerging technologies, such as hydrogen and ammonia fuels, CCS, and direct air capture have the potential to spur the global economy into net-negative emissions, though these technologies are under development and not currently available for widespread deployment. There are also other actions that the electric industry, other economic sectors, governments, and individuals can take to reduce environmental impacts, such as minimizing waste, improving material reuse and recycling, and restoring natural habitats.

The clean energy transition also presents opportunities for consideration of environmental justice (EJ) and energy equity [109] as an extension of addressing environmental challenges. The definition of EJ, the fair treatment and meaningful involvement of all people regarding environmental policies, laws, and enforcement, [109] provides a path as to how this concept may be incorporated into the energy transition. Identifying stakeholders and community members, then including them in planning, and continuously engaging and communicating with communities about the impacts of system planning investments, policies, laws, and enforcement, is critical to achieve a just transition *(Figure 5)*. Incorporating an EJ lens encourages the identification of regions that face the worst climate change impacts, prioritizes the remediation of those impacts, and promotes the health and safety of both the ecosystems and the people in those regions. While the concept of EJ, or in many cases environmental injustice, has been included in public conversation since the 1970s, the definitions, metrics, and incorporation of EJ into planning and execution of energy generation and delivery have been unclear.

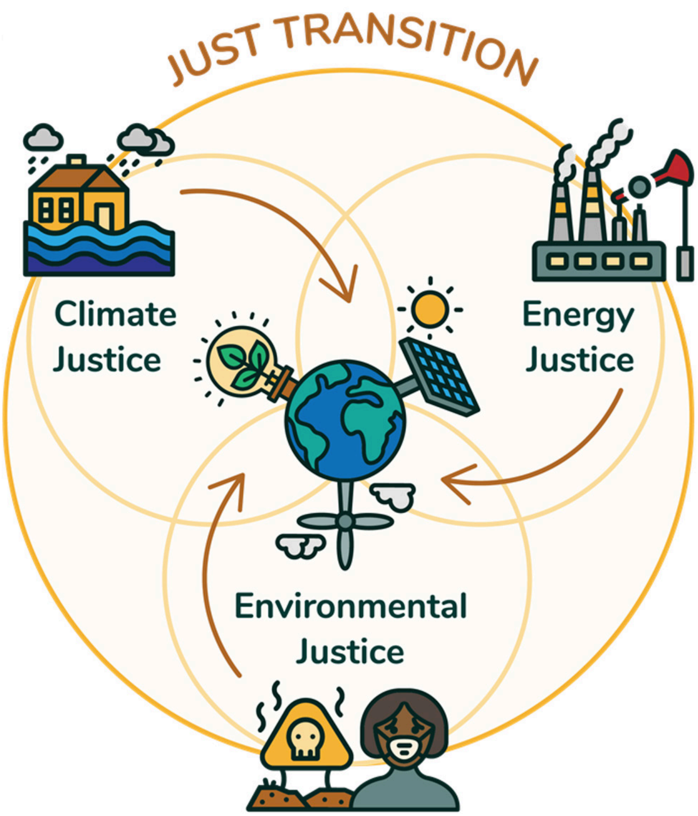


*Figure 5. Justice Triad for the Clean Energy Transition (Source: Initiative for Energy Justice)*

The clean energy transition is an opportunity for the energy sector to support the incorporation of equity and justice into operations, policies, laws, and public discussions that directly impact the communities served. Utilities may have unique opportunities to influence land and water use, environmental protection, species conservation, human health, and many other public goods by adapting corporate strategies, goals, and metrics that prioritize the environment, equity, and justice. Tools that endeavor to account for all aspects of the benefits and impacts of these changes, such as EPRI's Sustainability Optimization: Leveraging Value Estimation (SOLVE) and the EPA Benefits Evaluation Tools for Energy Efficiency and Renewable Energy Policies, may be used to balance benefit and cost distribution throughout the energy transition [111, 116].

## Minimizing the Severity of Climate Change

The transition to renewable and low-carbon clean energy generation and storage technologies is expected to reduce climate change impacts through electrification. State-level analyses of electrification for the power sector, buildings, transportation, and industry show promising results for our ability to reduce emissions and improve air quality in addition to reducing GHG emissions [103, 104, 105, 106, 107, 108]. These insights are useful to help identify an electrification pathway that maximizes air quality reduction and environmental benefits, but may not drive corporate decision-making processes without regulation.

Many utilities have set goals to achieve net-zero methane emissions from their gas infrastructure in the near future. These goals may be achieved, in part, through improving operational efficiency, use of renewable or alternative fuels, or enhancement of non-natural gas facilities. Each of these approaches requires an accurate understanding of the emissions baseline (whether combustion or fugitive emissions), drivers of emissions, and critical evaluation of today's technologies and future alternatives. Looking ahead to an electricity sector that has been substantially decarbonized also requires evaluation of the production, transport, and subsequent use of biomethane, which is captured and upgraded from sources such as landfills, agricultural sites, and wastewater treatment plants before refinement into pipeline-grade renewable natural gas (RNG).

## Increasing Deployment of Renewables, Energy Storage, and Low-Carbon Technologies

Achieving an economy-wide $CO_2$ emissions reduction of 50% by 2030, and a net-zero emissions economy by 2050 [120], will require rapid development and deployment of renewables, energy storage, and low-carbon technologies such as renewable natural gas, biofuels, hydrogen, and ammonia. Several major R&D areas that will require proactive solutions prior to widespread deployment include addressing environmental and social considerations of material extraction and processing in the upstream supply chain for newly needed key minerals and materials; mitigating the carbon and energy intensity associated with manufacture, transport and deployment of low carbon fuels and technologies; creating net land use benefits for renewable generation deployments; improving human and environmental safety tools for stored energy; and providing affordable, efficient and safe reuse and recycling options to minimize landfill disposal [42, 64, 79, 87, 88, 93, 98, 102].

Development and deployment of emerging technologies typically occurs faster than the standards, codes, and regulations intended to maximize safety and minimize environmental risks can be created. Thus, a paradigm of continual reevaluation and improvement is a necessary approach moving forward. The likelihood of increased siting of distributed energy facilities near to humans and throughout communities also enhances the possibility of exposure, and will require thoughtful design of facilities and their operations, as well as early and effective communication with neighbors. Clean energy technologies require a thorough examination of the distribution of benefits and costs, and how best to balance them for the common good.

## Sustainability and the Development of a Circular Economy

Rapid deployment of clean energy technologies will require equally rapid expansion of global supply chains in order to avoid bottlenecking and more permanent resource availability issues for key or critical materials that could slow the decarbonization process. However, the use of clean energy technologies also creates new considerations such as environmental and social impacts of mining, refining and associated global transport of materials; water and land use changes; and GHG release from transportation. These effects are often greatly reduced, and/or more localized, than those associated with GHG-generating technologies, but awareness and management of them must be incorporated to support a sustainable and equitable energy sector. Many required and voluntary guidelines currently exist and that may be enhanced for further transparency [93] and effectiveness across a broader range of materials and processes. Recent calls for development of new domestic industries for mineral extraction and recovery, manufacturing and recycling in a number of countries, including the U.S., may allow for the implementation of environmentally responsible industries throughout the asset lifecycle [60, 93, 112]. Planning for the full lifecycles of renewable generation and energy storage technologies can help stakeholders evaluate whether the total environmental costs and benefits are incorporated to maximize the resource value [112].

Stakeholders across all areas of business and technical operations within the electric utility industry are seeking ways to engage in circular economies as a way to enhance energy sustainability [27, 60]. The energy sector is beginning to embrace this challenge in areas such as developing sustainability benchmarking metrics [47, 110], facility life extension, redeveloping decommissioned thermal generation sites [58, 99, 113], beneficially reusing coal combustion products [10, 32, 44, 51], decreasing water use [20, 30, 33, 36, 55, 89], and reusing or recycling renewable energy assets that have reached the end of their operational life [25, 37, 38, 100, 112, 114] *(Figure 6)*. Incorporating circular economy practices into current operations provides the opportunity to increase and improve sustainability as society electrifies to support clean energy transition goals while balancing financial considerations to support a healthy planet [48, 92, 95].


*Figure 6. Electric Utility Roles in Renewable and Battery Circular Economies [112]*

## Conclusions

Achieving a clean energy transition that maintains affordability, reliability, and sustainability while simultaneously prioritizing balanced distribution of the costs and benefits across human, natural, and financial systems can be accomplished if action is taken by all stakeholders to accelerate solutions for legacy impacts, address current and future challenges, and incorporate environmental justice and energy equity into decision-making processes.

This transition will depend on clear communication and collaboration across all stakeholders. EPRI is supporting this transition by convening experts, facilitating conversations, and identifying and filling existing research and knowledge gaps. Working together, EPRI can aid the transition to a clean energy future while incorporating equity and justice that support a healthy planet.

## References

1. EPRI, 2001. In Situ Remediation of an Energized Substation. 1005169.
2. EPRI, 2004. Sediment Biotoxicity at Former MGP and Coking Sites. 1011168.
3. EPRI, 2005. Arsenic and Selenium Speciation in Fly Ash and Wastewater. 1005567.
4. EPRI, 2007. Handbook of Remedial Alternatives for MGP Sites with Contaminated Sediments. 1012592.
5. EPRI, 2007. Arsenic Health and Ecological Effects: Soil and Water. 1014015.
6. EPRI, 2008. Chemical Constituents in Coal Combustion Product Leachate: Arsenic. 1015550.
7. EPRI, 2008. MGP Site Characterization Best Practices Manual for Bedrock. 1018276.
8. EPRI, 2009. Arsenic Remediation Technologies for Groundwater and Soil. 1019476.
9. EPRI, 2010. Bioavailability of Arsenic in Soil. 1019851.
10. EPRI, 2010. Quantifying the Benefits of Using Coal Combustion Products in Sustainable Construction. 1020552.
11. EPRI, 2011. Evaluation of U.S. Environmental Protection Agency's Arsenic Ambient Water Quality Criteria: Speciation and Bioaccumulation Issues. 1021822.
12. EPRI, 2011. Arsenic Cancer Risk Assessment: Recent Advances and Next Steps. 1023096.
13. EPRI, 2012. Spatial and Temporal Assessment of Metal and Metalloid Bioaccumulation Patterns in Fish from the Ohio River. 1024924.
14. EPRI, 2012. Management of Process Wastewater at Coal-Fired Power Plants. 1023779.
15. EPRI, 2013. Program on Technology Innovation: Cumulative Risk Assessment of Urban Air Toxics: Pilot Modeling Study. 3002001021.
16. EPRI, 2013. The Impact of Recent Arsenic Research on Quantitative Risk Assessment. 3002001192.
17. EPRI, 2014. Quantifying Nonuse and Indirect Economic Benefits of Impingement and Entrainment Reductions. 3002003427.
18. EPRI, 2014. Methods Used to Develop Temperature Total Maximum Daily Loads (TMDLs): Implications for the Electric Power Industry. 3002003617.
19. EPRI, 2015. An Introduction to Social Costs and Resources for 316(b) Entrainment Evaluations. 3002006306.
20. EPRI, 2016. Wastewater Minimization Using Water Pinch Analysis. 3002006088.
21. EPRI, 2016. Conductor Cover Selection: An Animal Outage Device Selection Process to Maximize Installation Ease, System Compatibility, and Overall Performance. 3002006333.
22. EPRI, 2016. Relative Impact Framework for Evaluation Coal Combustion Residual Surface Impoundment Closure Options. 3002007543.
23. EPRI, 2016. Guidance Document for the Treatment of Flue Gas Desulfurization (FGD) Wastewater in Compliance with the 2015 Effluent Limitations Guidelines (ELGs). 3002008318.
24. EPRI, 2016. Managing the Impact of Regulatory Changes to Power Plant Effluent Limitations. 3002008319.
25. EPRI, 2016. Solar Photovoltaic Life Cycle Analysis: A Practical Handbook for Solar Photovoltaic Power Plant Owners and Operators. 3002008832.
26. EPRI, 2016. Guidance Document for Management of Closed-Loop Bottom Ash Handling Water in Compliance with the 2015 Effluent Limitations Guidelines (ELGs). 3002008345.
27. EPRI, 2016. Wind Project Life-Extension Roadmap.

3002009237.

28. EPRI, 2017. EPRI National Cost Estimate for Retrofit of U.S. Power Plants with Closed-Cycle Cooling. 1022212.
29. EPRI, 2017. Vegetation Best Management Practices to Protect Birds and Bats Along Electric Transmission Rights-of-Way. 3002010812.
30. EPRI, 2017. Water Use: Efficiency, Trading, and Pricing. 3002012043.
31. EPRI, 2017. Benefits Valuation of Site-Specific Entrainment Reduction Technologies under 316(b) of the Clean Water Act: Technical Resource Document. 3002010346.
32. EPRI, 2017. Flue Gas Desulfurization Gypsum as a Soil Amendment for Phosphorus Reduction in Agricultural Drainage: Milwaukee River Watershed Field Study. 3002010967.
33. EPRI, 2017. Watershed Activity Benefits Matrix. 3002011881.
34. EPRI, 2017. Hazardous Air Pollutants (HAPs) Emission Estimates and Inhalation Human Health Risk Assessment for U.S. Coal-Fired Electric Generating Units: 2017 Base Year Post-MATS Evaluation. 3002013577.
35. EPRI, 2018. Using Integrated Uncertainty Analysis to Improve Consistency in Criteria Pollutant Risk Analyses. 3002010870.
36. EPRI, 2018. Watershed Activities and Economic Considerations: Cost Benefit Tool and Technical Update. 3002011883.
37. EPRI, 2018. End-of-Life Disposal and Recycling Options for Wind Turbine Blades. 3002012240.
38. EPRI, 2018. Program on Technology Innovation: Feasibility Study on Photovoltaic Module Recycling in the United States. 3002012461.
39. EPRI, 2018. Multi-Pathway Human Health Risk Assessment for Coal-Fired Power Plants. 3002013523.
40. EPRI, 2018. Hazardous Air Pollutants (HAPs) Emission Estimates and Inhalation Human Health Risk Assessment for U.S. Coal-Fired Electric Generating Units: 2017 Base Year Post-MATS Evaluation. 3002013577.
41. EPRI, 2018. Integrated Uncertainty Analysis for Assessing Health Risks of Air Pollutants. 3002013586.
42. EPRI, 2018. Environmental Permitting for Stationary Lithium-ion Battery Energy Storage Systems: An Overview of Environmental, Health and Safety Regulations & Permitting Requirements. 3002013619.
43. EPRI, 2018. Water Stewardship Goals for the Electric Power Sector. 3002013694.
44. EPRI, 2018. Environmental Considerations for Coal Combustion Product Harvesting from Landfills and Surface Impoundments. 3002013741.
45. EPRI, 2018. Overview of Power Companies and Pollinators. 3002014014.
46. EPRI, 2018. Program on Technology Innovation: Environmentally Effective Siting of Renewables: Large Scale Data and Predictive Models for Birds and Bats. 3002014748.
47. EPRI, 2019. Context-Based Metrics (CBMs): Outlining Foundational Considerations and Summarizing Implementation Efforts. 3002013456.
48. EPRI, 2019. Sustainability Return on Investment: Advancing Understanding of Sustainability Value Creation to Inform Power Company Investments. 3002013450.
49. EPRI, 2019. Potential Resiliency Practices. 3002013858.
50. EPRI, 2019. Program on Technology Innovation: Evaluation of Emissions Profiles for Electric Generating Units That Shift from Baseload to Shoulder or Peaking Operations. 3002016350.
51. EPRI, 2019. Beneficiation Deep Dive: Carbon Reduction Technologies. 3002016510.
52. EPRI, 2019. SCICHEM Version 3.2. 3002016526.
53. EPRI, 2019. Inhalation Human Health Risk Assessment for U.S. Stationary Combustion Turbines: 2014 Base Year Evaluation. 3002016528.
54. EPRI, 2019. Human Health Effects at Low Particulate Matter Concentrations: Supralinearity Response. 3002016550.
55. EPRI, 2019. Review Tools to Evaluate the True Cost of Water. 3002016552.
56. EPRI, 2019. Compendium of Animal Caused Outage Prevention Products: 2019 Update. 3002016586.
57. EPRI, 2019. Unmanned Aircraft System-Based LiDAR versus Photogrammetry: A Critical Comparison for Vegetation Management. 3002016591.
58. EPRI, 2019. A Comprehensive Approach to Repurposing Retired Coal Power Plant Sites: Transforming Liabilities to Assets. 3002016691.
59. EPRI, 2019. Multi-Pathway Human Health Risk Assessment for U.S. Stationary Combustion Turbines: 2014 Base Year

Evaluation and Refined TRIM. 3002016745.

60. EPRI, 2019. Program on Technology Innovation: Life Cycle Assessment of Lithium-ion Batteries in Stationary Energy Storage Systems. 3002017000.
61. EPRI, 2019. Environmental Risk Screening Assessment for U.S. Combustion Turbines: 2014 Base Year Evaluation. 3002017441.
62. EPRI, 2019. Effects of Vegetation Management in Southeastern United States Electric Transmission Line Rights-of-Way on Pollinating Insects: Rights-of-Way and Pollinators. 3002017685.
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64. EPRI, 2020. Environmental Aspects of Utility-Scale Energy Storage Systems: An Environmental, Health, and Safety Comparison Across Commercially Available Technologies. 3002016593.
65. EPRI, 2020. Population-Level Risk to Hoary Bats Amid Continued Wind Energy Development: Assessing Fatality Reduction Targets Under Broad Uncertainty. 3002017671.
66. EPRI, 2020. Program on Technology Innovation: Minimizing Risks to the Electric Power Industry from Changing Surface Water Conditions. 3002017808.
67. EPRI, 2020. Potential Water-Related Risks to the Electric Power Industry Associated with Changing Surface Water Conditions. 3002017809.
68. EPRI, 2020. Laboratory Investigation of Formaldehyde Measurements Using Fourier Transform Infrared (FTIR) Spectroscopy: Assessment of Minimum Detectable Concentration. 3002018607.
69. EPRI, 2020. Closure Option Assessment Tool (COAT) v1.0. 3002018790.
70. EPRI, 2020. Coal Combustion Product Use Technology Profiles. 3002018793.
71. EPRI, 2020. Animal-Caused Outage Prevention Products: Effectiveness and Durability – A Framework for Product Testing. 3002018893.
72. EPRI, 2020. Cost of Deferring Vegetation Maintenance of Transmission Rights-of-Way: Direct and Indirect Cost Considerations in Determining Optimal Preventive Maintenance Intervals. 3002018894.
73. EPRI, 2020. Environmental Fate of Herbicides Used in Vegetation Maintenance on Transmission Rights-of-Way: An Assessment Based on Contemporary Integrated Vegetation Management Practices. 3002018895.
74. EPRI, 2020. A Guide to Establishing Native Habitat: Principles, Practices, and Plants. 3002018908.
75. EPRI, 2020. Review and Analysis of Personal-Ambient Ozone Measurements. 3002019022.
76. EPRI, 2020. Confounding in Air Pollution Epidemiology Studies. 3002019025.
77. EPRI, 2020. Framework for Research Informing the Ozone Secondary National Ambient Air Quality Standard. 3002019031.
78. EPRI, 2020. Review of Pertinent Ecological Receptors to Constrain Nitrogen Critical Loads. 3002019032.
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80. EPRI, 2020. Review of Satellite Capabilities for Observations of Surface-Level Concentrations and Emissions. 3002019034.
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82. EPRI, 2020. Identification of At-Risk Trees Using Satellite Imagery. 3002019050.
83. EPRI, 2020. Methane Emissions from Natural Gas Distribution and End Use Sources. 3002019054.
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86. EPRI, 2020. Data Quality Evaluation of Filterable Particulate Matter Tests on Natural Gas-Fired Combustion Turbines: Suitability for Emission Factor Development. 3002019389.
87. EPRI, 2020. Overview of Emissions Impacts from Grid-Connected Battery Energy Storage. 3002020074.
88. EPRI, 2020. Near-Field Air Modeling Tools for Potential Hazardous Material Releases from Battery Energy Storage System

Fires. 3002020094.

89. EPRI, 2020. Helping Electric Power Companies Understand and Take Action on Achieving Net Positive Water Impact. 3002020115.
90. EPRI, 2020. Supplemental Human Health and Environmental Risk Assessment for U.S. Combustion Turbines: 2014 Base Year Evaluation. 3002020134.
91. EPRI, 2020. Solar Grazing: Viability of Grazing Sheep for Vegetation Management. 3002020204.
92. EPRI, 2021. Sustainable Finance: An Overview of the Landscape and Opportunities. 3002019248.
93. EPRI, 2021. Sustainability Aspects of the Lithium Ion Battery Supply Chain. 3002019811.
94. EPRI, 2021. Estimating Total Ammonia Releases from Stationary Power Plants: 2021 Update. 3002020345.
95. EPRI, 2021. Repairing the Social Cost of Carbon Framework: Immediate and One Year Steps for Scientifically Reliable Estimates and Use. 3002020523.
96. EPRI, 2021. Power-in-Pollinators Initiative. 3002015352.
97. EPRI, 2021. Mobile-Platform Measurement of Air Pollutant Concentrations in California: Performance Assessment, Statistical Methods for Evaluating Spatial Variations, and Spatial Representativeness. 3002019492.
98. EPRI, 2021. EPRI Research Activities on Renewable and Battery End-of-Life Management. 3002019572.
99. EPRI, 2021. Guidance on the Design, Permitting, and Construction of Solar Facilities on Closed Coal Combustion Residual Sites. 3002019899.
100. EPRI, 2021. End-of-Life management for Lithium Ion Battery Technologies: Issues, Uncertainties, and Opportunities. 3002020006.
101. EPRI, 2021. Low-Cost Sensor Evaluation for Potential Use at Community Air Quality Monitoring Stations. 3002020434.
102. EPRI, 2021. Guidelines for Assessing End-of-Life management Options for Renewable and Battery Energy Storage Technologies. 3002020594.
103. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: Georgia. 3002021152.
104. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: West Virginia. 3002021153.
105. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: Louisiana. 3002021154.
106. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: Texas. 3002021155.
107. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: Ohio. 3002021156.
108. 108. EPRI, 2021. Air Quality Impacts of Electrification Scenarios: Illinois. 3002021157.
109. EPRI, 2021. Equity and Environmental Justice Considerations for a Clean Energy Transition 3002021206.
110. EPRI, 2021. 2021 Metrics to Benchmark Electric Power Company Sustainability Performance. 3002021713.
111. EPRI, 2021. Sustainability Optimization: Leveraging Value Estimation Tool (SOLVE) v2.3. 3002022227.
112. EPRI, 2021. Electric Sector Challenges in Circular Economies for Renewables and Batteries: Proceedings of the March 2021 Washington Seminar. 3002022231.
113. EPRI, 2021. Roadmap to Plant Retirement, Decommissioning, and Site Redevelopment. 3002022434.
114. Research gaps in environmental life cycle assessments of lithium ion batteries for grid-scale stationary energy storage systems: End-of-life options and other issues. 2020. Sustainable Materials and Technologies, Open Access article, Volume 23, e00120; https://doi.org/10.1016/j. susmat.2019.e00120.
115. Hazardous and Solid Waste Management Systems; Disposal of Coal Combustion Residuals from Electric Utilities, 80 Federal Register 21301 (April 17, 2015).
116. United States Environmental Protection Agency. Benefit Evaluation Tools for Energy Efficiency and Renewable Energy Policies. https://www.epa.gov/statelocalenergy/benefit-evaluation-tools-energy-efficiency-and-renewable-energy-policies
117. "Ar6 climate change 2021:the physical science basis," *Sixth Assessment Report*, Aug-2021. [Online]. Available: https://www.ipcc.ch/report/ar6/wg1/#SPM. [Accessed: 20-Aug-2021].
118. "Clean Air Act Overview," *EPA*. [Online]. Available: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health. [Accessed: 20-Aug-2021].
119. "Executive Order 12866 of September 30, 1993," *Federal Register*, 04-Oct-1993. [Online]. Available: https://www.archives.gov/files/federal-register/executive-orders/pdf/12866.pdf.

120. "FACT SHEET: President Biden Sets 2030 greenhouse gas pollution reduction TARGET aimed at Creating GOOD-PAYING union jobs and Securing U.S. leadership on clean energy technologies," *The White House*, 22-Apr-2021. [Online]. Available: https://www.whitehouse.gov/briefing-room/statements-releases/2021/04/22/fact-sheet-president-biden-sets-2030-greenhouse-gas-pollution-reduction-target-aimed-at-creating-good-paying-union-jobs-and-securing-u-s-leadership-on-clean-energy-technologies/#:~:text=Today%2C%20President%20Biden%20will%20announce,to%20tackle%20the%20climate%20crisis. [Accessed: 20-Aug-2021].

121. "FACT SHEET: Biden-Harris Administration 100-Day Battery Supply Chain Review," *The White House*, June 8, 2021. [Online]. Available: https://www.energy.gov/articles/fact-sheet-biden-harris-administration-100-day-battery-supply-chain-review [Accessed November 2, 2021].

122. "Federal Air Quality Law," *Authority*. [Online]. Available: https://www.aqmd.gov/nav/about/authority. [Accessed: 20-Aug-2021].

123. J. S. John, "Hawaii's plan to use dispatchable renewables and batteries to replace dirty power Plants: GTM Squared," *Hawaii's Plan to Use Dispatchable Renewables and Batteries to Replace Dirty Power Plants | Greentech Media*, 03-Aug-2019. [Online]. Available: https://www.greentechmedia.com/squared/dispatches-from-the-grid-edge/hawaiian-electrics-plan-for-dispatchable-renewables-batteries-and-grid-serv. [Accessed: 20-Aug-2021].

124. "Regulatory and Guidance Information by Topic: Air," *EPA*. [Online]. Available: https://www.epa.gov/regulatory-information-topic/regulatory-and-guidance-information-topic-air#:~:text=Under%20the%20Clean%20Air%20Act,%2C%20utilities%2C%20and%20steel%20mills. [Accessed: 20-Aug-2021].

125. S. Gross, "Renewables, land use, and local opposition in the United States," *Brookings*, 12-Aug-2021. [Online]. Available: https://www.brookings.edu/research/renewables-land-use-and-local-opposition-in-the-united-states/. [Accessed: 20-Aug-2021].

126. "Section .0400-Ambient Air Quality Standards." [Online]. Available: https://deq.nc.gov/about/divisions/air-quality/air-quality-rules/rules/ambient-air-quality-standards. [Accessed: 20-Aug-2021].

127. "South Coast Air Quality Management District," *Home*. [Online]. Available: http://www.aqmd.gov/. [Accessed: 20-Aug-2021].

128. "Air Quality and Climate Change," *Air Quality and Climate Change | UCAR Center for Science Education*. [Online]. Available: https://scied.ucar.edu/learning-zone/air-quality/air-quality-and-climate-change. [Accessed: 28-Sep-2021].

129. "Health & Environmental Effects of Air Pollution," *Commonwealth of Massachusetts Executive Office of Energy & Environmental Affairs*. [Online]. Available: https://www.mass.gov/doc/health-environmental-effects-of-air-pollution/download#:~:text=Air%20pollution%20can%20damage%20crops,(such%20as%20harsh%20weather).

130. "Based on Science: Climate Change," *nationalacademies.org*. [Online]. Available: https://www.nationalacademies.org/based-on-science/climate-change-global-warming-is-contributing-to-extreme-weather-events. [Accessed: 30-Sep-2021].

131. "Progress Cleaning the Air and Improving People's Health," EPA. [Online]. Available: https://www.epa.gov/clean-air-act-overview/progress-cleaning-air-and-improving-peoples-health. [Accessed: 17-Nov-2021].

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Founded in 1972, EPRI is the world's preeminent independent, non-profit energy research and development organization, with offices around the world. EPRI's trusted experts collaborate with more than 450 companies in 45 countries, driving innovation to ensure the public has clean, safe, reliable, affordable, and equitable access to electricity across the globe. Together, we are shaping the future of energy.

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