A Guide to Regional Decarbonization

Frameworks for public policy leaders and sustainability practitioners to create pathways to net zero across the US and globally

SUSTAINABLE DEVELOPMENT
SOLUTIONS NETWORK
A GLOBAL INITIATIVE FOR THE UNITED NATIONS

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About the SDSN

SDSN mobilizes global scientific and technological expertise to promote practical solutions for sustainable development, including the implementation of the Sustainable Development Goals (SDGs) and the Paris Agreement. For more information, please visit https://www.unsdsn.org/.

About the San Diego Regional Decarbonization Framework

The integrated Regional Decarbonization Framework is a partnership to move the region of San Diego toward zero-carbon emissions. It is the County's science-based, holistic approach to guide the region's decarbonization efforts in partnership with the UC San Diego School of Global Policy and Strategy, the University of San Diego Energy Policy Initiatives Center, and Inclusive Economics.

For more information, please visit https://www.sandiegocounty.gov/RDF/.

Disclaimer: This Guide was written by two authors from SDSN as part of the larger San Diego Regional Decarbonization Framework initiative commissioned by the County of San Diego.

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Acronym	Meaning
ACS	American Community Survey
AEO	Annual Energy Outlook
CAISO	California Independent System Operator
CAP	Climate Action Plan
CCUS	Carbon Capture, Utilization, and Storage
COMET Planner	CarbOn Management & Emissions Tool Planner
CO_2	Carbon Dioxide
CPAs	Candidate Project Areas
CPS	Current Population Survey
CPS-ORG	Current Population Survey Outgoing Rotation Group
EER	Evolved Energy Research
EP	EnergyPATHWAYS (Modeling Platform)
GHG	Greenhouse Gas
IMPLAN	Impact Analysis for Planning
IPCC	Intergovernmental Panel on Climate Change
IRP	Integrated Resource Plan
I-O	Input-Output
LSEs	Load Serving Entities
MMT CO_2e	Million Metric Tons of Carbon Dioxide Equivalent
MT CO_2e	Metric Tons of Carbon Dioxide Equivalent
MT CO_2e ha^{-1} yr^{-1}	Metric Tons of Carbon Dioxide Equivalent per hectare, per year
MWh	Megawatt Hour
QGIS	Quantum Geographic Information System
RDF	Regional Decarbonization Framework
RETI	Renewable Energy Transmission Initiative
RIO	Regional Investment and Operations (Modeling Platform)
SANDAG	San Diego Association of Governments
SanGIS	San Diego Geographic Information Source
SDGs	Sustainable Development Goals
SDSN	Sustainable Development Solutions Network
TDM	Transportation Demand Management
UN	United Nations
US EIA	United States Energy Information Administration
US EPA	United States Environmental Protection Agency

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1. The Approach: Getting Started on Regional Decarbonization

In order to reduce the worst impacts of climate change, including sea level rise, extreme temperatures, and increasingly frequent and intense storms, wildfires, and flooding events worldwide, the international community has agreed that societies must limit the rise in mean global temperature to well below 2°C, as specified by the Paris Agreement within the United Nations Framework Convention on Climate Change.[1] Meeting this goal requires that global net emissions of greenhouse gases reach zero by the year 2050. This entails a profound transformation and the deep decarbonization of our societies—a multidimensional challenge that is currently at the forefront of global dialogues and priorities.

Efforts to address climate change in the United States have been fragmented and challenged by the temporal, political, and jurisdictional boundaries in which our societies are organized. Recognizing our shared responsibility to reduce emissions, the important progress being made, and the limited geographies within which our city council members, mayors, and governors must work, it is essential that a coordinated effort to connect bottom-up and top-down endeavors across the US is realized in order to attain full decarbonization. As stated by UC San Diego's Gordon McCord, "Thousands of regional and local governments across the US need science-based frameworks to support decision-making over the next 25 years, helping policymakers lay out plans that are coherent across jurisdictions and balance climate, ecological, economic, and equity priorities."

Deep decarbonization demands the implementation of integrated, systems-wide solutions that account for social, economic, and environmental well-being. As cities, counties, and states across the country continue to commit to reducing their emissions, it is crucial that lessons are shared in a comprehensive and intentional manner in order to accelerate and support decarbonization planning and implementation processes. To address the interconnected challenges of scalability, technology adaptation, sustainability, and inequality and social justice, innovative policy solutions must be adopted and iterative learning and ongoing collaboration achieved. This Guide attempts to provide a starting point for districts and counties across the United States by summarizing the process, tools, and key resources used in the creation of the 2022 San Diego Regional Decarbonization Framework (RDF).[i]

The RDF is a zero-carbon sustainability plan that is intended to inform policy-making in regional, county, and city governments toward reducing greenhouse gas (GHG) emissions in the region of San Diego, California in the United States. The RDF defines the San Diego region by the boundaries with Orange County, Imperial County, and Mexico, as well as the boundary with state waters.[2] Some analyses additionally cover the unincorporated areas of San Diego, those outside of the 18 cities and Indian Reservations of the county that are under the jurisdiction of the Board of Supervisors, its legislative and executive authority. The RDF presents a science-based approach to help governments in the region plan for policies and investments to reduce emissions based on different pathways, or blueprints. The framework provides a technical roadmap, gap analysis, and recommended policy actions toward deep decarbonization across all jurisdictions in the region.

i https://www.sandiegocounty.gov/RDF/

Building on work published over the last two decades, it examines the potential for natural climate solutions, the impact of jobs during the decarbonization transition, and employs energy systems modeling to analyze how changes in the electricity, transportation, land use, and buildings sectors could make up technical pathways for arriving at net-zero emissions.

Due to the interconnectedness of the global climate and energy systems, as well as the multifaceted nature of decarbonization itself, the framework also emphasizes the need for these sectors to work in conjunction with one another and other regions to reach emissions reduction goals. Transitioning toward decarbonization additionally requires local, state, and national governments to work in concert to align policies and investments, through both vertical and horizontal collaborations across jurisdictions. The findings of the RDF present a clear vision of actions and feasible decarbonization pathways for coordination among governments and sectors in San Diego county, which can help inform the establishment of other such roadmaps across the United States.[ii]

1.1 Motivation and Target Audience of this Guide

Despite the expanding recognition of the need for decarbonization and rising amount of pledges worldwide, guidance material on successful examples and best practices for long-term decarbonization planning at a subnational, regional level are scarce. **This Guide aims to fill this knowledge gap by sharing the process undertaken by the County of San Diego, which can serve as a case study for other jurisdictions to learn from and replicate in their own decarbonization planning and implementation endeavors.**

Although national studies on decarbonization efforts carried out in specific countries are available, and guides for policymakers on the decarbonization of specific sectors do exist, guidance materials like this Guide that offer step-by-step suggestions for realizing long-term, systems-wide decarbonization planning at a subnational, regional level are limited. However, examples of other such guides include the *2050 Pathways Platform Handbook* (https://www.2050pathways.org/wp-content/uploads/2017/09/2050Pathways-Handbook-1.pdf) and *Making Long-Term Low GHG Emissions Development Strategies a Reality* report (https://2050pathways.org/wp-content/uploads/2020/06/GIZ_NewClimate _LTS_Guide ForPolicy Makers_2020.pdf), as well as the *World Bank Group Decarbonizing Development* report (https://www.worldbank.org/content/dam/Worldbank/document/Climate/dd/decarbonizing- development-overview.pdf), and the *Partners for Climate Protection Milestone Framework* (https://www.pcp-ppc.ca/program). Still, this Guide, and the tools and strategies it offers, differ from those provided in such works. Rather than piecing together findings from distinct efforts and providing a "one-size- fits-all" approach, this Guide is grounded in the process undertaken by a single jurisdiction, from start to finish. It identifies which elements of the RDF are specific to San Diego county and extracts others that can be applied elsewhere based on different contexts and enabling factors for the nearly 90,000 local governments across the United States.

ii The primary target audience of this Guide consists of US governing bodies, research groups/universities, and sustainability practitioners, as the process undertaken by the County of San Diego was designed to transform an already evolved energy system, in line with the emissions reduction goals and regulatory obligations set by the governments of California and the US. Although the resources within this Guide are relevant and applicable to decarbonization framework projects elsewhere, frameworks being created in the context of emerging economies will likely use different approaches, perspectives, and strategies in climate action planning.

This Guide will serve as a toolkit for city, county, state, and regional governing bodies (particularly in the US) to follow in their own pursuit of net-zero emissions. **As an addendum to the larger San Diego RDF report, this Guide will distill the high-level process undertaken by the County of San Diego, highlight the enabling factors for success, and provide a step-by-step instruction manual for other jurisdictions that wish to undertake similar long-term decarbonization planning processes. Although several elements of this project are replicable and applicable to other jurisdictions, the strategies provided in the RDF and this Guide must be tailored to each local context.** This includes determining which actions are feasible and which ones are not, as well as recognizing where engagement with other stakeholders at lower or higher levels will be needed to achieve the multidimensional coordination required to achieve deep decarbonization.

Furthermore, when utilizing this RDF and Guide, the limitations and uncertainties that are inherent in decarbonization research and long-term planning efforts must also be accounted for, especially as circumstances and needs change over time. These include potential variability and unprecedented outcomes in terms of technology development, political cycles, downscaling processes, and competing priorities. In addition, although decarbonization can create various situations that all stakeholders benefit from, win-win scenarios cannot be guaranteed in every instance. In these cases, strategies must be implemented and adapted to assist those who are at risk of being left behind, such as displaced fossil fuel-based industries and workers. Thus, even though the data-driven information and processes described here can serve as a strong basis for other jurisdictions to chart their own paths toward decarbonization, this RDF and Guide do not offer a "silver bullet" approach. Instead, they are meant to provide initial guidance on the design and implementation of regional decarbonization frameworks and long-term planning efforts to reach climate goals. Achieving deep decarbonization anywhere requires ongoing innovation and multiple, flexible, context-specific strategies to prompt the holistic action needed to reach net zero.

1.2 Getting Started: The Process in Brief

For the city, county, state, and regional governing bodies that are working on facilitating and enabling the transition toward decarbonization across their jurisdictions, the process undertaken by the County of San Diego can provide a roadmap for how to carry out holistic, data-driven, long-term planning efforts. This particular section provides an overview of the extensive process undertaken to create the San Diego RDF. These steps are a suggested starting point of fundamental actions that could inform similar projects.

To get started, the first course of action is to identify your region's leverage[iii] and the sources and sinks of carbon within and outside of your control. This requires **mapping the emissions profile and sectoral landscape** of a given jurisdiction and an in-depth look into its overall energy system dynamics (see Section 1.4). Once the jurisdiction's emissions-intensive commodities and activities are determined, **relevant sector experts and stakeholder groups are invited** to participate in a comprehensive project team that needs to be assembled (see Section 1.4). This team then conducts the **technical modeling and analysis** (e.g., sector-by-sector, geospatial, jobs, and policy) to determine what physical and economic choices are available to put the current energy system on the path to meet net-zero emissions goals by mid-century or sooner (see Section 2). In the San Diego RDF, the energy transition scenarios generated in the technical modeling inform the sector-by-sector and geospatial analyses, which both inform the evaluation of employment impacts; all of these

iii The RDF defines "leverage" as "the direct or significant influence [of a given jurisdiction] over actions to achieve deep decarbonization."[3]

findings are then used in designing relevant policy solutions. **Public consultations and community outreach** are carried out throughout all of these processes, as they are integral to ensuring just and sustainable decarbonization efforts (see Section 1.5). It is important to account for justice and sustainability in decarbonization planning from the beginning, for example, by highlighting those sectors, industries, and workforces that may need to be compensated or re-trained during the transition, working with marginalized communities, and quantifying the impacts of inaction in order to bring on all stakeholders from the onset.

The technical analyses are followed by the identification of **"low regret" policies** that can be implemented by the public and private sectors (see Section 3.2). After identifying the "low-regret" policies, their feasibility must be evaluated by **determining where the capacity and leverage** to put them into effect is already possessed, and where engagement with other stakeholders at higher (e.g., state, federal) and lower levels (e.g., community, city) will be necessary. This is supplemented by a **comparison between the existing policy landscape of a given jurisdiction and the decarbonization pathway(s)** to understand the extent of existing policy action and identify gaps that should be addressed. Finally, an **integrated framework is prepared, and the benefits of climate mitigation are demonstrated to local communities**, so that they: are informed about decarbonization, understand what it means for their daily lives, recognize the tremendous opportunity and responsibility that the transition presents for current and future generations, and can participate in the ongoing decarbonization process. Taking these actions to create a decarbonization framework, and ultimately achieving net-zero emissions, is aided by various factors, such as: ongoing and flexible planning, innovation and technological capacity, economic growth assurances, equitable collaboration, transparency, jurisdictional alignment, political support, and pursuing co-benefits and reducing risk whenever possible. The following sections of this Guide provide more in-depth information about the different steps and strategies used to create the San Diego Regional Decarbonization Framework, as well as how these **enabling factors** were incorporated throughout the process.

1.3 Setting Up Your Framework

The process below was followed by the San Diego Regional Decarbonization Framework team as they worked to develop their analyses over the course of a year. It should be noted that this project had an incredible library of data, resources, and precedence across the region and state to work from. As one of the most, if not the most, progressive states working to address climate change in the US, districts in California benefit from clear state level mandates and executive orders on which to align their efforts (e.g., Executive Order B-55-18).[iv] This has also led to the development of several local climate action plans on which to build this project, as well as a vast array of databases and environmental impact studies. Because of this array of background material to work from at the onset, the research team was able to put forward two specific and ambitious research questions, which served as the basis of the project outline below:

> *"(1) What changes are required to renewable energy infrastructure, patterns of energy use in transportation and buildings, and modes of transportation for the San Diego region to decarbonize consistent with the state's goals; and*
>
> *(2) What policy actions must be taken at a local level for the region to achieve these changes?"*[2]

iv https://www.ca.gov/archive/gov39/wp-content/uploads/2018/09/9.10.18-Executive-Order.pdf

Figure 1. An overview of the regional decarbonization framework creation process and the key elements and stakeholders involved.

Government Leadership

City, county, state, and/or regional governing bodies commit to decarbonization and lead the development of an RDF project.

Key Elements: Community Engagement, Innovation & Flexibility, Political Will & Alignment

Key Stakeholders: Government, Tribal Nations

Jurisdictional Scoping

The emissions profile and sectoral landscape of the jurisdiction(s) of focus are mapped to examine the overall energy system dynamics.

Key Elements: Community Engagement, Technical Expertise

Key Stakeholders: Academic Institution, Community Liaisons, Industry & Union Representatives, Modeling Teams, Tribal Nations

Stakeholder Outreach

Public consultations, stakeholder meetings, and interviews with subject matter experts from academia, the private sector, and civil society are carried out to establish the project team and scope.

Key Elements: Community Engagement

Key Stakeholders: Academic Institution, Community Liaisons, Government, Industry & Union Representatives, Modeling Teams, Professional Networks, Tribal Nations

Pathways Development

Technical and modeling analyses are carried out (sector-by-sector, geospatial, jobs, policy) to create decarbonization pathways to mid-century or sooner.

Key Elements: Innovation & Flexibility, Modeling Tools, Technical Expertise

Key Stakeholders: Academic Institution, Modeling Teams

Energy

Buildings Manufacturing Transport

Industry Sustainable Materials

Jobs **Land Use**

Localization & Socialization

Community engagement is carried out to share the initial results with local communities and solicit feedback to promote inclusivity and contextualize findings.

Key Elements: Community Engagement, Technical Expertise

Key Stakeholders: Academic Institution, Community Liaisons, Government, Industry & Union Representatives, Modeling Teams, Professional Networks, Tribal Nations

Implementation

A region-wide institutional governance structure for decarbonization is created to establish an implementation playbook, prioritize near-term, "low regret" policies, and engage with other jurisdictions.

Key Elements: Community Engagement, Innovation & Flexibility, Political Will & Alignment

Key Stakeholders: Academic Institution, Government, Community Liaisons, Industry & Union Representatives, Professional Networks, Tribal Nations

Realizing the special parameters on which this project was built, this project outline is meant to serve as an example process by which you may get started on your framework. Users of this document should feel at liberty to adapt these steps to suit their needs, contingent on the resources and policy benchmarks relevant to their local jurisdiction. The following sections of this Guide provide more detailed information on the specific strategies used to carry out the tasks outlined below.

Project Outline:[v]

Task 1: Conduct Initial Stakeholder Outreach

1.0 Research greenhouse gas emissions inventories or local climate action plans

1.1 Identify potential framework stakeholders and collaborators

1.2 Participate in stakeholder meetings

1.3 Conduct interviews with subject matter experts

1.4 Prepare scoping document

Task 2: Technical Framework Modeling and Analysis

2.0 Consult with a local modeling team to determine what kind of modeling methodology will be used in your analysis

2.1 Collect data required for modeling

Regional Up/Downscaling: Identify any local, regional, state, or national decarbonization pathways analyses on which to align your own assessment for scaling purposes later.

Electric Power Sector Analysis: Spatial analysis to identify low-impact, high quality, technically feasible areas for renewable energy infrastructure development, and to coordinate the early planning of the transmission network needed to interconnect new, low-impact renewable energy power plants (and/or distributed resources) to the grid.

Land Use Analysis: Identify bioenergy opportunities,[vi] negative emissions technologies, and ecological conservation and restoration considerations.

Transportation Analysis: Spatial analysis to identify opportunities for alternative modes of transport, vehicle electrification, and reduction of vehicle miles traveled.

Buildings Analysis: Use existing data sources to characterize buildings stock in the region and estimate efficiency (appliance and building shell), as well as fuel switching/decarbonization potential over time. Estimate energy use and emissions by sector and building type over time, estimating impact of fuel choice in new and existing buildings. Quantify monetary costs and benefits of different scenarios, coordinating with the energy system model. Analyze gas pipeline economics and customer fuel choice impacts.

v See Appendix 1 for a checklist of the tasks needed to create a regional decarbonization framework.

vi In doing so, recognizing the current debate about the true decarbonization potential of bioenergy, despite it being described as an essential part of a global net-zero energy system (e.g., by the International Energy Agency, https://www.ieabioenergy.com/wp-content/uploads/2022/04/IEA-Bioenergy-Annual-Report-2021.pdf, and the IPCC, https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-2-Bioenergy-1.pdf). While some research promotes bioenergy as a carbon-neutral energy source, other research suggests that emissions resulting from biofuel production and use, including those from indirect land use change and across the whole value chain (plant growth, crop harvest, transportation, conversion, and final distribution), may be higher than those generated by fossil fuels (https://iopscience.iop.org/article/10.1088/1748-9326/aaa512/meta). Additionally, the time scales for emitting and storing carbon in the biosphere are often misaligned with land use management strategies and emission reduction goals.

Industrial Analysis: Identify which industrial sectors are relevant and the local labor unions or private sector corporations which manage these sectors. Make sure to involve these partners early on in the project scoping period.

Jobs Analysis: Highlight considerations for an equitable and just transition to decarbonization, so that policymakers are cognizant of consequences of policy decisions for jobs and distributional impacts of policies across demographic groups.

Policy Analysis: After detailing the physical system transformation, connect the infrastructure plan to policy levers at your jurisdictional level and at the state and federal policy level to identify synergies and potential challenges.

2.2 Conduct modeling and other analysis (e.g., sector-by-sector, geospatial, jobs, policy)

2.3 Prepare draft report on technical framework for decarbonization

2.4 Participate in an intensive community engagement campaign

Share framework scoping and initial results with local communities and solicit feedback to promote an inclusive process, identify gaps, contextualize findings, and obtain important qualitative factors that would otherwise be omitted by the modeling analyses (e.g., divergent views across stakeholder groups and cultural perceptions).

2.5 Prepare non-technical summary for communication of findings to the general public

Task 3: Conduct Local Policy Opportunity Analysis

3.1 Develop and/or update related policy databases

Either create or find updated databases of existing federal, state, and local regulations to capture the most recently adopted laws and policies related to GHG reduction activities in the sectors evaluated in Task 2. This effort will also update the databases to include all local ordinances related to GHG reduction activities, as well as those regulations that challenge decarbonization efforts.

Include a careful review of any local climate action plans that should be mapped in the overall framework to identify synergies and gaps. Further, any large private sector commitments or efforts in your region should also be included in these databases in order to align these trajectories with the overall regional framework.

3.2 Conduct Gap Analysis

Compare the decarbonization pathway(s) and policy actions described in Task 2 with the inventory of regulations and policies from Task 3.1, including those spanning across jurisdictions to understand the extent of existing policy action and to identify gaps. The policies should also be evaluated alongside their implementation schedules and associated financial measures and resources in order to examine feasibility.

3.3 Identify Local Policy Opportunities

Based on the comparison in Task 3.2, identify how existing GHG reduction efforts can be leveraged to reduce carbon emissions in the region, and describe additional actions that can be taken, either through individual agency action or collectively, to meet the goal of regional carbon neutrality.

3.4 Prepare Final Report

Bring together the technical framework report from Task 2.3 and the local policy opportunity analysis from Task 3.3 into a final single integrated report.

Task 4: Implementation through Science-Based Policymaking

4.1 Create a region-wide institutional governance structure for decarbonization

Organize this evolving structure into a Regional Steering Committee, Sector Working Groups, and Front-Line Advisors (see Figure 4) to coordinate ongoing learning and experimentation across jurisdictions and stakeholders.

Supplement this structure with a conference of governments that regularly convenes policymakers and local stakeholders and facilitates coordination.

4.2 Establish implementation playbook based on scientific models

Create ambitious, adjustable, collective sectoral and policy milestones anchored in technically feasible solutions that are tailored to your local context. Adding decadal milestones can align planning with aging infrastructure and can mitigate stranded assets.

4.3 Prioritize near-term, “low regret” policies

Adapt policies, programs, and incentives to work in the varied political, economic, and socio-environmental contexts of your region and prioritize sector-specific solutions that will be worthwhile regardless of how longer-term uncertainty resolves itself.

4.4 Establish incentives and penalties to mobilize action

Incentivize active learning and experimentation to test diverse ideas, collaboration to assess solutions across jurisdictions, adjustment of policies in light of new information, and breaking away from old investment patterns that will not achieve deep decarbonization.

4.5 Engage continuously with outside agencies to influence policy and generate action beyond your jurisdiction

Actively engage with higher levels of governance to generate influence and advocate for policies and programs that support local decarbonization needs. Additionally, engage with external efforts to create followership among others and discover solutions being developed outside of your jurisdiction. Formal agreements with other agencies or jurisdictions, both in and outside your region, can be established, for example, via Memoranda of Understanding or Joint Powers Agreements.

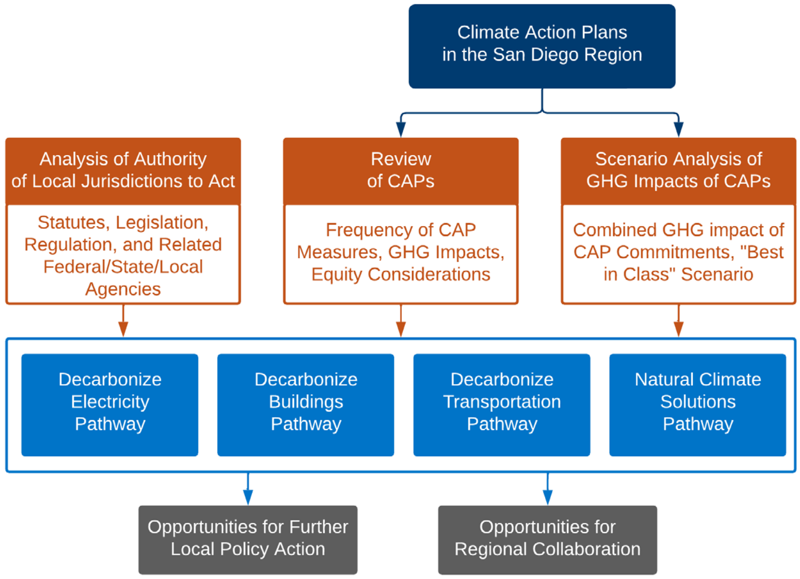

Figure 2. The overall approach to identifying local policy options undertaken in the creation of the San Diego RDF (described in Task 3 of the project outline above). *Source: RDF Chapter 8, Local Policy Opportunity.*

1.4 How to Identify Key Sectors and Stakeholders

Because decarbonization intersects with daily lives and livelihoods in so many ways, planning and implementation to ensure a just and sustainable transition to net zero requires identifying which key sectors and stakeholders must be involved in these processes to support informed and participatory decision-making. Cooperation and collaboration among these key players are essential to secure the long-term stability of decarbonization outcomes through comprehensive, multijurisdictional efforts. **Therefore, the first step in this process after mapping a given jurisdiction's emissions profile and sectoral landscape is to identify key sectors and stakeholders.**

In order to determine which key players must participate in the creation of a decarbonization framework, it is first necessary to **understand the overall energy system dynamics of a given jurisdiction.** To examine the jurisdiction's emissions-intensive sectors, goods, and services, a first step is to map its emissions profile and sectoral landscape by **evaluating its GHG inventories.** GHG inventories are estimates of greenhouse gases emitted to or removed from the atmosphere. They are an essential tool for understanding a jurisdiction's current emissions and past trends, projecting future emissions, and identifying the sectors, sources, and activities responsible for emissions. GHG inventories allow jurisdictions to measure their progress toward decarbonization goals and to develop data-informed climate policies and action plans based on established priorities and best practices. In the case of a jurisdiction without published GHG inventories, the Greenhouse Gas Protocol[vii] serves as a comprehensive, global, standardized framework for measuring and managing emissions, and offers guidance and calculation tools to ensure uniformity and comparability in reporting.

vii https://ghgprotocol.org/

Understanding a given jurisdiction's overall energy system dynamics also calls for an **analysis of its available natural climate solutions** (see Section 2.3). Natural climate solutions are land management practices and natural resource uses that bolster carbon storage and either maintain or increase carbon removal in natural and working lands.[4] The conservation, restoration, and sustainable management of forests, grasslands, and wetlands are examples of natural climate solutions. While performing decarbonization naturally, they also generate various ecological, economic, and social co-benefits, including water and air quality regulation, biodiversity protection, and public health improvements. Although natural climate solutions should be a complement, and not a substitute for, decarbonizing the energy and industry sectors, protecting and preserving terrestrial and marine ecosystems is essential to reaching net zero, as studies show that nature-based solutions can provide up to 37% of the emission reductions needed by 2030 to keep global temperature increases under 2°C.[5] Thus, jurisdictions must analyze the decarbonization potential and natural carbon stocks of their ecosystems (both natural emissions sinks and sources) to identify areas for conservation and restoration, as well as which sector and land use practices must be prevented or promoted in order to reduce emissions naturally.

The natural climate solutions and sectors analyzed in the RDF were chosen based on the emissions profile of San Diego county; others that were not modeled in the report may need to be evaluated in other decarbonization frameworks, depending on the local context of the given jurisdiction. Because the methodology included in this Guide is based on the process undertaken in San Diego, the industrial, manufacturing, and sustainable materials management sectors are not covered here, as these are not prominent sectors in the county. However, in recognizing that San Diego does not represent the diversity of sectors, industrial hubs, resource pools, and sociopolitical circumstances found across different jurisdictions in the US, each of which requires its own close and calibrated review of how to achieve decarbonization using a systems approach, the Guide authors hope to work with other jurisdictions across the country to undertake similar RDF projects in different contexts. Furthermore, although not covered in depth in this Guide, tools and resources to examine the natural climate solutions (e.g., fire management) and sectors (e.g., industry) that were not analyzed in the San Diego RDF can be found in the Decarbonization Resource Directory (see Appendix 2).

Conducting initial stakeholder outreach to help define priorities and better understand what work is already underway in the jurisdiction will further facilitate understanding of the overall energy system dynamics. **Interviews with subject matter experts** from academia, the private sector, and civil society should also be conducted to obtain insights and different perspectives on data, modeling, policies, and the system-wide challenges for decarbonization in the region. By allowing stakeholders' needs to be accounted for from the start, early consultations can also help avoid potential negative impacts of decarbonization projects, as well as the need to compensate for those consequences in the future (see Section 1.5). In the San Diego RDF process, a local community engagement consultant was contracted to support this work, so that an inclusive mechanism to incorporate community feedback was established from the project onset.

For example, County staff and the outreach consultants actively engaged the San Diego agricultural community to ensure that the needs, concerns, and critical role of farmers in decarbonization efforts were properly addressed in the framework. Farmers are important in the local San Diego context because, among other reasons, the region has the highest number of organic farmers per county in the nation. The San Diego Association of Governments (SANDAG) also played an important role in these efforts, as the mayors, council members, and county supervisors from each of the region's local governments that comprise the association offered a wide array of direct connections to local community members and groups that provided their input.

The San Diego Regional Decarbonization Framework project team recognizes the crucial role that indigenous communities play in climate change mitigation and adaptation efforts at local, national, and global scales. We recognize the historic injustices that indigenous peoples have endured, as well as the need to coordinate with tribal nations in the creation of regional decarbonization pathways in order to undo the injustices of the past and to foster opportunities for reciprocal knowledge exchange. As other jurisdictions begin or continue their decarbonization planning processes, they should ensure that **mutually collaborative partnerships are established with tribal nations to advance common goals** in ways that are sustainable and compatible with all stakeholders' needs from the beginning.

Once the energy system dynamics are understood, the goods and services of a jurisdiction that must be decarbonized will be identified. However, because the process of decarbonization is highly complex and wide-ranging, it is important to refine the focus of the project during this stage. **Setting boundary conditions** will help narrow down the scope of the analyses of the project and the questions it will attempt to answer. Because stakeholders have differing degrees of leverage over particular issues areas, **determining the feasibility of certain actions, and which players have the capacity to realize them**, will also help define the scope of the project.

To address the decarbonization needs identified and defined through these processes, **a project team should consist of leaders and specialists in their respective fields across the academic, public, and private sectors.** For this kind of comprehensive exercise, a large comprehensive team of collaborators is recommended to ensure that a technically robust result is obtained. Each of the areas of the energy system that the decarbonization framework is aiming to address should be represented by experts in the project team. For instance, in the San Diego case, the deeply technical skills involved included energy systems modeling, economics, public policy, and geospatial planning across the sectors of focus (transport, buildings, land). Like in San Diego, **the team encompassing these technical skills should be complemented by additional members that include community liaisons, professional national or international networks, and local labor union representatives.** These members should include stakeholders from other sectors that might impact or be impacted by decarbonization and energy system transformations, such as water and food systems actors.[6] Moreover, in the experience of the San Diego RDF, the University of San Diego served as the principal investigator for the project. Identifying an academic institutional lead for this kind of framework development provides a local stakeholder who is able to participate with limited conflicts of interest. Further, university leads often have the resources to identify and engage the high-level expert stakeholders needed.

Figure 3. Potential array of expertise of a regional decarbonization framework project team.

1.5 Community Engagement and Ensuring a Just Transition

By completely transforming the ways that energy is produced and consumed, the process of deep decarbonization will generate profound changes that extend across entire economies and societies. As the world transitions toward a clean energy economy, the contraction of fossil fuel industries will inevitably create situations in which there will be both "winners" and "losers," with decarbonization entailing job losses and resulting in hardships for displaced communities whose livelihoods currently depend on fossil fuels. At the same time, however, decarbonization presents the opportunity to create millions of clean energy jobs[7] and an entirely new system that addresses current and historic social injustices. **By implementing a just transition,[viii] the benefits of a clean energy future can be equitably distributed so that it works for everyone, minimizes negative impacts and maximizes positive ones, and ensures that no one is left behind**—one of the universal values of the United Nations and international human rights framework.

As an indispensable building block of sustainable development—which aims to "meet the needs of the present without compromising the ability of future generations to meet their own needs"[8] —the principles of a just transition are also linked across the UN Sustainable Development Goals (SDGs),[ix] ranging from climate action (SDG 13) and reduced inequalities (SDG 10) to decent work and economic growth (SDG 8) and affordable and clean energy (SDG 7). Furthermore, as an integral part of many global commitments, the importance and need for a just transition are also highlighted in the Paris Agreement, which acknowledges "the imperatives of a just transition of the workforce and the creation of decent work and quality jobs in accordance with nationally defined development priorities."[1]

Thus, in order to ensure a sustainable future for all, decarbonization frameworks can and will only be successful if they plan in a manner that advances racial, economic, and environmental justice. It is important to consider that a just transition is not a fixed set of rules; it is an ongoing process and vision based on the needs and inputs of all stakeholders, relevant to their geopolitical and sociocultural contexts. It is a complex, hyperlocal, and continuous process, implemented with a set of guiding principles and strategies that center equity and promote community engagement, such as those described below.

Ongoing **community engagement** is required to enable inclusive planning and implementation processes that truly address the needs of the communities they impact. Local participation and public support throughout the entire process secure the long-term stability of decarbonization outcomes by guaranteeing local stakeholders' desire for, understanding of, and ownership of decarbonization efforts. In addition, community engagement throughout the creation and implementation of decarbonization frameworks establishes a pathway for ongoing understanding of where and how actions and policies may succeed or fail, based on the wide range of experiences and perspectives of community members. Continuously engaging with communities throughout the process also allows for the identification of needed changes or adaptations over time, based on the constant flow of up-to-date information from those on the front lines, thus also increasing resilience in the face of unprecedented challenges.

viii A "just transition" refers to one in which displaced workers and communities are protected, supported, and compensated when a society makes significant policy decisions that result in job loss in affected industries (https://www.sandiegocounty.gov/content/dam/sdc/lueg/regional-decarb-frameworkfiles/Putting%20San%20Diego%20County%20on%20the%20High%20Road_June%202022.pdf). In this context, it refers to a framework of efforts to ensure that fossil fuel-dependent workers and communities are able to transition into a new, decarbonized economy with a comparable level of economic security or retire with dignity, without being forced to bear the cost of change. (https://www.ituc-csi.org/climate-change).

ix https://sdgs.un.org/goals

When creating the San Diego RDF, community engagement was carried out via three parallel tracks of **outreach intended for the public, public agencies, and stakeholders.** The County of San Diego began the outreach process with a **public notice of the project, public hearings and workshops about it, and a call for the submission of public comments.** Initial stakeholder outreach was also conducted to identify key stakeholders and sectors (see Section 1.4). With regard to public agencies, **all regional agencies and 18 cities within the county were notified of the project and invited to receive further information, provide input, and collaborate.** Lastly, over 60 local organizations working in energy, transportation, land use, and buildings were invited to participate in **sector-specific focus groups.** These groups consisted of stakeholders from public agencies, businesses, and labor, environmental, and community organizations. Participants answered questions related to the framework and provided input directly to the chapter authors to inform early efforts in developing the RDF.

Moreover, planning and implementing a **just transition** for communities and workers with the aim to ensure they have access to high-quality jobs helps create opportunities to protect and empower those most affected by the social and economic transformations of the decarbonization transition. Adopting strategies to ensure that decarbonization is used as a catalyst to further social and environmental justice by prioritizing underserved and displaced communities is essential. As decarbonization creates new jobs through direct, indirect, and induced sources (see Section 2.4) across areas including construction; management; life, physical, and social sciences; and office and administrative support, policies must facilitate the ability of displaced fossil fuel industry employees to move into these new areas of employment. The scope and cost of policies to manage a just transition will depend on whether the contraction of fossil fuel jobs is steady or episodic, with a steady transition being the most favorable.[9]

The San Diego RDF highlights five key just transition policy measures:

- **Pension guarantees** for all workers in fossil fuel-based industries, especially those workers who will be retiring voluntarily over the transition period;
- **Reemployment guarantees** for all displaced workers;
- **Wage insurance** for all displaced workers;
- **Retraining support** for workers who required this in their new areas of employment; and
- **Relocation support** to cover full moving expenses for all workers who are forced to relocate.[9]

Other strategies include:

- Prioritizing infrastructure in **communities of concern**;[x]
- **Culturally and linguistically relevant and accessible education** campaigns and materials; and
- **Working with community-based organizations** that can serve as trusted and credible partners to support communication and engagement with hard-to-reach, underrepresented, and environmental justice communities.

x The RDF uses the term "communities of concern" as adopted by the City of San Diego in their Climate Equity Index, which defines the term as "those [communities] within census tracts in the top 30th percentile of the California Office of Environmental Health Hazard Assessment's CalEnviroScreen 3.0 tool, census blocks eligible for Community Development Block Grants, and areas within a half-mile radius of affordable housing" (https://www.sandiego.gov/sites/default/files/2019_climate_equity_index_report.pdf). In a more general sense, the term "communities of concern" is usually used to represent a diverse set of populations that could be considered disadvantaged, underserved, or vulnerable in terms of both current and potential future conditions, due to the systemic disparities and barriers they face to access needed resources and services.

Overall, long-term planning, focused investment and engagement, and both top-down and bottom-up collaboration are crucial to ensuring justice in this global transition. An extensive library of state-level studies that are currently working to facilitate a just transition have been published by the Political Economy Research Institute (PERI) at the University of Massachusetts Amherst.[xi] The work of the San Diego RDF report and this Guide was supported by the lead author of these studies, Dr. Robert Pollin, Distinguished University Professor of Economics and Co-Director of the PERI, who offered his expertise on helping fossil fuel-based economies develop state transition programs that promote decarbonization, good jobs, and justice at the same time. These studies and other comprehensive resources, such as the Climate Equity Index created for the City of San Diego in 2019,[xii] can be found in Appendix 2 of this Guide.

xi https://peri.umass.edu/publication/item/1032-green-new-deal-for-u-s-states

xii https://www.sandiego.gov/climateequity

2. Methodology: The Analytical Tools for Designing a Decarbonization Framework

When disruptive energy transformations occur, history has shown that the impacts are felt far and wide, as energy is so integrally linked across all aspects of modern life. Therefore, when approaching a long-term planning exercise such as this, it is important to use a multidimensional approach in order to adequately capture the various needs and impacts across society. In our experience, there are three key dimensions that should be considered, directly linked to the three pillars of sustainable development.

First, the physical and **environmental** dimension of the energy system must be explored in order to determine what elements must be transformed, developed, or protected. In the San Diego RDF, this dimension was accounted for in the sectoral decarbonization analyses (land use, energy, transport, and buildings), the geospatial plotting of potential renewable energy source infrastructure, and the examination of natural climate solutions across the region. Analyzing the environmental dimension of the transition is essential to understanding the full extent of a jurisdiction's local carbon budget, and consequently, to establishing the priorities and goals it must pursue to reach net zero emissions.

Second, it is important to realize that a true energy system transformation is likely to be disruptive to some industries, most notably the fossil fuel industry. In order to understand the extent of this disruption, it is important to explore the potential **economic** impacts on livelihoods and industry-dependent communities alongside the physical infrastructure scenarios. In the San Diego RDF, this dimension was accounted for in the analysis of the employment effects of decarbonization in the region, which was conducted using input-output modeling.

And finally, it is important to align near-term and long-term policy options that support the transition and maximize efficiencies and gains across **society**. This part of the transition planning is arguably the most challenging, as this is where the potential "winners" and "losers" need to come together to determine how best to achieve net zero equitably and with as little disruption to everyday life as possible. Accounting for the social dimension of decarbonization also includes ensuring that underserved communities are not disproportionately impacted or burdened throughout the transition. In the San Diego RDF, this dimension was accounted for in the geospatial modeling analysis that prioritized investments in frontline communities,[xiii] the community outreach and engagement processes, and the local policy recommendations that highlighted important just transition policy measures. It is only with careful planning, uniquely designed policies, and innovative financing mechanisms that a truly socially just transition can be realized.

xiii Frontline communities are those that are, and will be, disproportionately impacted by climate change. These communities often experience the impacts of climate change "first and worst" due to the historic and current systemic inequities they face that limit their capacity to adapt. Examples of frontline communities include Black, Indigenous and People of Color (BIPOC communities), low-income communities, the elderly, the homeless, outdoor workers, individuals with disabilities, women, and children.

2.1 Pathways Approach and Technical Modeling Options

The RDF uses the term "pathway" to mean a blueprint for the energy system that reaches future GHG reduction targets. It should be noted explicitly that pathways are not forecasts of what will happen, but only potential trajectories based on a predefined end goal (e.g., net zero). While the energy system physics and emissions accounting that underpin the models are well-established, projecting technological progress (particularly cost) and energy service demand has a mixed track record, even over time spans much shorter than 30 years. Thus, selecting a single pathway as the basis for public policy is faulty, as it does not account for the changes in quickly advancing technologies and economies which may change the pathways over time. This uncertainty necessitates an ongoing planning process, with periodic updating as new information becomes available and as progress, or lack thereof, toward goals is achieved.

As elaborated in full in the beginning of the RDF by the energy system modeling team, "Rather than providing a prediction of the future, pathway studies are valuable for four reasons:

- Identifying and lowering the risk of dead-end strategies;
- Identifying key decision points;
- Identifying commonalities in pathways under sensitivity analyses; and
- Situating near-term policy targets with respect to long-term goals."[2]

Back casting from a mid-century net-zero energy system to the present via pathways allows for the identification of near-term milestones or benchmark values (often ranges) that are consistent with long-term goals. This also allows for the incorporation of capital retirement timelines and the localization of infrastructure planning and financing. Find an elaborated explanation of this approach in Chapter 1 of the RDF.[2]

2.1.1 Energy System Modeling and Open Modeling Tools

Comprehensive energy system modeling has evolved rapidly over the last decade. Because the energy sector is the largest source of anthropogenic emissions and is so interconnected to all aspects of modern society, the importance and use of such tools will continue to grow. This growth is especially helpful to chart the evolution of our energy systems over time, as old polluting infrastructure is replaced or supplemented with clean net-zero alternatives. As the potential array of replacement technologies or emissions abatement solutions will vary given jurisdictions' different natural resources, local cultures, built infrastructure, and historical experiences, the proposed tools and methods to follow in this section and Guide should be considered technology agnostic. This section does not attempt to prescribe the scenarios to move forward, but rather attempts to explain the process by which the configuration of options and timelines for fossil fuel-based equipment retirement or retrofitting can be created to make up pathways to decarbonization, providing a variety of choices and scenarios from which policy can be formed and continually evolve.

Globally, the Intergovernmental Panel on Climate Change (IPCC) is the premier climate modeling outfit that uses global integrated assessment models to depict future climate scenarios based on different emission trajectories and model configurations. Energy system modeling, however, represents the opposite side of the spectrum. **Rather than depicting the potential future impacts of emissions, energy system models attempt to identify the sources of emissions specifically from the energy system.** Climate Watch,[xiv] an initiative of the World Resources Institute, provides a database of pathway approaches which shows the wide range of ways in which this approach can be undertaken and the various tools and models developed for this purpose. This and other resources can be found in Appendix 2.

The energy system models used in the San Diego RDF ("EnergyPATHWAYS" and "RIO") build on many years of research stemming from original modeling work about technology pathways to deep decarbonization in California, originally published in Science in 2012.[10] The methodology, data, and modeling tools used for the RDF systems-level analysis were presented in Williams et al. (2021)[11] and were also used in SDSN's Zero Carbon Action Plan,[7] the Princeton Net-Zero America study,[12] and the Decarb America Initiative.[13] The RDF energy system modeling was generated at the state and national level by Evolved Energy Research.[xv] Insights from both the US at large and Southern California were downscaled to the San Diego region. The larger energy system contexts provided by the state and national level modeling created an important backdrop for San Diego county, as well as the detailed, sector-level pathways offered in the RDF report.

From Evolved Energy Research: "EnergyPATHWAYS (EP) is a bottom-up energy sector model with stock-level accounting of all energy infrastructure. EP was specifically built to explore a range of potential energy system transformations, and to this end, the model leaves most energy system decisions to the user. Thus, it is appropriate to think of EP as a complex accounting system or simulation model that keeps track of and determines the implications of detailed user scenario decisions. EP is the offspring of an analytical approach that has already proven to be a successful strategy to dramatically change the climate policy discussion at the global, national, and subnational levels. The basic insight is that climate policy was stuck in the realm of short-term, incremental changes discussed in abstract and academic terms, and that this failure was reinforced by the analysis and modeling approaches used. The pathways strategy was to force the policy and business worlds to address, head on, the reality that achieving greenhouse gas targets requires transformation, not incrementalism; that only a long-term perspective on the kind of infrastructure and technology changes required can prevent short-term investments that result in high-emissions lock-in; and that only an analysis that moves past the abstract focus on tons of CO_2 along an emissions trajectory to a focus on the energy supply and end use equipment that produces the CO_2 would speak to practical decision-makers in the regulatory, business, and investment worlds."[14]

It should be noted that the model used in the San Diego RDF encompassed the whole energy system, which included power,[15] transportation,[16] and buildings.[17] Land use considerations were taken into account through the use of geospatial tools described in Section 2.3.

xiv https://www.climatewatchdata.org/pathways/models?category=10&currentLocation=267&indicator=388&model=3&scenario=182%2C181%2C180%2C183&subcategory=36

xv https://www.evolved.energy/

To find other open-source models which may serve your local context, the Open Model Initiative[xvi] is another helpful source of information for anyone who is just getting started. This is a grassroots initiative composed of researchers and modelers around the world that aims to produce tools and data to inform better energy decision-making globally. It should be noted that the development of an energy system model is time- and data-intensive and should be developed with the support of professional modelers, given the granularity and complexity of system inputs and outputs.

2.1.2 Data Needs and Scalability

The energy system modeling which was done in the San Diego RDF exercise was extrapolated from previous state and national modeling exercises in which hourly dispatch supply and demand energy inputs fed into the model. This larger energy backdrop data came primarily from the 2021 US Annual Energy Outlook[18] and five scenarios were ultimately created. A reference or "baseline" scenario was created against which to compare the other four scenarios developed based on potential behavioral, social, and technical developments. An elaboration of this approach can be found in Appendix A of the RDF report and a full list of the assumptions is included in Table A1.[19] If this approach is to be replicated, research teams should conduct an exhaustive search of pathways work at both smaller and larger scales to ensure continuity and compatibility, and to build on already existing data collection efforts.

The scenario options and assumptions chosen were based on years of experience working throughout the US on decarbonization analysis. It is critical that other research teams consider what their key thesis questions encompass in order to clearly articulate the parameters by which their scenarios will be based, whether they be based on changes in costs, behaviors, or markets over time. Further, the assumptions made in the San Diego RDF energy modeling analysis are specific to San Diego county and all assumptions must be made relative to the local context of a project. While the San Diego exercise was based on California's goal to reach net-zero emissions state-wide by 2045, other jurisdictions must also adhere to the IPCC's urgent call to identify both near-term goals to 2030 and mid-term goals to 2040, as the consequences of the climate action, or lack thereof, carried out throughout the next two decades may unlock irreversible positive feedback loops in the global climate system.[20]

2.1.3 Key Takeaways

- Regional and local decarbonization policies should be informed by detailed analyses of the most emissions intensive sectors and these should be consistent with a system-wide path to decarbonization at regional, state, and national scales, as they are available.
- Sectoral analyses in the RDF were informed by the results of energy system modeling at the state and national levels that outlined pathways to net-zero emissions, described in more technical detail in RDF Appendix A.[19] However, alternative approaches may be taken given the amount of pre-existing work available in a certain region.
- Technical pathways studies are valuable for identifying dead-end strategies; identifying key decision points; identifying commonalities in pathways under sensitivity analyses; and situating near-term policy targets with respect to long-term goals.
- Uncertainty necessitates an ongoing planning process, with periodic updating as new information becomes available and as progress, or lack thereof, toward goals is achieved.
- Pathways creation is an intensive exercise that takes both energy systems and sectoral expertise and data to develop.

xvi https://openmod-initiative.org/

2.2 Geospatial Analysis for Energy Production and Conservation

2.2.1 Geospatial Modeling and Open Mod Tools
Geospatial analytics is a form of computational analysis that uses geographic, spatial, and location information, as well as high resolution satellite imagery, to extract structured data that can be used for specific purposes. Geospatial analytics uses data from various sources and types of technology to build visualizations that allow users to understand complex phenomena and find trends in relationships between different variables. These visualizations include maps, graphs, and statistics that reveal patterns, such as historical changes and current shifts, which also allow users to generate more accurate predictions about future outcomes. **In the San Diego RDF, the geospatial analysis of renewable energy production uses modeled electricity demand from the Central Case[xvii] of the Evolved Energy Research (EER) model to identify low-impact, high-quality, technically feasible areas[xviii] for wind and solar development in the San Diego region.** It is also used to compare the resource potential of the region to the modeled 2050 demand forecast for a fully decarbonized economy, in addition to determining near-term least-cost actions across various site selection scenarios. The analysis also examines the capacity, costs, and potential co-benefits of prioritizing urban infill[xix] and rooftop solar. Overall, the spatial analysis of the electric sector in the RDF is intended to inform the planning and deployment of renewable electricity capacity in the San Diego region based on several technological, economic, and environmental variables, such as energy cost, resource availability, and environmental conservation.[15]

By integrating data from widely disparate sources and handling large volumes of it, geospatial analytics allows users to explore data in a holistic manner that improves their ability to anticipate and prepare for the future. It also allows decision-makers to develop targeted, location-based solutions that are based on their specific context and needs. However, it is important to consider that geospatial tools tend to be expensive and that some variables may be difficult to analyze over time at a very high resolution. The quality of the data collected and used for the geospatial analysis also directly affects the accuracy of the end system.

xvii Five scenarios were modeled to help inform the RDF. Geospatial analyses were based on the Central Case, which meets reference energy service demand with high demand-side uptake of electric, efficient technologies and with all energy-supply technology options available. The Central Case is the scenario through which the San Diego region can achieve zero CO_2 emission in 2050 at the lowest net cost.[19]

xviii The authors of the geospatial analysis chapter of the San Diego RDF describe "low-impact, high-quality, and technically feasible" as a set of spatially explicit criteria (identified through GIS analysis) for renewable energy sites that can be used according to the specific preferences of different stakeholders. The "low-impact" criteria refers to the impacts on natural and working lands caused by the siting of renewable energy, the "high quality" criteria refers to energy production potential based on the solar and wind characteristics within the defined area of a site, and the "technically feasible" criteria refers to land on which it is possible to develop renewable energy sites based on the requirements or limitations of the technologies being deployed. Each stakeholder will apply and define the criteria differently based on their own context, needs, and priorities, as a site that is considered "low-impact" in one jurisdiction, for example, may not be considered as such elsewhere.

xix The RDF defines "infill" as undeveloped land in more densely populated areas.[15]

2.2.2 Data Needs and Scalability

To identify the resource potential of utility-scale solar and wind energy generation in San Diego and neighboring Imperial County,[xx] the geospatial analysis generated in Chapter 2 of the RDF considers candidate project areas (CPAs), land areas where renewable development is possible. The CPAs were identified in the 2009 Renewable Energy Transmission Initiative (RETI)[xxi] and were selected through a collaborative process between key stakeholders. CPAs within urbanized areas or infill were also considered in the analysis and were extracted from a dataset under development by The Nature Conservancy. The analysis also uses spatial building footprint data from Microsoft[xxii] to consider the potential capacity and costs for rooftop solar in the San Diego region. This methodology can be replicated across and beyond the US, based on the availability of data of areas that are suitable for the establishment of renewable energy infrastructure in a given jurisdiction. Moreover, while the San Diego RDF examined wind, solar, and geothermal energy, other project teams that are creating a decarbonization framework need to determine which sources of renewable energy they should evaluate when conducting their own geospatial analyses based on their local context. They should also note that while the RDF geospatial analysis focuses on current regional resources, infrastructure, and available technologies, other frameworks can additionally study exploratory technologies and innovations as they develop over time.

Table 1 below breaks down the different assessments generated from the geospatial analysis of renewable energy production in Chapter 2 of the RDF. For each type of analysis, the table lists its corresponding method and the data source(s) used to generate it, in an effort to demonstrate examples of what kinds of data are needed to carry out this type of study when creating a decarbonization framework.

xx The RDF includes geospatial assessments of Imperial County based on the assumption of power transfer between San Diego and Imperial counties.[15]

xxi https://grist.org/wp-content/uploads/2009/11/reti-1000-2009-001-f.pdf

xxii https://hub.arcgis.com/datasets/esri::microsoft-building-footprints-features/about

Table 1. Geospatial Analyses and Data Sources.[xxiii]

Geospatial Analysis or Estimate	Method	Purpose	RDF Figures	Data Source Names & URLs
Spatial distribution of low-impact, high-quality areas for renewable electricity development	RDF CPAs and Downscaling	To constrain and analyze CPAs within San Diego and Imperial counties	N/A	Open-sourced QGIS software CPAs from 2009 RETI report Conserved Lands identified by SANDAG Google Satellite Imagery Power density assumption for solar from Ong et al., 2013 Power density assumption for wind from Denholm et al., 2009
Annual generation (MWh) for each CPA polygon	RDF CPAs and Downscaling	To analyze CPA annual generation estimates	N/A	Urban areas from 2019 US Census Urban Areas dataset Brownfield solar and wind data from US EPA "Repowering America" initiative Offshore wind data from Leslie et al., 2021 Wave energy data from 2011 Electric Power Research Institute study
Total potential utility-scale and infill annual generation from wind and solar CPAs	RDF CPAs and Downscaling	To calculate the total annual electricity generation for each CPA and compare it to the forecasted electricity demand for San Diego in 2050	Table 2.1 Figure 2.2	EER Central Case forecasted demand for Southern California in 2050[xxiv] Existing/planned wind and solar capacity from EIA-860 Form

xxiii An explicit list of just the spatial data sources used in Chapter 2 can be found in Appendix 2.B of the RDF.[21] Other geospatial tools that can be used to inform decarbonization planning can be found in the Appendix 2 of this Guide.

xxiv In the RDF geospatial analysis, the forecasted demand for Southern California was downscaled to San Diego by applying the percentage of Southern California population in San Diego (13.75%).[15]

Geospatial Analysis or Estimate	Method	Purpose	RDF Figures	Data Source Names & URLs
Levelized cost of energy (adjusted cost of electricity production per MWh)	CPA Cost Estimates	To estimate the wholesale cost of electricity for utility-scale CPAs	Figures 2.3 - 2.5	Capital expenditure cost assumption for utility-scale solar and wind from 2020 National Renewable Energy Laboratory Annual Technology Baseline Transmission cost assumption from 2019 US National Renewable Energy Laboratory Regional Energy Deployment System Model Substation dataset from US Department of Homeland Security, 2020 Capital recovery factor from Masters, 2004 Average of large and small non-residential capital cost for solar from Berkeley Lab, 2020
Additional CPAs beyond the utility-scale solar and onshore wind resources mapped in Figures 2.3-2.5 in San Diego and Imperial counties	CPA Cost Estimates	To map CPAs for offshore wind, brownfield solar, brownfield wind, rooftop solar, wave energy, and geothermal development, as well as the LCOE for offshore wind	Figure 2.6	Offshore wind CPAs from Leslie et al., 2021 Brownfield CPAs from US EPA "Repowering America" initiative Geothermal CPAs from 2009 RETI report
Energy storage in the San Diego region	Energy Storage	To map the location and amounts of energy storage types in the 2032 IRP[xxv] portfolio	Figure 2.7	"Modeling Assumptions for 2022-23 Transmission Planning Process" storage system in 2032 IRP portfolio

xxv "Senate Bill (SB) 3507 created Public Utilities Code Sections 454.51 and 454.52 which mandated the 'Integrated Resource Plan' (IRP) proceeding at the California Public Utilities Commission. The IRP proceeding ensures that load serving entities (LSEs) meet targets that allow the electricity sector to contribute to California's economy-wide greenhouse gas emissions reductions goals…IRP modeling produces ten-year look-ahead portfolios, which are refreshed every two years to incorporate the latest LSE procurement status and plan information."[15]

Geospatial Analysis or Estimate	Method	Purpose	RDF Figures	Data Source Names & URLs
Scenario 1 (solar and wind resources within San Diego region) **Scenario 2 (solar, wind, geothermal resources within San Diego and Imperial counties, with assumed transfer of power between the two)**	Least-Cost Site Selection Scenarios	To choose and sequence the development of renewable energy sites needed to achieve 100% renewable energy by 2050, starting with least cost	Figures 2.10 - 2.11	10-year timesteps from the EER Central Case estimated demand forecast for San Diego starting in 2030 Site selection algorithm modeled after Wu et al., 2020 Estimated geothermal resource potential in Imperial County from E3 and CPUC statewide Integrated Resource Plan (R-20-05-003)[xxvi]
Scenario 3: Minimize Loss of Land with High Conservation Value	Alternate Scenarios	To show renewable site selection under a scenario in which environmental impact is highly prioritized	Table 2.5 Figure 2.12	Most restrictive siting level areas for wind and solar resource potential areas in the West (SL 4) from Wu et al., 2020
Scenario 4: Minimize Loss of Land with High Pecuniary Value	Alternate Scenarios	To identify CPAs that factor in the pecuniary value of land	Table 2.5 Figure 2.13	Cropland Data Layer raster from US Department of Agriculture, 2020
Scenario 5: Minimize Loss of Land with High Carbon Sequestration Potential	Alternate Scenarios	To show renewable site selection under a scenario in which carbon sequestration potential is highly prioritized	Table 2.5 Figure 2.14	Identification of carbon pools within San Diego County from RDF Chapter 5 2021 SANDAG Vegetation Dataset Vegetation with high CO2 Sequestration potential from RDF Appendix 2.H
Scenario 6: Utilize only Developable Land	Alternate Scenarios	To minimize legal and social barriers by selecting sites which exist on land that is identified as developable	Table 2.5 Figure 2.15	2010 SANDAG Developable Land data

xxvi The total available generation for the San Diego region is downscaled and it is assumed that 94.7% of the power generated will go to San Diego for an estimated geothermal resource of 10,113 GWh.[15]

Geospatial Analysis or Estimate	Method	Purpose	RDF Figures	Data Source Names & URLs
Scenario 7: Infill and Rooftop Solar Scenario	Alternate Scenarios	To show renewable site selection under a scenario in which rooftop solar and urban infill solar are prioritized, including in frontline communities	Tables 2.5 - 2.6 Figures 2.8 - 2.9, 2.16	Building footprint spatial data from Microsoft Assumed capacity factor based on National Renewable Energy Lab System Advisor Model simulations, 2018 City of San Diego Climate Equity Index Spatial distribution of county-designated Communities of Concern from SANDAG Social Equity Report Chapter State-designated Disadvantaged Communities
Scenario 8: Mid-Range Scenario	Alternate Scenarios	To generate a mid-range multi-benefit scenario that balances competing priorities that result from inherent tradeoffs between and across the other five scenarios	Tables 2.5 Figure 2.18	Data from other five CPA scenarios (detailed above) California Independent System Operator (CAISO) interconnection queue City of San Diego Climate Equity Index Brownfield sites from US EPA “Repowering America” initiative
Scenario 9: High Rooftop, Low-Impact to Conservation Lands, Avoid Valuable Agriculture Lands	Alternate Scenarios	To show renewable site selection under a scenario in which rooftop and infill solar, environmental impact, and protecting valuable agricultural lands are highly prioritized.	Table 2.5 Figure 2.18	Multiple Species Conservation Plan

2.2.3 Key Takeaways

- Geospatial analytics uses data from various sources to build visualizations that allow users to understand complex phenomena and find trends in relationships between different variables.
- The San Diego RDF uses geospatial analysis to evaluate renewable energy production by identifying low-impact, high-quality, and technically feasible areas for wind and solar development in San Diego and neighboring Imperial County.
- Geospatial analysis can be used to select sites for renewable energy production development that prioritize environmental protection, cost, carbon sequestration potential, equity, and land value.
- Transitioning to a 100% decarbonized energy system requires that societal expectations are met and regulatory standards for reliability are implemented, which will require significant but uncertain investments across additional resources.
- The assumptions made in the San Diego RDF geospatial analysis (listed in Appendix 2.C of the larger report)[22] are specific to San Diego county and all assumptions must be made relative to the local context of a project.
- Jurisdictions should coordinate with relevant agencies to ensure the reliability of energy systems. Additional coordination with other stakeholders, such as federal governments and academia, could facilitate the identification and adoption of the best strategies, while abandoning those strategies that do not work.

2.3 Assessing Natural Climate Solutions and Other Land Use Considerations

2.3.1 Natural Climate Solutions, Land Use Change, and Decarbonization

As mentioned previously in this Guide, assessing natural climate solutions and other land use considerations plays a key role in both understanding a jurisdiction's overall energy system dynamics and in determining what regional decarbonization frameworks should address (see Section 1.4). **Natural climate solutions, "those actions which maintain or increase negative emissions and bolster carbon sinks in natural and working lands,"[4] should be accounted for in all decarbonization pathways and planning efforts because of their significant capacity to sequester[xxvii] carbon dioxide from the atmosphere and to store[xxviii] it in plant tissues for the medium- to long-term.** With the potential to naturally contribute about 30% of the global mitigation needed by 2050 to keep warming to 1.5°C,[24] maintaining and enhancing carbon sequestration and storage processes provided by natural climate solutions is essential for meeting net-zero emissions goals. However, achieving these goals is not possible through the use of natural climate solutions alone, as they must be protected and restored in conjunction with the deep decarbonization of the energy, transport, buildings, sustainable materials management, and industry sectors, accomplished via non-natural carbon capture, utilization, and sequestration mechanisms.[xxix]

xxvii The RDF defines "carbon sequestration" as "the flow of CO_2 from the atmosphere into soils, biomass, geological formations, etc."[4]

xxviii The RDF defines "carbon storage" as "an accumulated stock of CO_2 stored as carbohydrates and other carbon-containing molecules." Natural and working lands hold large quantities of carbon in soils and living and dead biomass.[4]

xxix In its latest flagship report, the IPCC highlights the importance of large-scale carbon dioxide removal (CDR) deployment in meeting global climate targets. CDR, sometimes also called "negative emissions technologies," refers to "anthropogenic activities that remove CO_2 from the atmosphere and store it durably in geological, terrestrial, or ocean reservoirs, or in products."[20] Although CDR deployment is subject to multiple feasibility and sustainability constraints at large scales, all pathways that limit global warming to 1.5°C with limited or no overshoot project the use of CDR on the order of 100–1000 gigatons of CO_2 over the 21st century, in order to lower net CO_2 or net GHG emissions in the near-term, counterbalance 'hard-to-abate' residual emissions to help reach net zero CO_2 or net zero GHG emissions in the mid-term; and achieve net negative CO_2 or GHG emissions in the long-term.[20]

Nevertheless, **natural climate solutions represent important tools for reaching net-zero emissions from local to global scales, all while providing a host of co-benefits that other mitigation approaches do not offer**, such as reduced impacts from natural disasters, increased food and fiber production, pollution and particulate mitigation, and increased biodiversity and ecological resilience.

Decarbonization pathways and frameworks should also assess the implications of land use change. Besides serving as one of the major drivers of global biodiversity loss, l**and use change results in net positive emissions when productive carbon sequestering lands are transformed into less productive lands for human purposes**. For instance, when forests are cleared to make space for agricultural pastures and croplands, the carbon that was once stored within the forest soil and biomass is released into the atmosphere, while the potential of that ecosystem to sequester future emissions is also lost. Thus, the **consequences of losing natural and working lands to land use change are twofold**.[4] The consequences of losing natural and working lands through land use change are also exacerbated by the emissions-intensive operations that replace them, such as urban settlements, agriculture, and mining enterprises. Furthermore, **land use change has important implications for the decarbonization of all sectors, including energy production, transportation, and housing and development**. While energy supply decarbonization will require some land use change to build renewable energy sites and transmission infrastructure, land use change will also be required to update and expand public transit and electric vehicle charging infrastructure, and to construct sustainable housing and community buildings.[4] Such trade-offs should be accounted for by assessing land use considerations in long-term decarbonization planning efforts.

2.3.2 Data Needs and Scalability

Although carbon sequestration rates and potential vary by the prevailing climate conditions, levels of disturbance, and dominant plant species of a given jurisdiction, the most common natural climate solutions across the globe are reforestation, afforestation, forest management, agroforestry, and other tree-based solutions.[4] Others include implementing biochar; restoring and protecting savannas, woodlands, peat, and coasts; and grazing land management.[5] The analysis of natural climate solutions and other land use considerations in Chapter 5 of the RDF focuses on those that are most appropriate and effective for the San Diego region in particular, given the jurisdiction's highly diverse, shrub-dominated ecology.[4] More specifically, the assessment of land use and natural climate solutions in the RDF focuses on net carbon dioxide equivalent emissions and was conducted based on two major considerations: 1) maintaining or increasing annual GHG sequestration in natural and working lands, and 2) maintaining or decreasing potential GHG emissions from the land and coastal ecosystems and thereby protecting the stored carbon.[4] The RDF analysis of the San Diego region's carbon accounting in natural and working lands aims to demonstrate the broad carbon implications that decision-makers should address in their decarbonization plans and policies. It does so without being exhaustive or comprehensive, which can be very challenging to accomplish regionally. Additionally, it should be noted that there is a growing field of study aiming to better understand the flux of carbon in and out of the soil and the implications of warming temperatures around the globe. To learn more, check out the AmeriFlux Management Project.[xxx]

xxx https://ameriflux.lbl.gov/about/ameriflux-management-project/

The RDF analysis focused on four natural climate solutions: protection of natural lands from land use change (except where land use change is required for other decarbonization actions), carbon farming, protection of blue carbon, and urban forestry. For each of these solutions, Table 2 describes its importance, how its carbon sequestration and storage potential can be enhanced or maintained, as well as how it was assessed, in an effort to demonstrate examples of what kinds of natural climate solutions and data can be used for this type of study when creating a decarbonization framework. Although these examples can serve as a helpful starting point, project teams must decide which natural climate solutions and land use considerations to account for in their own frameworks based on their local context. For instance, natural climate solutions that were not covered in the RDF include non-forest management, fire management, and tree planting in public, non-urban lands. Jurisdictions should also address non-CO_2 GHGs, such as methane, a GHG with a much higher global warming potential than carbon dioxide, whose largest sources of anthropogenic emissions include agriculture and land use. In fact, the latest IPCC annual assessment report posits that limiting warming to 1.5°C requires global GHG emissions to peak before 2025 at the latest and be reduced by 43% by 2030, with a 27% reduction in CO_2 emissions and a 34% reduction in methane emissions by the same year.[20]

Table 2. Natural Climate Solutions and Other Land Use Considerations: Assessments and Data Sources.

Natural Climate Solution/ Land Use Consideration	Contribution to Decarbonization/ Importance	Methods to Maintain or Enhance Carbon Sequestration and/or Storage Potential	Assessments & RDF Figures	Data Source Names & URLs
Protection of natural lands from land use change	Protecting existing carbon pools and carbon sequestration potential in natural and working lands through preventing land use change is highly effective and relatively less expensive than other solutions; Lands can sequester atmospheric carbon in plant tissues, thereby removing anthropogenic emissions from the atmosphere; Lands can provide stable, long-term carbon storage and keep CO_2 out of the atmosphere; Protecting natural lands also protects the co-benefits of the ecosystem services they provide (e.g., food, water, medicine, safety from natural hazards, construction materials, and resistance to pathogens).	Prevent land use change from transforming current natural and working lands to settlements or barren landscape; Enhance lands' ability to sequester and store carbon through land management; Restore degraded or lost natural and working lands to their natural state; Protect conserved lands; Expand protections to additional lands; Research the carbon sequestration potential of natural lands to improve carbon accounting and inform better management policies and practices.	Table 5.2: Total carbon storage (MMT CO_2e) and sequestration (MMT $CO_2e\ yr^{-1}$) in the San Diego region; Figure 5.3: Total stored carbon (MT $CO_2e\ ha^{-1}$) estimates for the San Diego region; Figure 5.4: Annual sequestration rate (MT $CO_2e\ ha^{-1}\ yr^{-1}$) estimates for the San Diego region	Geospatially explicit vegetation data types from SanGIS Carbon storage and sequestration value from the literature (RDF Appendix 5.A) QGIS 3.16

Natural Climate Solution/ Land Use Consideration	Contribution to Decarbonization/ Importance	Methods to Maintain or Enhance Carbon Sequestration and/or Storage Potential	Assessments & RDF Figures	Data Source Names & URLs
“Carbon farming”	The terms “carbon farming” and “climate farming” refer to agricultural climate solutions; Nationally, agriculture is a net GHG emitter because agricultural activities result in net positive emissions of methane, nitrous oxide, and CO_2; Agriculture is the only sector that can switch from net positive to net negative emissions, all while producing agricultural goods and services; All climate farming techniques have co-benefits for farmers, ranchers, and landowners (e.g., increased soil water retention, more shade for livestock, increased agricultural yield), in addition to the ecosystem services provided by natural and working lands.	**Increasing sequestration:** Amend soils, increase average annual vegetation cover, or change farming practices to increase the stored carbon in the soil and annual sequestration; Add compost to soils, plant cover crops, plant trees in or around farms or pastures, plant perennial plants rather than annuals, prevent premature loss of existing (orchard) trees, add biochar; Restore degraded, abandoned, or marginal agricultural lands and riparian ecosystems; On-site anaerobic manure digestion, methane capture or digestion from enteric fermentation. **Preventing emissions:** Cover cropping; practice no or low-till agriculture; Plant trees; utilize on-farm compost; Methane reduction from enteric fermentation; Riparian restoration.	Carbon storage and sequestration potential of different carbon farming methods in the San Diego Region	United States Department of Agriculture COMET planner California-specific COMET planner tool Batra, 2018

Natural Climate Solution/ Land Use Consideration	Contribution to Decarbonization/ Importance	Methods to Maintain or Enhance Carbon Sequestration and/or Storage Potential	Assessments & RDF Figures	Data Source Names & URLs
Protection of blue carbon	Blue carbon generally refers to the carbon storage and sequestration potential in vegetated coastal ecosystems (e.g., eelgrass beds, marshes, wetlands, mangrove forests). It sometimes specifically refers to restoring vegetated coastal ecosystems to improve carbon sequestration and storage; Coastal ecosystems collectively store disproportionately higher levels of carbon per unit area than the majority of ecosystems; Coastal ecosystems store carbon on the order of millennia; Coastal ecosystems provide numerous ecosystem services (e.g., storm surge reduction, wave and wind buffering, fish nursery habitats, and air and water quality improvements).	Protect and conserve wetlands, marshes, mudflats, and riparian habitats from loss; Promote marine protected areas; Restore degraded or lost coastal ecosystems; Sustainably manage blue carbon habitats; Enable sustainable, inclusive, and resilient blue economies; Research the carbon storage and sequestration potential of blue carbon habitats to inform better management policies and practices.	Table 5.3: Total lost habitat, annual carbon sequestration, and long-term storage per blue carbon vegetation class Figure 5.5: Blue carbon habitats that will be lost under 1 foot of sea level rise in the San Diego region	Sea level rise projections from ICF, 2019, Sweet et al., 2022, and California Coastal Commission Sea Level Rise Policy Guidance, 2018 Orange and San Diego county sea level rise data from National Oceanic and Atmospheric Agency sea level rise database Vegetation layers from SanGIS Carbon stock and sequestration values from the literature (RDF Appendix 5.B) QGIS

Natural Climate Solution/ Land Use Consideration	Contribution to Decarbonization/ Importance	Methods to Maintain or Enhance Carbon Sequestration and/or Storage Potential	Assessments & RDF Figures	Data Source Names & URLs
Urban Forestry and Greening	Urban trees are trees that exist within urban boundaries and were either planted or are maintained; Urban trees provide the only natural climate solutions for urban areas and settlements that have replaced natural and working lands, thus, they can sequester and store carbon in an environment that would otherwise not be able to do so; Urban trees contribute to negative CO_2 emissions because their growth reduces atmospheric CO_2; Urban trees provide co-benefits and ecosystem services that were lost to land use change and urban expansion (e.g., reducing air pollution, providing shade, cooling buildings, and increasing aesthetic value); Urban trees can provide co-benefits to populations that are disproportionately affected by high temperatures, poor air quality, and little shade or green space.	Increase urban tree canopy cover; Choose tree species and adjust tree management practices to maximize carbon benefits; Tree species should be low-water, long-lived, low-maintenance, and large trees that are well-suited for the local climate; Plan or encourage private landowners to plan tree locations to maximize cooling effects on structures or surfaces; Empower and encourage local communities to collect data on trees in their areas to inform distribution, size, and species urban forest information to aid decision-makers.	Carbon storage and sequestration potential of urban tree cover in the San Diego region	American Forests report, 2003 Nowak et al., 2021 Chamberlin et al., 2020 Analysis by The Nature Conservancy of California, 2020

2.3.3 Key Takeaways

- Natural climate solutions play a key role in decarbonization because they naturally sequester and store carbon dioxide, but they must be used in conjunction with other sectoral decarbonization efforts to achieve net-zero emission goals.
- Natural climate solutions offer co-benefits of ecosystem services that provide economic, social, environmental, and public health gains that may also help justify their cost. These co-benefits should be characterized, quantified, and monetized to allow for the full understanding of the effects of natural climate solutions.
- Maintaining or enhancing natural carbon sequestration and storage processes can be accomplished by protecting, conserving, and restoring natural ecosystems and the climate solutions they provide.
- The consequences of losing natural and working lands to land use change are twofold: the release of stored carbon and the elimination of future sequestration in those areas.
- There are important trade-offs between land use change and the decarbonization of energy production, transportation, and housing and development, which must be considered in decarbonization plans and policies.
- In order to accurately account for net carbon land use emissions, local data need to be collected and integrated into regional carbon calculations.
- The natural climate solutions and land use considerations assessed in the San Diego RDF analysis are specific to San Diego county and such assessments must be made relative to the local context of a project.

2.4 Measuring Economic Impact and Employment Trajectories

2.4.1 Input-Output Employment Modeling

Input-output (I-O) modeling is a form of macroeconomic analysis that is based on the interdependencies between different industries or economic sectors. Since its initial development in the 1930s, this method has recently been used by economists to study the impacts of clean energy investments.[23] In the San Diego RDF, an **I-O model is used to estimate the employment impacts of advancing the clean energy decarbonization program within the Central Case developed for the San Diego region by Evolved Energy Research (EER).** The I-O model focuses on the 2021-2030 time period to inform future analysis on workforce development strategies for San Diego County, with additional job creation figures for the 2020-2050 period encompassed by EER. More specifically, the I-O employment modeling in Chapter 6 is used to measure job creation estimates, while US Bureau of Labor Statistics data is used to assess job quality indicators and prevalent job types across various energy supply investment and energy demand expenditure areas. Current employment levels in relevant sectors also come from the I-O model, while job contraction rates for workers in fossil fuel-based industries are based on assumptions within the EER model.[9]

The transparency and relatively limited number of assumptions of the I-O model, when compared to other more complex general equilibrium models,[23] makes this method particularly useful.[xxxi] In fact, Chapter 6 of the RDF explains that given the structure of the economies of the broader US and San Diego region, figures from the I-O model provide the most accurate evidence available about the outcomes within private and public enterprises when they produce goods and services. This includes details about how many workers were hired and what materials were purchased in the process.

xxxi Although the RDF uses I-O modeling in its employment impact analysis, various methodologies for the assessment of employment effects of policy scenarios do exist. Selecting which methodology to use depends on the type and quality of available data, the questions a project is aiming to answer, and other factors, such as the project budget. Examples of other methodologies that are available to analyze green jobs include inventories and surveys, social accounting matrices, and computable general equilibrium models (https://www.ilo.org/wcmsp5/ groups/public/---ed_emp/---emp_ent/documents/publication/wcms_176462.pdf) Macro-econometric tools, like the E3ME model by Cambridge Econometrics (https://www.e3me.com/), can also facilitate conducting such analyses.

On the other hand, however, I-O models are helpful for planning purposes, but should not be taken as an absolute, as models cannot capture all macroeconomic forces, such as those that may unexpectedly come into play. Moreover, the figures used for the I-O tables are based on technologies that are prevalent in the present, even though production technologies and I-O relationships are certain to change over time, including over the 2021-2030 time period analyzed in the model. To address this and the fact that clean energy investments will vary during the period, the San Diego RDF works under the assumption that average labor productivity in all the expenditure areas included in the EER model will rise by 1% annually through 2030. Furthermore, EER model cost estimates for zones (like Southern California) have been treated as broad approximations in the RDF employment impact analysis. This is because the regional level demand and supply costs cover broad geographic areas and their distribution depends on various factors that are difficult to estimate over time at a very high spatial resolution.

2.4.2 Data Needs and Scalability

The employment estimates generated by the I-O model used in Chapter 6 of the RDF are based on **data from national surveys of public and private economic enterprises within the US and organized systematically within the official US I-O model.** The **"inputs"** of the model are all of the resources utilized in public and private enterprises within the US to create goods and services (i.e., employees, materials, land, energy, and other products). The **"outputs"** of the model are the resulting goods and services themselves that are then made available in both domestic and global markets (i.e., consumers from households, private businesses, and governments). This methodology can be expanded and used in jurisdictions beyond the US, when the needed data from national surveys and I-O models is available.[9]

The San Diego RDF I-O modeling exercise also reports on all three sources of job creation associated with any expansion of spending: **direct, indirect, and induced effects**. This comprehensive analysis of impacts is applicable to the use of I-O models elsewhere, although estimating induced effects (or multiplier effects) within I-O models is much less reliable than the direct and indirect effects. Additionally, in order to understand the impact on jobs of a clean energy investment activity, project teams need to incorporate a time dimension in their employment creation analysis. While the San Diego RDF uses a **jobs-per-year measure** (year-to-year breakdown of the overall level of job creation), project teams also have the choice of using a **job years measure** (cumulative job creation over the total number of years that jobs have been created). However, a jobs-per-year measure is more effective because using job years prevents users from scaling the impact of investments on job markets at a given point in time.[9]

Moreover, because the EER model for Southern California includes 13 counties in addition to the county of San Diego, the RDF employment impact analysis was conducted under certain assumptions to generate estimates that were specific to San Diego county itself. The job creation estimates generated by the EER Central Case were **downscaled** to San Diego county based on the assumption that the level of employment creation in the county will amount to 15% of the employment creation in Southern California overall. In addition, estimates of fossil fuel job contraction rates were generated based on the assumptions within the EER model that through 2030: oil consumption declines by 20%, natural gas consumption remains constant, and construction activity in the natural gas sector falls to zero.[9]

Project teams creating decarbonization frameworks should develop assumptions that relate to the specific features of their own models. Other factors that project teams should consider in their employment impact analyses are the labor force attrition rates due to voluntary retirements and whether the rate of fossil fuel job contraction will be **steady** (uniform, stable rate of employment losses) or **episodic** (relatively large episodes of employment losses). Project teams could also use tools such as Neighborhoods at Risk[xxxii] to identify at-risk communities and better develop long-term plans and local policy tools to ensure a just transition (see Section 1.5).

Table 3 below breaks down the different estimates generated using I-O modeling in Chapter 6 of the RDF to analyze the employment impacts of decarbonization for the San Diego region. For each type of estimate, the table lists the data source used to generate it, in an effort to demonstrate examples of what kinds of data are needed to carry out this type of analysis when creating a decarbonization framework.

Table 3. Employment Impact Estimates and Data Sources.

Employment Impact Estimate	RDF Tables	Data Source Name & URL
Job creation through energy demand expenditures or energy supply expenditures	Tables 6.1-6.4	IMPLAN 3.1
Job creation through combined energy supply and energy demand expenditure program	Table 6.5	Central Case of the EER energy model for Southern California
Job quality for the direct jobs that will be generated through energy demand expenditures or energy supply investments	Tables 6.6-6.9	CPS 2015-2019 ACS 2015-2019 IMPLAN 3.1
Prevalent job types through energy demand investments or energy supply expenditures	Tables 6.10-6.11	ACS 2015-2019 IMPLAN 3.1 CPS-ORG 2015- 2019
Job contraction rates for workers in fossil fuel-based industries	Table 6.12	Central Case of the EER energy model for Southern California
Current levels of fossil fuel-based employment	Table 6.13	IMPLAN 3.0
Characteristics of fossil fuel and ancillary industry jobs	Table 6.14	ACS 2015-2019 CPS ORG 2015- 2019
Prevalent job types in San Diego County's fossil fuel-based industries (job categories with 5% or more employment)	Table 6.15	ACS 2015-2019 IMPLAN 3.1 CPS-ORG 2015-2019

xxxii https://headwaterseconomics.org/apps/neighborhoods-at-risk/6073/explore/map

Employment Impact Estimate	RDF Tables	Data Source Name & URL
Attrition by retirement and job displacement for fossil fuel workers	Table 6.16	US Bureau of Labor Statistics data
Job creation in Southern California through geothermal energy projects in Imperial County	Table 6.A.1	IMPLAN 3.0 EIA Study Pollin et al. (2021)

In order of appearance, the data sources included in the table are described as follows:

1. *IMPLAN* is an input-output model that uses data from the US Department of Commerce as well as several other public sources;
2. *The Central Case of the EER model* is one of the five scenarios modeled to help inform the RDF, which meets reference energy service demand with high demand-side uptake of electric, efficient technologies and with all energy-supply technology options available; it is the scenario through which the San Diego region can achieve zero CO_2 emission in 2050 at the lowest net cost;[19]
3. *The Current Population Survey (CPS)* is the primary source of labor force statistics for the US population, it is is a monthly household survey sponsored by the US Census Bureau and the US Bureau of Labor Statistics that collects information on topics including basic demographics and employment status;
4. *The American Community Survey (ACS)* is the premier source for detailed US population and housing information, it is a yearly household survey developed by the US Census Bureau that collects information on topics including jobs and educational attainment;
5. *The CPS Outgoing Rotation Group (ORG)* is a subset of the CPS's monthly sample among which respondents are asked more detailed employment questions, including about their wages and union status;
6. *The US Bureau of Labor Statistics data* is from the Current Population Survey (CPS), which is the primary source of labor force statistics for the US population;
7. *The EIA study, "Levelized Costs of New Generation Resources in the Annual Energy Outlook 2021,"* presents average values of levelized cost of electricity, levelized cost of storage, and levelized avoided cost of electricity for electric generating technologies entering service in 2023, 2026, and 2040 as represented in the National Energy Modeling System for the AEO2021 Reference case; and
8. *The Pollin et al. (2021) study, "A Program for Economic Recovery and Clean Energy Transition in California,"* was used to generate the geothermal energy job creation estimate in the RDF by converting the Energy Information Administration capital costs in the overall levelized cost framework into lump sum capital expenditures.

2.4.3 Key Takeaways

- Input-Output (I-O) modeling can be used to study the employment and production impacts of clean energy investments. The San Diego RDF uses it to generate different estimates across various energy supply investment and energy demand expenditure areas.
- I-O model employment estimates can be based on data from national surveys of public and private economic enterprises within a given country and organized systematically within that country's official I-O model.
- I-O models estimate three types of impacts: direct, indirect, and induced.
- A time dimension must be incorporated into the measurement of employment creation to understand the impact on jobs of a given spending activity. This can be accomplished in terms of "jobs-per-year" or "job years."
- Certain assumptions can be made in order to downscale models to a desired level, as needed. The assumptions made in the San Diego RDF analysis are specific to San Diego county and all assumptions must be made relative to the local context of a project.
- Governments must develop viable just transition policies for workers that will experience job displacement throughout the transition to decarbonization.
- The costs of a just transition will be lower if the transition occurs steadily rather than episodically. Under a steady transition, the proportion of workers who will retire voluntarily in any given year will be predictable, making the need to provide support for many more workers avoidable.

3. Implementation: Science-Based Policy-Making

3.1 Planning Alongside Uncertainty

Transitioning away from fossil fuels to decarbonized sources of energy requires the use of structures, mechanisms, and principles that are flexible to the changes and uncertainties inherent in this long-term process. These **flexible systems need to allow for ongoing learning and innovation in decarbonization planning and implementation efforts**, which should also evolve over time as science and technology advance. This is especially true in the face of uncertainties around resources and future environmental, economic, social, and political shocks and realities, which may make many of the actions needed to realize decarbonization unknown and unknowable throughout different stages of the transition. These uncertainties may also be exacerbated by various areas of contention that arise throughout the decarbonization process, such as supply chain issues, election cycles, stakeholder risk profiles, and tax revenue sources, all of which must be identified and mitigated as they emerge over time.

Creating such flexible and evolving systems can be accomplished by **implementing an institutional structure and processes that generate durable solutions alongside uncertainty**. A region-wide institutional governance structure for decarbonization can promote the use of best practices by incentivizing experimentation, rapid learning, and building on the science of energy modeling and pathways through **continued collaborative action**.[3] The facilitation of continued collaborative action—between government officials, planning bodies, regulators, industry stakeholders, experts, civil society, and frontline workers—can increase leverage in cases of limited spheres of influence, generate capacity from combined resources,[25] enable the coordination needed to address region-wide emissions, and promote the more equitable distribution of resources.[3] Such an institutional structure must also coordinate with Tribal governments in order to promote knowledge sharing and the achievement of shared goals.[3] For regional leaders, continuous **engagement with outside agencies** is particularly important at the state and federal levels to generate influence and advocate for policies and programs that support local decarbonization needs. Engaging with outside actors is also key in order to push the frontier of science on climate solutions by testing and deploying technologies developed outside of a given jurisdiction.[3]

As explained in Chapter 7 of the San Diego RDF report, embedding the tenets of **experimentalist governance** and lessons of successful climate institutions described by Victor and Sabel[26] is essential for orchestrating such an institutional structure for decarbonization.

A regional governance structure for decarbonization should be designed to:

- **Respond to the needs and feedback of those on the front lines;**
- **Draw on local expertise**;
- **Be broken down into sectors** to ensure solutions respond to distinct technological, economic, social, and political needs;
- **Prioritize near-term, "low regret" policies**;
- **Invest in and incentivize innovation, experimentation, and cooperation;** and
- **Respond to changing conditions and lessons learned.**

The figure below outlines recommendations for organization, incentives, and mechanisms as a starting point for a system of regional governance to support decarbonization efforts among a wide range of heterogeneous actors. Such a system should include representation from governments and agencies, industry networks and individuals, academic institutions, civil society institutions, and frontline advisors (stakeholder organizations interested in decarbonization from the public and private sectors).[3] This **representation from multiple sectors, stakeholders, and levels of leverage ensures that all efforts are holistic and sustainable**, that no one is left behind, and that the processes undertaken can evolve and adapt to changes over time. An institutional structure built for uncertainty and limited degrees of influence can be supplemented by the establishment of a **conference of governments** that regularly convenes policymakers and local stakeholders, promotes decarbonization frameworks, and facilitates coordination to discover lasting solutions across jurisdictions. It can also be supplemented by other formal mechanisms, such as a Regional Climate Action Joint Powers Agreement, which could facilitate cooperation and help scale strategic thinking and decision-making around decarbonization.

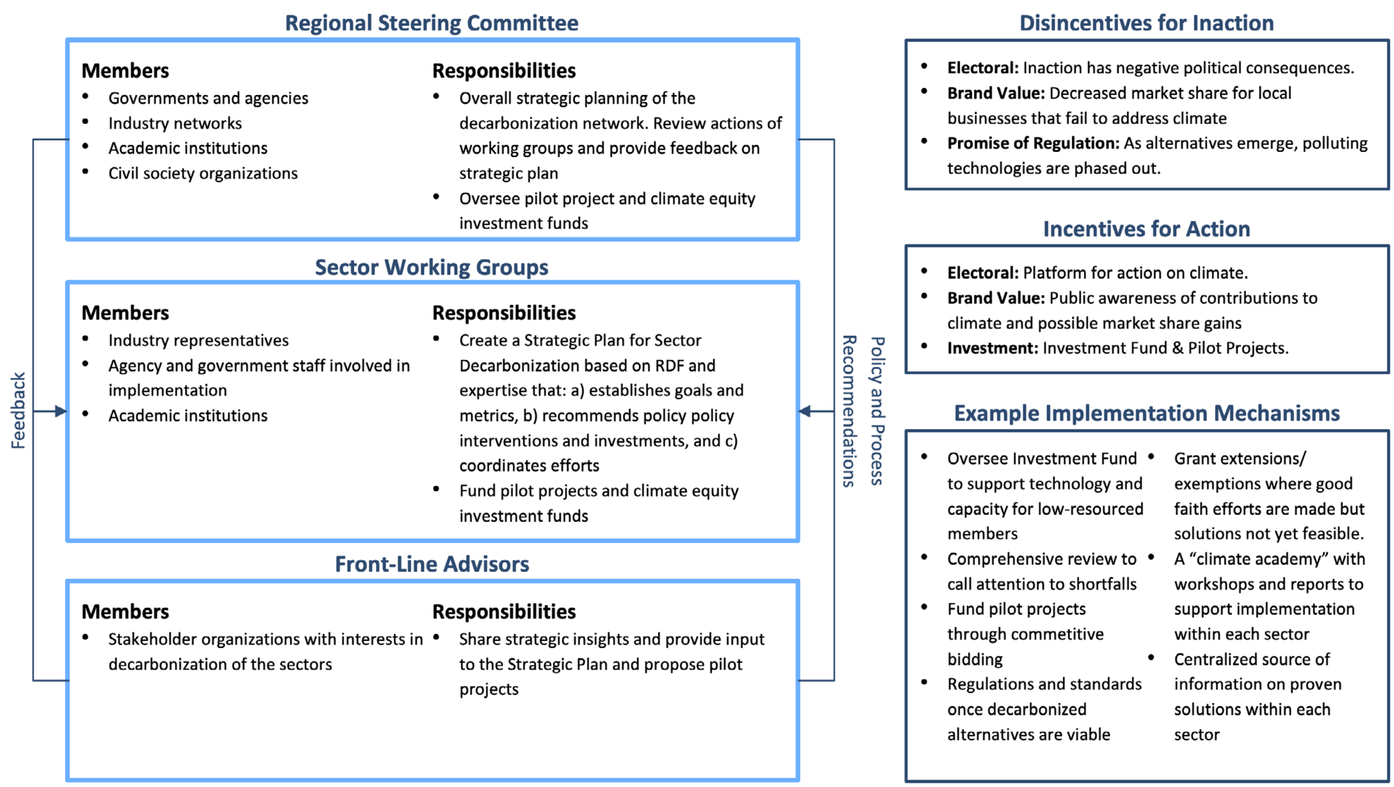

Figure 4. Proposed Regional Governance of Decarbonization. *Source: RDF Chapter 7, Key Policy Considerations.*

3.2 Local Policy Toolkit

The multidimensional challenge of reaching net-zero emissions by mid-century or earlier requires that decarbonization frameworks have a clear vision of both near- and long-term policies at multiple levels. In particular, policy planning and implementation at the local level plays a crucial role in decarbonization, as local governments have often stepped up as leaders in climate and sustainability in the absence of meaningful action at the national level. While there are limitations to the agency with which local governments can control large-scale infrastructure, there are several mechanisms by which local US governments have leverage over key issues, such as zoning, urban land use, transit, roads, and building codes, which play essential roles in achieving emissions reduction targets.

Here, we include an overview of the local policy solutions (see Table 4) that were outlined in the San Diego RDF report to inform policy-making toward reducing greenhouse gas emissions across the electric, transportation, land use, and buildings sectors in the region. We also provide a directory of examples of available resources and databases that provide quick access to current, validated decarbonization information at the US national and international levels (see Appendix 2). Both tables are intended to help inform local decarbonization policy development processes by providing examples of resources and policies that are effective in promoting progress toward decarbonization goals. They are not exhaustive, and the resources and policies included in them should be used and implemented in conjunction with one another, according to the unique technological and political realities of a given jurisdiction.

Moreover, when using this toolkit and/or developing decarbonization policies in general, it is important to account for the following considerations:

- **Prioritizing near-term, "low-regret" policies**;[xxxiii]
- **Tailoring policies** to local contexts and sector needs;
- **Balancing environmental, social, and economic factors**;
- **Promoting coordination** across multiple levels, jurisdictions, sectors, and stakeholders;
- **Advancing innovation** to discover new solutions and ensure flexibility; and
- **Providing incentives** to reward collective action and disincentivize inaction.

Policies should also be **aligned and upscaled vertically (to higher levels of governance) and horizontally (across peer regions)** to ensure that efforts are coherent and comprehensive across different scales. This gives jurisdictions the opportunity to achieve influence past their boundaries and further contribute to the global climate agenda. In addition, while Chapter 7 of the RDF describes several mechanisms that can provide guidance for the San Diego region to achieve influence beyond its borders, including political entrepreneurship, policy entrenchment, and incentivizing competition (see Figure 5 below),[3] Chapter 9 and the accompanying Appendix 9.A of the report also offer extensive lists of national and international consortiums that should be engaged with in order to scale the impact of regional decarbonization frameworks and policies across jurisdictions.[27,28] Moreover, the creation and impact of decarbonization policies in other jurisdictions can be further informed by the analysis described Chapter 8 of the RDF, which reviews the authority of local governments and agencies to influence and regulate GHG emissions, as well as all of the climate action plans of the San Diego region.[29]

xxxiii The RDF defines "low-regret" policies as "near-term actions that will be worthwhile regardless of how longer-term uncertainty resolves itself," as they are the "options with lowest costs, highest technical feasibility, and most familiar."[3]

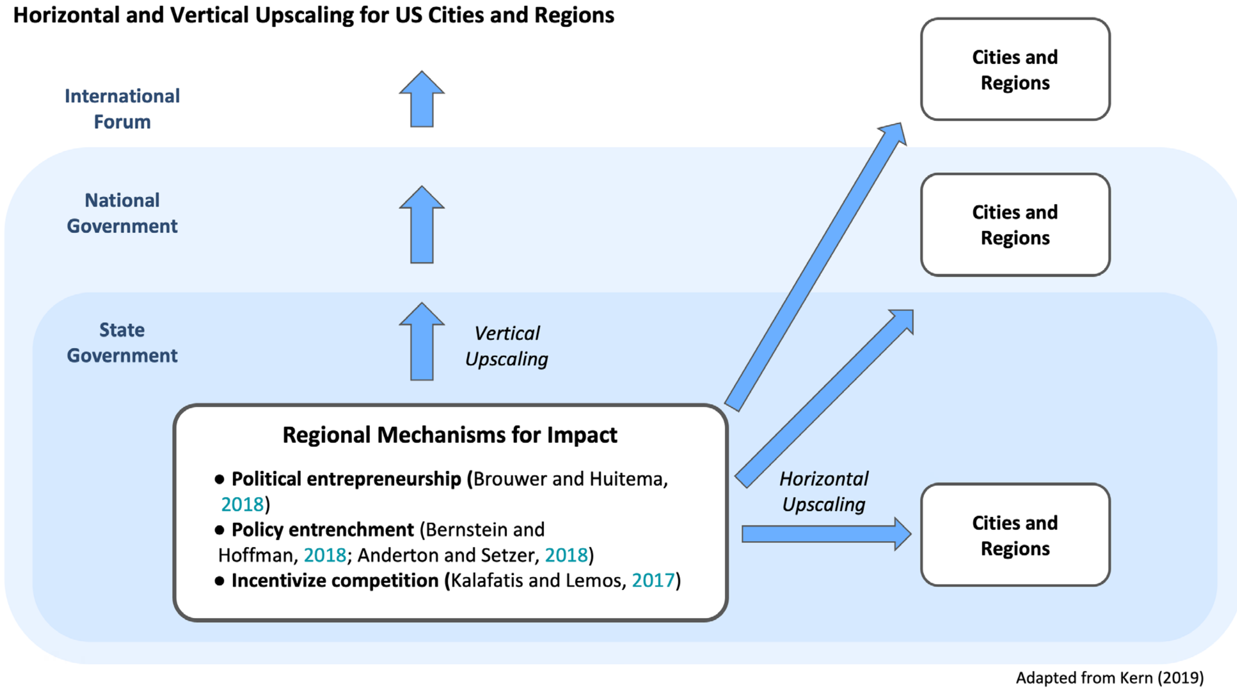

Figure 5. Mechanisms for Vertical and Horizontal Upscaling of Local Policies. The RDF defines the terms highlighted in the figure as the following: (1) policy entrepreneurship is described as the process in which individuals initiate and realize dynamic policy change by investing their resources (https://doi.org/10.1111/j.1541-0072.1996.tb016 38.x). Local leaders seeking to achieve influence beyond the borders of their jurisdiction can lead to upscaling; (2) policy entrenchment is described as the process in which policies become embedded into other governance structures for broader impact; and (3) incentivizing competition is described as the process in which "competition among local jurisdictions can provide incentives for innovation that lead to the emergence of scalable policies and technologies that are useful in other regions." *Source: RDF Chapter 7, Key Policy Considerations.*

While the vertical and horizontal upscaling of local policies are important to reaching emissions reduction goals, city, county, state, and regional leaders should also **leverage state and federal policies to maximize the impact of their locally driven decarbonization efforts. The US Federal and State governments offer a plethora of cutting-edge tools, strategies, and resources curated by reputable experts and institutions that jurisdictions across the country can benefit from**. Tapping into these abundant state resources, such as those provided by the US Department of Energy,[xxxiv] and federal resources, such as those provided via the "Build Back Better Framework,"[xxxv] supports the creation, promotion, and implementation of local decarbonization policy solutions, such as those described in Table 4 below. **Downscaling these policies and their associated resources from higher levels of governance** allows local jurisdictions to elicit the support they need to establish local regulations and create regional decarbonization frameworks, which they may otherwise lack the capacity to accomplish on their own. Additional resources available to jurisdictions to support the development of regional decarbonization frameworks and local policies can be found in Appendix 2.

xxxiv https://www.energy.gov/eere/states-and-local-communities

xxxv https://www.whitehouse.gov/build-back-better/

Table 4. Local Policy Solutions.[xxxvi]

Policy	Sector	Policy Type[xxxvii]	RDF Chapter
Investments in intermittent and flexible generation, storage, and demand-side management	Electricity	Market Instrument, Technological Intervention	2
Aggressive public electric vehicle charging target	Electricity, Transportation	Direct Regulation	3
Aggressive fleet adoption target	Electricity, Transportation	Direct Regulation	3
Prioritize electric vehicle infrastructure in communities of concern and then in places where transit is not yet viable	Electricity, Transportation, Buildings, Land Use	Direct Regulation	3
Require new development to include electric vehicle charging and require existing development to retrofit parking with electric vehicle charging	Electricity, Transportation, Buildings	Direct Regulation	3
Increase dollar value and streamline consumer vehicle purchase incentives with application to both new and used vehicles, and increase dollar value and opportunities to retire gas vehicles	Transportation	Market Instrument	3
Streamline permitting process for charging infrastructure	Electricity, Transportation, Buildings	Direct Regulation	3
Train workforce to support electric vehicle ecosystem	Transportation	Direct Regulation	3

xxxvi While this table provides important examples, the chapter texts of the RDF provide extensive lists of policies to achieve decarbonization across the sectors they examine. See Chapter 3 of the RDF for transportation policies to accelerate electric vehicle adoption (Figure 3.3, Table 3.6, and Table 3.8) and to reduce vehicle miles traveled (Tables 3.7 and 3.9).[16] See Chapter 4 of the RDF for building policy recommendations (Section 4.6).[17] See Chapter 5 of the RDF for land use policy recommendations (Sections 5.2.6, 5.3.4, 5.4.6, 5.5.4, and 5.7).[4] See Chapter 7 of the RDF for key local decarbonization policies across the four sectors (Tables 7.1 and 7.2).[3] See Chapter 8 of the RDF for a review of local jurisdictional opportunities and authority to influence and regulate GHG emissions, including key legislation and regulation at the federal and state levels in the US (Section 8.2), as well as an analysis of all the climate action plans in the San Diego region that can help inform planning elsewhere (Sections 8.3-8.8).[29]

xxxvii The *Zero Carbon Action Plan* defines three broad categories of policy instruments: (1) direct regulations are often in the form of mandates, standards, and other command-and-control interventions (e.g., state-level renewable portfolio standards and building energy efficiency standards); (2) market instruments include price incentives and interventions in existing market structures or the creation of new ones (e.g., cap-and-trade systems or implementation of a carbon tax); and (3) technological interventions consist of either direct or indirect subsidies, or broader industrial policy (e.g., production tax credits).[7]

Policy	Sector	Policy Type[xxxvii]	RDF Chapter
Expand geographic reach and service hours of bus and rail services in areas where development can support transit use	Transportation, Land Use	Direct Regulation	3
Provide incentives and regulatory relief to facilitate higher density infill and transit-oriented development	Transportation, Land Use	Direct Regulation, Market Instrument	3
Disincentivize development in rural (or non-infill) areas that cannot support efficient transit use or multi-modal transportation options	Transportation, Land Use	Direct Regulation, Market Instrument	3
In existing rural, non-infill, or underserved transit areas, invest in transportation network companies partnerships prioritizing electric and high-occupancy vehicles to ensure sufficient access to opportunities	Transportation, Land Use	Market Instrument, Technological Intervention	3
Expand modal options including a wide range of e-bikes, e-scooters, bikeshare, micro transit, shuttles, and transportation network company partnerships	Transportation	Direct Regulation	3
Encourage Transportation Demand Management (TDM) programs that incentivize some proportion of telework, telemedicine, remote learning, and use of transit	Transportation	Direct Regulation, Market Instrument, Technological Intervention	3
Reduce emissions from space heating and water heating by increasing adoption of their electrification in both new and existing buildings, with particular focus on assistance for low-income residents and rental buildings	Buildings	Direct Regulation, Market Instrument, Technological Intervention	4

Policy	Sector	Policy Type[xxxvii]	RDF Chapter
Set "electrification-ready" or "all-electric" standards for new construction and major renovations through building energy codes to reduce costs associated with transitioning away from fossil fuels	Buildings	Direct Regulation	4
Building energy use disclosure policies that enable building performance standards and/or energy actions, in both existing and new buildings	Buildings	Direct Regulation	4
Incentivize building electrification and retrofitting, as well as appliance replacement	Buildings	Market Instrument, Technological Instrument	4
Mitigate stranded cost risk by minimizing unnecessary extensions or replacements of the gas pipeline system and aligning depreciation of existing utility assets with their utilization lifetimes	Buildings	Direct Regulation	4
Invest in retrofitting existing housing in communities of concern to help ensure equitable access to decarbonization technologies; develop initiatives in conjunction with these communities, tailored to their needs	Buildings	Direct Regulation, Market Instrument	4
Invest in natural climate solutions	Land Use	Market Instrument	5
Prevent land use change from natural and working lands to settlements or other less productive lands when possible; restore natural climate solutions when possible	Land Use	Direct Regulation	5

Policy	Sector	Policy Type[xxxvii]	RDF Chapter
Support infill development and natural growth in rural communities that minimize loss of carbon sequestration potential and co-benefits from natural and working lands; disincentivize sprawl growth in natural and working lands	Land Use	Direct Regulation, Market Instrument	5
Support studies to accurately measure and report local carbon stocks and sequestration rates, including with regard to climate farming	Land Use	Market Instrument	5
Incorporate the costs of carbon dioxide emissions from land use change and the lost carbon dioxide sequestration potential into land use planning decisions	Land Use	Market Instrument	5
Incentivize "climate farming," and engage farmers and other stakeholders to create carbon farming policies that are equitable, just, and beneficial to farmers and farming communities	Land Use	Direct Regulation, Market Instrument	5
Actively protect and restore blue carbon habitats to increase coastal carbon storage and to prepare for loss due to sea level rise	Land Use	Direct Regulation	5
Increase urban tree canopy cover	Land Use	Direct Regulation	5
Pension guarantees for all workers in fossil fuel-based industries, especially those workers who will be retiring voluntarily over the transition period	All	Direct Regulation	6
Reemployment guarantees for all displaced workers	All	Direct Regulation	6
Wage insurance for all displaced workers	All	Direct Regulation	6
Retraining and relocation support for all displaced workers	All	Direct Regulation	6

4. Recommendations for Future Research

Deep decarbonization pathways is a relatively young area of research that is also subject to various uncertainties. As new information develops and different societal circumstances impact decarbonization progress over time, evolving planning and research strategies must be undertaken to address changes and gaps as they unfold. This section provides a summary of recommendations for future research to build upon the findings and limitations of the San Diego RDF report, in both San Diego and beyond.

Statewide Energy System Modeling: Future work should take into consideration the scope and intention of Evolved Energy Research (EER) models in different analyses, especially in the face of uncertainties. For instance, model results on the quantity of energy supply resources at the end of the modeling period should be understood as solely directional because energy system reliability may change throughout a decarbonization transition process. Moreover, future work should account for the fact that EER model cost estimates are intended to estimate broad approximations over larger geographic areas, rather than detailed estimations at a sub-regional level, as supply and demand changes affect regional costs and their distribution over time.

Geospatial Analysis of Renewable Energy Production: Future research should build upon the spatial analysis of renewable energy power generation presented in the San Diego RDF by quantifying the local economic and public health benefits of a scenario maximizing rooftop and urban infill solar and energy storage in frontline communities. Additionally, infill and rooftop solar energy potential should be updated to include anticipated new buildings over time, and a detailed Integration Capacity Analysis including other jurisdictions should be performed to confirm distribution grid capability. In general, near- and long-term planning should adequately consider environmental protection, cost, carbon sequestration potential, equity, and land value in deployment processes.

Accelerating Deep Decarbonization in the Transport Sector: Future analyses should address the remaining gaps in the San Diego RDF's analysis of deep decarbonization in transportation: technology advances and limited leverage for interjurisdictional travel (including air travel and cross-border traffic), shipping, long-haul freight and trucking, transportation by and around military and local military bases, environmental externalities of electrification (e.g., end-of-life waste and roadway maintenance emissions), unforeseen future lifestyle changes (e.g., work from home patterns, home delivery of goods, and suburban migration), and transit agency policy responses to pandemic conditions (e.g., to address lower ridership levels). Moreover, future research should consider possible interactions among different measures and avoid overestimating the potential of multiple strategies that target the same type of trip or the same population.

Decarbonization of Buildings: Future projects can expand upon the buildings decarbonization research of the San Diego RDF. For instance, teams may desire results that are more precise than the bookend case provided in the report for the impact of changes in gas sales and the number of gas customers as county residents and businesses decarbonize their buildings. This can be accomplished by applying mitigation actions or modeling the impact of electrification on electric rates and bills in the analysis. In addition, teams may also want to expand on the RDF's examination of the Central Case (high electrification) for building decarbonization, which does not extend to an hourly look at load shapes from different end uses. Mostly, future research should work to identify the fuel type for space heating and water heating systems and the capacity of electrical panels, as well as to collect equity-related metrics to enable the design of equitable initiatives and monitoring processes.

Natural Climate Solutions and Other Land Use Considerations: Future work should heed the caveats to the data used in the natural climate solutions and land use analysis of the RDF: local data were unavailable for some vegetation classes, soil carbon estimates were not universally included in the literature, and greenhouse gas accounting in agricultural lands is usually embedded with uncertainties. Also, future analyses should account for the relatively shorter lifespans of urban trees, their potential requirement of large resource inputs, and the need to select species based on local conditions. Furthermore, future work should characterize, quantify, and monetize the ecosystem services and co-benefits offered by natural climate solutions other than carbon storage and sequestration (e.g., water savings, groundwater recharging, air and water quality improvements, equity improvements, property damage reductions from storm surges and other natural phenomenon, biodiversity protection, climate and other refugia protection, and wildfire prevention). It should also improve localized carbon cycling data to better inform carbon farming techniques and policies. Other areas that require future research and consideration include topics that were not covered in the RDF, such as other trade-offs between preventing land use change and development, other carbon farming techniques (e.g., opportunities to reduce methane and nitrous oxide emissions from agriculture and integrating compost and mulch), and other natural climate solutions (e.g., wildfire prevention via educational programs and infrastructure hardening).

Employment Impacts through Decarbonization: When examining labor productivity growth, future analyses should consider the changes in economic input-output relationships that will occur over time. This includes changes in clean energy investments, technological innovations, and employment effects, which will ultimately differ from the present.

Key Policy Considerations: Future work should prioritize near-term, “low-regret” policies. Because long-term actions are embedded with uncertainty, future research should promote experimentation and learning among stakeholders to innovate and find new solutions that ensure greater confidence in specific outcomes. Future research should also address the remaining gaps and uncertainties identified in the key actions and areas of leverage in Chapter 7 of the San Diego RDF, such as alternative fuels for transportation and upgrading transmission system capacities.

Local Policy Opportunity Analysis: Future research should heed the limitations associated with analyzing and comparing local policy commitments in Climate Action Plans (CAPs), as CAPs may vary across factors such as methods and inputs, jurisdiction, and target years. Limitations of the CAP scenario analysis conducted in the RDF should also be considered, such as the impact of future state and federal policies and the potential lack of implementation of the measures included in the plans, which ultimately may not be put into effect. Future work should also build upon the RDF local policy opportunity analysis by evaluating policy options based on criteria other than achieving deep decarbonization targets (e.g., cost, scalability, implementation feasibility, and social equity implications), as well as by examining other public agency GHG reduction plans (e.g., those of the San Diego Unified Port District and San Diego International Airport) and their relationship to local CAPs.

Outcome Gap Analysis: A gap analysis should be conducted in all future work. By conducting an outcome gap analysis, a project team can compare the actual performance and results of their decarbonization framework with what was initially expected or desired. Such evaluations allow teams to understand what processes and methods need to be abandoned or newly adopted, as well as where there are opportunities for improvement. With this type of analysis, a project team can create effective strategies to reduce or eliminate identified gaps in order to achieve decarbonization goals, which is especially important as circumstances continue to change over time. For instance, project teams should compare the existing policy landscape of a given jurisdiction and the decarbonization pathway(s) they create to identify gaps that should be addressed in their frameworks.

Decarbonization Projects Underway: The San Diego County team and those creating other regional decarbonization frameworks should learn from the experiences of other efforts. Several decarbonization projects are underway across the US, including some that are in distinct political contexts (ranging across blue, red, and purple states) that require the use of different approaches and strategies. Examples of such projects that can serve as case studies to inform other decarbonization frameworks in similar contexts are described in Chapter 7 of the RDF, such as the Metropolitan Washington 2030 Climate and Energy Action Plan,[xxxviii] the Kansas City Regional Climate Action Plan,[xxxix] Denver's 80 x 50 Climate Action Plan,[xl] and Orlando's East Central Florida Regional Resilience Collaborative.[xli]

Regional Communities Ecosystem Metrics: Future research should work to create a regional communities ecosystem metrics project, that is, an innovative, community-based data infrastructure around decarbonization (and sustainable development) capacity and progress that can serve as a common language for jurisdictions to use to align interests and actions. While jurisdictions continue committing to reach net-zero emissions by 2050 or sooner, many are also unclear about what decarbonization entails and how to accomplish it at the local level. A regional communities ecosystem metrics project would serve as an integrated, open-access set of consistent metrics and roadmaps for community stakeholders pursuing decarbonization across different contexts, scales, and geographies. Such a project would allow stakeholders to, for example, learn about the major components of a decarbonized energy system, how to measure those components and system, and how to create regional decarbonization frameworks. Through the extrapolation of local datasets and learnings that could be translated regionally, it would also allow stakeholders to understand the efforts of regional peers and what is present or lacking in their region that they could benefit from—resulting in comprehensive, macro- and micro-level understandings of where decarbonization gaps and opportunities exist. Such a project would be inspired and accompanied by the American Manufacturing Communities Collaborative's "Manufacturing Communities Ecosystem Metrics Project" (https://americanmcc.org/the-big-6/).

xxxviii https://www.mwcog.org/documents/2020/11/18/metropolitan-washington-2030-climate-and-energy-action- plan/

xxxix https://kcmetroclimateplan.org/wp-content/uploads/2021/05/Climate-Action-Plan.pdf

xl https://www.denvergov.org/files/assets/public/climate-action/documents/ddphe_80x50_climateactionplan.pdf

xli https://www.ecfrpc.org/r2c

The world needs to make critical breakthroughs to tackle the climate crisis while the window of opportunity is still open. Doing so requires working together across sectors to share information, resources, and expertise to find and communicate solutions that match the scale of the challenges we face. It also requires rapid, immediate, and sustained change made possible by continual technological breakthroughs, innovation, and collaboration. Because decarbonization is not a uniform, one-size-fits-all process, it must be achieved in ways that are just, inclusive, and systemic to ensure community resilience and that no one is left behind. While climate change and decarbonization are among the greatest challenges we currently face, addressing them is also the greatest social, economic, political, and environmental opportunity of the century. Where past diplomatic efforts have failed to achieve enough progress, regional models of problem-solving that account for both global commitments and local needs, like the San Diego RDF, can emerge as a robust and impactful strategy. It is our hope that sharing the process undertaken by San Diego County through this Guide will help equip researchers, scientists, and political leaders across the US and beyond with the resources they need to advance science-based pathways to regional decarbonization during this decisive Decade of Action.

References

1. Paris Agreement to the United Nations Framework Convention on Climate Change, Dec. 12, 2015, T.I.A.S. No. 16-1104.

2. Jones, Ryan. 2022. Study Framework. Pages 7-15 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

3. Bettles, Joseph, G.C. McCord, D.G. Victor, E. Carlton. 2022. Key Policy Considerations for the San Diego Region. Pages 263-293 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

4. Hanson, Elise & E. Leslie. 2022. Natural Climate Solutions and other Land Use Considerations. Pages 171-222 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

5. Griscom, B. W., Adams, J., Ellis, P. W., Houghton, R. A., Lomax, G., Miteva, D. A., Schlesinger, W. H., Shoch, D., Siikamäki, J. V., Smith, P., Woodbury, P., Zganjar, C., Blackman, A., Campari, J., Conant, R. T., Delgado, C., Elias, P., Gopalakrishna, T., Hamsik, M. R., … Fargione, J. (2017). Natural Climate Solutions. *PNAS*, *114*(44), 11645-11650. https://doi.org/10.10 73/pnas.1710465114

6. Sklarew D., & Sklarew J. (2018). Integrated Water-Energy Policy for Sustainable Development. *Foresight and STI Governance, 12*(4), 10–19. http://doi.org/10.17323/2500-2597.2018.4.10.19

7. SDSN. (2020). Zero Carbon Action Plan. Sustainable Development Solutions Network. https://irp-cdn.multiscreensite.com/6f2c9f57/files/uploaded/zero-carbon-action-plan.pdf

8. World Commission on Environment and Development. (1987). Our Common Future. UN-Document A/42/427. http://www.un-documents.net/our-common-future.pdf

9. Pollin, Robert, J. Wicks-Lim, S. Chakraborty, G. Semieniuk. 2022. Employment Impacts through Regional Decarbonization Framework for the San Diego Region. Pages 223-262 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

10. Williams, J. H., DeBenedictis, A., Ghanadan, R., Mahone, A., Moore, J., Morrow, W. R., Price, S., & Torn, M. S. (2012). The Technology Path to Deep Greenhouse Gas Emissions Cuts by 2050: The Pivotal Role of Electricity. *Science*, *335*(6064), 53–59. https://doi.org/10.1126/science.1208365

11. Williams, J. H., Jones, R. A., Haley, B., Kwok, G., Hargreaves, J., Farbes, J., & Torn, M. S. (2021). Carbon-Neutral Pathways for the United States. *AGU Advances 2*(1). https://doi.org/10.1029/2020AV000284

12. Larson, E., Greig, C., Jenkins, J., Mayfield, E., Pascale, A., Zhang, C., Drossman, J., Williams, R., Pacala, S., Socolow, R., Baik, E., Birdsey, R., Duke, R., Jones, R., Haley, B., Leslie, E., Paustian, K., & Swan, A. (2020). Net-Zero America: Potential Pathways, Infrastructure, and Impacts, Interim Report, Princeton University. https://netzeroamerica.princeton.edu/img/Princeton_NZA_Interim_Report_15_Dec_2020_FINAL.pdf

13. Walter, L., Jantarasami, L., & Schneider. C. (2021). Pathways to Net-Zero Emissions. Decarb America Research Initiative. https://decarbamerica.org/report/pathways-to-net-zero-emissions/

14. Evolved Energy Research. (n.d.). EnergyPATHWAYS. https://www.evolved.energy/_files/ugd/294abc_84c491c8c2c449d2a7baa2dd3a0dbced.pdf

15. Leslie, Emily & J. Bettles. 2022. Geospatial Analysis of Renewable Energy Production. Pages 16-65 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

16. Cole, Katy, C. Richer, E. Hunts. 2022. Accelerating Deep Decarbonization in the Transportation Sector. Pages 66-116 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

17. Eash-Gates, Philip, J. Frost, S. Kwok, J. Litynski, K. Takahashi, A. Hopkins. 2022. Decarbonization of Buildings. Pages 117-170 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

18. U.S. Energy Information Administration. (2021). Annual Energy Outlook 2021. https://www.eia.gov/outlooks/archive/aeo21/

19. Jones, Ryan. 2022. Appendix A: Summary of Statewide Energy System Modeling. Pages 457-471 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

20. IPCC, 2022: *Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926

21. Leslie, Emily & J. Bettles. 2022. Appendix 2.B: List of Spatial Data Sources. Pages 58-59 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

22. Leslie, Emily & J. Bettles. 2022. Appendix 2.C: List of Key Assumptions. Page 60 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

23. UNIDO and GGGI (2015). Global Green Growth: Clean Energy Industry Investments and Expanding Job Opportunities. Volume I: Overall Findings. Vienna and Seoul. https://www.unido.org/sites/default/files/2015-05/GLOBAL_GREEN_GROWTH_REPORT_vol1_final_0.pdf

24. Roe, S., Streck, C., Obersteiner, M., Frank, S., Griscom, B., Drouet, L., Fricko, O., Gusti, M., Harris, N., Hasegawa, T., Hausfather, Z., Havlík, P., House, J., Nabuurs, G. J., Popp, A., Sanz Sánchez, M. J., Sanderman, J., Smith, P., Stehfest, E…Lawrence, D. (2019). Contribution of the land sector to a 1.5 °C world. *Nature Climate Change*, *9*, 817–828. https://doi.org/ 10.1038/s41558-019-0591-9

25. Morrill, R. L. (1989). Regional Governance in the United States: For Whom? *Environment and Planning C: Government and Policy, 7*(1), 13–26. https://doi.org/10.1068/c070013

26. Sabel, C., & Victor, D. G., (2022). *Fixing the Climate: Strategies for an Uncertain World*. Princeton University Press. https://press.princeton.edu/books/hardcover/9780691224558/fixing-the-climate

27. Crete, Elena & J. Topf. 2022. The San Diego Region as a Model. Pages 443-453 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

28. Crete, Elena & J. Topf. 2022. Appendix 9.A: Relevant US and Global Communities of Practice Lists. Pages 449-453 in: McCord, G.C., E. Hanson et al. San Diego Regional Decarbonization Framework: Technical Report.

29. Anders, S., Silva-Send, N., Kaatz, J., Gu, Y., & Steele, M. (2022). Local Policy Opportunity. In San Diego Regional Decarbonization Framework. https://www.sandiegocounty.gov/content/sdc/sustainability/regional-decarbonization.html

Appendix 1: Checklist for Creating a Regional Decarbonization Framework

This checklist is meant to summarize the series of tasks needed to create a regional decarbonization framework according to the example process used to develop the San Diego RDF. Users should tailor these tasks to best suit the needs of their local context.

☐ **Task 1: Conduct Initial Stakeholder Outreach**

☐ **1.0 Research greenhouse gas emissions inventories or local climate action plans**

☐ **1.1 Identify potential framework stakeholders and collaborators**

☐ **1.2 Participate in stakeholder meetings**

☐ **1.3 Conduct interviews with subject matter experts**

☐ **1.4 Prepare scoping document**

☐ **Task 2: Technical Framework Modeling and Analysis**

☐ **2.0 Consult with a local modeling team to determine what kind of modeling methodology will be used in your analysis**

☐ **2.1 Collect data required for modeling**

Regional Up/Downscaling: Identify any local, regional, state, or national decarbonization pathways analyses on which to align your own assessment for scaling purposes later.

Electric Power Sector Analysis: Spatial analysis to identify low-impact, high quality, technically feasible areas for renewable energy infrastructure development, and to coordinate the early planning of the transmission network needed to interconnect new, low-impact renewable energy power plants (and/or distributed resources) to the grid.

Land Use Analysis: Identify bioenergy opportunities,[xlii] negative emissions technologies, and ecological conservation and restoration considerations.

Transportation Analysis: Spatial analysis to identify opportunities for alternative modes of transport, vehicle electrification, and reduction of vehicle miles traveled.

Buildings Analysis: Use existing data sources to characterize buildings stock in the region and estimate efficiency (appliance and building shell), as well as fuel switching/decarbonization potential over time. Estimate energy use and emissions by sector and building type over time, estimating impact of fuel choice in new and existing buildings. Quantify monetary costs and benefits of different scenarios, coordinating with the energy system model. Analyze gas pipeline economics and customer fuel choice impacts.

xlii In doing so, recognizing the current debate about the true decarbonization potential of bioenergy, despite it being described as an essential part of a global net-zero energy system (e.g., by the International Energy Agency, https://www.ieabioenergy.com/wp-content/uploads/2022/04/IEA-Bioenergy-Annual-Report-2021.pdf, and the IPCC, https://www.ipcc.ch/site/assets/uploads/2018/03/Chapter-2-Bioenergy-1.pdf). While some research promotes bioenergy as a carbon-neutral energy source, other research suggests that emissions resulting from biofuel production and use, including those from indirect land use change and across the whole value chain (plant growth, crop harvest, transportation, conversion, and final distribution), may be higher than those generated by fossil fuels (https://iopscience.iop.org/article/10.1088/1748-9326/aaa512/meta). Additionally, the time scales for emitting and storing carbon in the biosphere are often misaligned with land use management strategies and emission reduction goals.

Industrial Analysis: Identify which industrial sectors are relevant and the local labor unions or private sector corporations which manage these sectors. Make sure to involve these partners early on in the project scoping period.

Jobs Analysis: Highlight considerations for an equitable and just transition to decarbonization, so that policymakers are cognizant of consequences of policy decisions for jobs and distributional impacts of policies across demographic groups.

Policy Analysis: After detailing the physical system transformation, connect the infrastructure plan to policy levers at your jurisdictional level and at the state and federal policy level to identify synergies and potential challenges.

- [ ] **2.2 Conduct modeling and other analysis (e.g., sector-by-sector, geospatial, jobs, policy)**

- [ ] **2.3 Prepare draft report on technical framework for decarbonization**

- [ ] **2.4 Participate in an intensive community engagement campaign**

Share framework scoping and initial results with local communities and solicit feedback to promote an inclusive process, identify gaps, contextualize findings, and obtain important qualitative factors that would otherwise be omitted by the modeling analyses (e.g., divergent views across stakeholder groups and cultural perceptions).

- [ ] **2.5 Prepare non-technical summary for communication of findings to the general public**

- [ ] **Task 3: Conduct Local Policy Opportunity Analysis**

- [ ] **3.1 Develop and/or update related policy databases**

Either create or find updated databases of existing federal, state, and local regulations to capture the most recently adopted laws and policies related to GHG reduction activities in the sectors evaluated in Task 2. This effort will also update the databases to include all local ordinances related to GHG reduction activities, as well as those regulations that challenge decarbonization efforts.

Include a careful review of any local climate action plans that should be mapped in the overall framework to identify synergies and gaps. Further, any large private sector commitments or efforts in your region should also be included in these databases in order to align these trajectories with the overall regional framework.

- [ ] **3.2 Conduct Gap Analysis**

Compare the decarbonization pathway(s) and policy actions described in Task 2 with the inventory of regulations and policies from Task 3.1, including those spanning across jurisdictions to understand the extent of existing policy action and to identify gaps. The policies should also be evaluated alongside their implementation schedules and associated financial measures and resources in order to examine feasibility.

3.3 Identify Local Policy Opportunities

Based on the comparison in Task 3.2, identify how existing GHG reduction efforts can be leveraged to reduce carbon emissions in the region, and describe additional actions that can be taken, either through individual agency action or collectively, to meet the goal of regional carbon neutrality.

3.4 Prepare Final Report

Bring together the technical framework report from Task 2.3 and the local policy opportunity analysis from Task 3.3 into a final single integrated report.

Task 4: Implementation through Science-Based Policymaking

4.1 Create a region-wide institutional governance structure for decarbonization

Organize this evolving structure into a Regional Steering Committee, Sector Working Groups, and Front-Line Advisors (see Figure 4) to coordinate ongoing learning and experimentation across jurisdictions and stakeholders.

Supplement this structure with a conference of governments that regularly convenes policymakers and local stakeholders and facilitates coordination.

4.2 Establish implementation playbook based on scientific models

Create ambitious, adjustable, collective sectoral and policy milestones anchored in technically feasible solutions that are tailored to your local context. Adding decadal milestones can align planning with aging infrastructure and can mitigate stranded assets.

4.3 Prioritize near-term, "low regret" policies

Adapt policies, programs, and incentives to work in the varied political, economic, and socio-environmental contexts of your region and prioritize sector-specific solutions that will be worthwhile regardless of how longer-term uncertainty resolves itself.

4.4 Establish incentives and penalties to mobilize action

Incentivize active learning and experimentation to test diverse ideas, collaboration to assess solutions across jurisdictions, adjustment of policies in light of new information, and breaking away from old investment patterns that will not achieve deep decarbonization.

4.5 Engage continuously with outside agencies to influence policy and generate action beyond your jurisdiction

Actively engage with higher levels of governance to generate influence and advocate for policies and programs that support local decarbonization needs. Additionally, engage with external efforts to create followership among others and discover solutions being developed outside of your jurisdiction. Formal agreements with other agencies or jurisdictions, both in and outside your region, can be established, for example, via Memoranda of Understanding or Joint Powers Agreements.

Appendix 2: Decarbonization Resource Directory

This directory provides a wide array of examples of open-source resources that can be used to support the creation of regional decarbonization frameworks and the development of decarbonization policies at various scales. We classify the resources according to the following categories: (1) Tools are individual instruments used to collect, measure, and analyze data (e.g., geospatial maps, policy trackers, and data models); (2) Databases/Resource Hubs are collections of multiple tools and relevant datasets; and (3) Case Studies/Reports are written documents that present the findings of specific research investigations. The resources in the directory were selected based on their applicability in both the US and abroad, including the Case Studies/Reports whose findings can be used to inform efforts beyond their areas of study. The resources were identified via a standard desktop review, citations in the San Diego RDF chapter bibliographies, suggestions from the San Diego RDF project team, the San Diego RDF sector workshop audiences, and a selection of decarbonization experts from SDSN's global network of knowledge institutions.

Although some of the resources were designed to be used by specific stakeholder groups (e.g., government policymakers, financing institutions, and infrastructure developers), the majority are user-friendly and were designed to be used by wider audiences (e.g., academics, consultants, homeowners, and utilities, among others). We have not included IPCC materials in the directory under the assumption that users of this Guide will know to refer to the Panel, as the premier scientific body responsible for monitoring, assessing, and advancing global knowledge on climate change. Moreover, this list is only representative and not exhaustive. If you would like to contribute to this directory, please reach out to media@unsdsn.org with additional resources. To access the directory via a digital platform that is searchable by category, please visit http://sdgpolicyinitiative.org/guide/.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local	A New Lease on Energy: Guidance for Improving Rental Housing Efficiency at the Local Level	Case Study/ Report	American Council for an Energy-Efficient Economy and Urban Sustainability Directors Network	A guide for local governments that describes actions they can take to reduce energy use in rental properties, maintain or increase housing affordability, and enable local communities to inform and implement equitable policies.
Local	A Survey of Urban Climate Change Experiments in 100 cities	Case Study/ Report	Global Environmental Change, Elsevier	A report that analyzes 627 urban climate change experiments in a sample of 100 global cities to uncover the heterogeneous array of actors, settings, governance arrangements and technologies involved in the governance of climate change in cities in different parts of the world.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local	Carbon Neutrality Plan: A Roadmap for Airport Carbon Accreditation and Beyond	Case Study/ Report	AECOM and San Diego International Airport	A summary of the San Diego County Regional Airport Authority's approach to carbon management and emissions reduction to achieve carbon neutrality, including strategies for managing air quality from a holistic perspective.
Local	Carbon Valuation in San Diego's Natural Landscapes	Case Study/ Report	San Diego State University	An assessment of the available information on sequestration rates for the vegetation communities in the region of San Diego to support the integration of GHG reduction goals with regional conservation, natural resource management, and land management efforts.
Local	Cities Climate Law: A Legal Framework for Local Action in the US	Case Study/ Report	Sabin Center for Climate Change Law, Columbia University	A study that explores legal issues that might inhibit or enable municipal carbon mitigation policy adoption and implementation across equity, buildings, transport, energy, and waste.
Local	City of San Diego Climate Equity Index	Tool	City of San Diego	San Diego's Climate Equity Index (CEI) was developed in 2019 and revised in 2021 to measure the level of access to opportunity residents have within a census tract, as well as to examine the degree of potential impact from climate change to these areas. CEI scores are also provided alongside indicator layers in a separate, interactive map.
Local	Closing Urban Tree Cover Inequity (CUTI)	Tool	The Nature Conservancy	A tool that provides an overview of the disparity in urban tree cover, summer temperature, and Urban Heat Island within three urban areas in California: Greater Los Angeles, the Inland Empire of San Bernardino and Riverside Counties, and the Sacramento area.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local	Draft City of San Diego Climate Action Plan: Our Climate, Our Future	Case Study/ Report	City of San Diego	The City of San Diego's policy commitment to set clear goals to reduce GHG emissions. The Plan outlines federal, regional, and local actions to avoid GHG emissions and holds the City accountable in terms of implementation.
Local/State/ National	Electric Utility Investment in Truck and Bus Charging: A Guide for Programs to Accelerate Electrification	Case Study/ Report	Union of Concerned Scientists	A report that provides recommendations for proactive steps that electric utilities can take to develop the infrastructure and rate designs needed for truck and bus charging across the US.
Local/ International	Entrepreneurship in Climate Governance at the Local and Regional Levels: Concepts, Methods, Patterns, and Effects	Case Study/ Report	Regional Environmental Change, SpringerLink	A study that presents a simple conceptual framework connecting actors, contexts, strategies, and outcomes in a systematic way to evaluate policy entrepreneurship in local and regional climate governance systems.
Local	Equity in Sustainability: An Equity Scan of Local Government Sustainability Programs	Case Study/ Report	Urban Sustainability Directors Network	A report that aims to provide guidance by sharing good practices, supported by real case studies, that local governments can adopt to ingrain equity more fully in their sustainability efforts.
Local/State	Evaluation of US Building Energy Benchmarking and Transparency (B&T) Programs: Attributes, Impacts, and Best Practices	Case Study/ Report	Energy Analysis and Environmental Impacts Division, Lawrence Berkeley National Laboratory	A report that summarizes US B&T policy design and implementation characteristics (e.g., building types and sizes, phased implementation, data submission and requirements, and market education and outreach). The report also summarizes impacts from jurisdictions with B&T policies and discusses opportunities for increasing their efficacy of and future research.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local	Examining the Distributional Equity of Urban Tree Canopy Cover (UTCC) and Ecosystem Services Across United States Cities	Case Study/ Report	PLOS One	A study that quantifies the monetary value of multiple ecosystem services (ESD) provisioned by urban forests across nine US cities and examines the distributional equity of UTCC and ESD using commonly investigated socioeconomic predictor variables.
Local/State	Handbook for Analyzing Greenhouse Gas Emission Reductions, Assessing Climate Vulnerabilities, and Advancing Health and Equity	Case Study/ Report	California Air Pollution Control Officers Association	A planning resource designed for local governments, communities, and project developers to provide information and tools for evaluating GHG reduction measures, climate vulnerabilities, and promoting equity to support sustainable, resilient, and equitable land use planning and project design.
Local	Linking Climate-friendly Farming Practices to San Diego County's Climate Action Plan: An Opportunity Analysis of Carbon Farming in the Unincorporated County	Case Study/ Report	Batra Ecological Strategies and San Diego Food System Alliance	An opportunity analysis that outlines carbon farming's sequestration potential, mechanisms to fund carbon farming, and how carbon farming can synergize with other ecological programs in San Diego County.
Local	Port of San Diego Climate Action Plan	Case Study/ Report	Port of San Diego	The Port of San Diego's long-term vision for sustainability by reducing GHG emissions through transportation and land use, energy conservation and efficiency, alternative energy generation, clean transportation, water conservation, and waste reduction.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local/National	Putting Data to Work: Using Data from Action- Oriented Energy Efficiency Programs and Policies	Case Study/ Report	Institute for Market Transformation and Office of Energy Efficiency and Renewable Energy, United States Department of Energy	As part of the Institute for Market Transformation's Putting to Work Project, this guide describes best practices, tools, and recommendations for how cities can go beyond data collection to design programs and action-oriented policies to advance energy efficiency across the US. The guide builds on the previous project outputs by focusing on how local government decision-makers can collect and manage asset information from associated audits.
Local	SANDAG Regional Climate Action Planning Framework	Case Study/ Report	San Diego Association of Governments	A guide that presents a technical framework for regionally consistent climate action planning that preserves policy flexibility for the context of each of the San Diego region's 19 local government jurisdictions. The guide identifies best practices for preparing and monitoring the implementation of CAPs.
Local	SANDAG 2021 Regional Plan	Case Study/ Report	San Diego Association of Governments	A long-term blueprint of the goals, strategies, and implementation actions for the San Diego region to meet regulatory requirements, address traffic congestion, and create equal access to jobs, education, healthcare, and other community resources.
Local/State	TerraCount	Tool	California Department of Conservation, The Nature Conservancy, Merced County	A scenario planning tool for California cities, counties, districts, and other land use planners and decision-makers that models the GHG and natural resource implications of different development patterns and management activities.

Scope	Title and URL	Type	Creator/Host Institution	Description
Local	The Politics of Decarbonization and the Catalytic Impact of Subnational Climate Experiments	Case Study/ Report	Policy Sciences, SpringerLink	A study that presents a new framework to explore policy pathways and mechanisms that can disrupt carbon lock-in through normalization, capacity building, coalition building, and subnational climate governance experiments.
Local	Urban Tree Canopy (UTC) Assessment: A Community's Path to Understanding and Managing the Urban Forest	Case Study/ Report	United States Department of Agriculture	Designed to help urban natural resource planners, the report provides an overview of the approaches, methods, and data sources used in UTC assessments. The report also offers guidelines for ensuring quality results and resources for planning and implementing UTC analyses.
State/National	Advanced Energy Legislation Tracker	Database/ Resource Hub	Center for the New Energy Economy at Colorado State University	Database that serves as a central resource for tracking state advanced energy legislation and policy trend analyses across the US.
State	Biogeographic Information and Observation System (BIOS)	Tool	California Department of Fish and Wildlife	An integrated information tool designed to enable the management, visualization, and analysis of biogeographic data in California.
State	CalEnviroScreen	Tool	California Office of Environmental Health Hazard Assessment	A mapping tool that helps identify California communities that are most affected by many sources of pollution, and where people are often especially vulnerable to pollution's effects.
State/National	Clean Mobility Equity: A Playbook	Case Study/ Report	Greenlining Institute	This report serves as both a guide for California, as the state continues evolving its clean mobility programs to more meaningfully center equity, and for other states and the federal government as they move to develop and implement clean transportation equity programs across the US.

Scope	Title and URL	Type	Creator/Host Institution	Description
State/National/ International	Crosscutting Renewable Energy Data and Tools	Database/ Resource Hub	United States National Renewable Energy Laboratory	A variety of geospatial tools that provide crosscutting renewable energy data across different scales, including in the US, Asia, Africa, South America, and more.
State/National	Database of State Incentives for Renewables & Efficiency (DSIRE)	Database/ Resource Hub	NC Clean Energy Technology Center at North Carolina State University	The most comprehensive source of information on incentives and policies that support renewable energy and energy efficiency in the US.
State	Deep Decarbonization in a High Renewables Future - Updated Results from the California PATHWAYS Model	Case Study/ Report	California Energy Commission	An evaluation of long-term energy scenarios in California through 2050 using the California PATHWAYS model to achieve a 40% reduction in GHG emissions by 2030 and an 80% reduction in GHG emissions by 2050, relative to 1990 levels.
State	Driving California's Transportation Emissions to Zero	Case Study/ Report	Institute of Studies Transportation at University of California	A research-driven analysis of possible policy options that could, if combined, put the state on the pathway to a carbon-neutral transportation system by 2045. As the first report to comprehensively evaluate a path to carbon neutrality within this time frame, this study also seeks to center important factors such as equity, health, and workforce impacts in the analysis.
State	Enhancing Equity While Eliminating Emissions in California's Supply of Transportation Fuels	Case Study/ Report	University of California Santa Barbara	A study that examines options for reducing California's supply of transportation fuel in parallel with reductions in demand. The report also considers paths to promote health and economic equity when decarbonizing the transportation sector.

Scope	Title and URL	Type	Creator/Host Institution	Description
State	Getting to Neutral: Options for Negative Carbon Emissions in California	Case Study/ Report	Office of Scientific and Technical Information, United States Department of Energy	An assessment of negative emissions pathways that can help California achieve carbon neutrality by 2045, or sooner. The unique scope of the study only addresses practices and technologies for removing carbon dioxide from the air, and intentionally avoids the discussion of policies.
State/National	Green Economy Transition Programs for US States	Case Study/ Report	Political Economy Research Institute at University of Massachusetts Amherst	Eight studies (for California, West Virginia, Pennsylvania, Ohio, Maine, Colorado, Washington, and New York) that show how these states can achieve sharp declines in CO_2 emissions, an expansion of good jobs, and a just transition for workers and communities currently dependent on the fossil fuel industry.
State	Impacts of Vehicle Miles Traveled Reduction Strategies on Selected Areas and Groups	Case Study/ Report	Washington State Transportation Center	A report that examines impacts of vehicle miles traveled reduction strategies mandated by Washington State legislation on selected geographic areas and groups (small businesses with employees who cross county lines to go to work, low-income residents, farmworkers, distressed counties, and counties with more than half the land in federal or tribal ownership).
State	Appendix D: Market Adoption Barriers and Potential Solutions, Residential Building Electrification in California	Case Study/ Report	Energy and Environmental Economics, Inc.	A comprehensive list of market barriers and opportunities for residential building electrification in the state of California.

Scope	Title and URL	Type	Creator/Host Institution	Description
State	Meeting State Climate Goals: Energy Efficiency Will Be Critical	Case Study/ Report	American Council for an Energy-Efficient Economy	A report that summarizes the clean electricity standards, emissions reduction goals, and the role of energy efficiency in each US state, while providing state policymakers with recommendations for leveraging energy savings to reach climate goals equitably.
State/National	Methods for State DOTs to Reduce Greenhouse Gas Emissions from the Transportation Sector	Case Study/ Report	National Academies of Sciences, Engineering, and Medicine	A guide that presents tools, methods, and data sources for State Departments of Transportation (DOTs) to use in reducing GHG emissions from the transportation sector.
State	Nature-Based Climate Solutions	Tool	The Nature Conservancy	A GIS tool that allows users to explore opportunities for nature-based climate solutions across California.
State/National	State Climate Policy Maps	Tool, Database/ Resource Hub	Center for Climate and Energy Solutions	Maps of greenhouse gas emissions targets, climate action plans, carbon pricing policies, electricity portfolio standards, and low carbon and alternative fuel standards at the state level across the US.
State/National	State Climate Policy Resource Hub	Database/ Resource Hub	ClimateXChange	Policy pages provide information, resources, and model rules on 50+ state climate policies across seven distinct policy areas.
State/National	State Climate Policy Tracker	Tool, Database/ Resource Hub	ClimateXChange	Interactive 50 state map that tracks passed climate policy at the state level, with links to policies and further resources.
State	The Impact of Policies and Business Models on Income Equity in Rooftop Solar Adoption	Case Study/ Report	Office of Scientific and Technical Information, United States Department of Energy	An analysis of how some state policy interventions and business models can expand PV adoption among low- and moderate-income households across the US.

Scope	Title and URL	Type	Creator/Host Institution	Description
State	UCLA Energy Atlas	Tool	California Center for Sustainable Communities at University of California, Los Angeles	A database of California building energy consumption that links utility account information to building characteristics, sociodemographic data, and other significant attributes that can be expressed spatially.
State/National	WINDExchange	Database/ Resource Hub	Wind Energy Technologies Office, United States Department of Energy	A platform that shares the best available science and fact-based wind energy information across the US.
National	America's Zero Carbon Action Plan (ZCAP)	Case Study/ Report	Sustainable Development Solutions Network	Comprehensive policy framework that presents a strategic plan to create a carbon-neutral economy for the US by 2050 and includes key policy recommendations.
National	A Zero Emissions All-Electric Multifamily Construction Guide	Case Study/ Report	Redwood Energy	This report aims to evaluate the trend toward all-electric multifamily housing, summarize best practices, and provide designers a useful catalog of electric products to help cities and developers embrace lower cost, all-electric building construction practices across the US.
National	Clean Energy and Clean Industry Policy	Case Study/ Report	ClearPath	Resources and policies that aim to accelerate market-based, breakthrough innovations that reduce emissions in the energy and industrial sectors.
National	Climate and Economic Justice Screening Tool	Tool	White House Council on Environmental Quality	A tool that aims to help federal agencies identify disadvantaged communities that are marginalized, underserved, and overburdened by pollution across the US.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Council on Environmental Quality Report to Congress on Carbon Capture, Utilization, and Sequestration	Case Study/ Report	White House Council on Environmental Quality	A report delivered to the US Congress that provides an inventory of existing permitting requirements for carbon capture, utilization, and storage (CCUS) deployment and identifies best practices for advancing the development of CCUS projects at increased scale across the US.
National	Decarbonization Trajectories of US Utilities (2018 - 2050)	Tool	Energy and Policy Institute	Analysis of large US investor-owned utilities stated decarbonization goals.
National	Electrification Futures Study: End-Use Electric Technology Cost and Performance Projections through 2050	Case Study/ Report	United States National Renewable Energy Laboratory	A report that is part of a series of Electrification Futures Study publications, a multi-year research project to explore potential widespread electrification in the future US energy system. This report provides projected cost and performance assumptions for electric technologies considered in the series, including direct electric technologies that could meet future end-use service demands in the transportation, residential and commercial buildings, and industry sectors for the contiguous US through 2050.
National	Electrification Futures Study: Scenarios of Electric Technology Adoption and Power Consumption for the United States	Case Study/ Report	United States National Renewable Energy Laboratory	A report that is part of a series of Electrification Futures Study publications, a multi-year research project to explore potential widespread electrification in the future US energy system. This report presents scenarios of electric end-use technology adoption and resulting electricity consumption across the transportation, residential and commercial buildings, and industrial sectors in the US.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Emissions & Generation Resource Integrated Database (eGRID)	Database/ Resource Hub	United States Environmental Protection Agency	A comprehensive source of data from EPA's Clean Air Markets Division on the environmental characteristics of almost all electric power generated in the US.
National	Energy Policy Simulator	Tool, Database/ Resource Hub	Rocky Mountain Institute and Energy Innovation	An open-source model for estimating the environmental, economic, and human health impacts of hundreds of climate and energy policies at the state level across the US.
National	Energy Zones Mapping Tool	Tool	United States Environmental Protection Agency	A map-based tool for identifying areas within the United States that may be suitable for power generation and energy corridors.
National	Environmental Justice Screening and Mapping Tool (EJScreen)	Tool	United States Environmental Protection Agency	A new environmental justice mapping and screening tool that is based on US nationally consistent data and an approach that combines environmental and demographic indicators in maps and reports.
National	Environmental Justice Tools and Resources	Database/ Resource Hub	United States National Oceanic and Atmospheric Administration	An array of tools and resources that can help communities plan for environmental justice in their policies and climate efforts.
National	Generation and Use of Thermal Energy in the US Industrial Sector and Opportunities to Reduce its Carbon Emissions	Case Study/ Report	Joint Institute for Strategic Energy Analysis	A report that quantifies industrial sector GHG emissions and identifies opportunities for non-GHG emitting thermal energy sources to replace the most significant US industry GHG emitters based on targeted, process-level analysis of industrial heat requirements.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Greenhouse Gas Emissions and Removals from Forest Land, Woodlands, and Urban Trees in the United States, 1990–2019	Case Study/ Report	Forest Service, United States Department of Agriculture	An overview of the status and trends of GHG emissions and removals from forest land, woodlands in the grassland category, harvested wood products, and urban trees in settlements in the US from 1990 to 2019. The estimates are based on those reported in the US Environmental Protection Agency 2021 submission to the United Nations Framework Convention on Climate Change.
National	Greenhouse Gas Inventory Data Explorer	Tool	United States Environmental Protection Agency	An interactive tool that provides access to data from the Environmental Protection Agency's annual Inventory of the US greenhouse gas emissions and sinks.
National/ International	Grid Modernization Data and Tools	Database/ Resource Hub	United States National Renewable Energy Laboratory	An array of data and tools for the analysis of grid technologies and strategies, including solar and wind energy integration data sets and models of the electric power system.
National	Hydrogen Strategy: Enabling a Low-Carbon Economy	Case Study/ Report	Office of Fossil Energy, United States Department of Energy	A summary of current hydrogen technologies and the US Department of Energy's Office of Fossil Energy's strategic plan to accelerate research, development, and deployment of hydrogen technologies in the US.
National	Innovations in Climate Policy: The Politics of Invention, Diffusion, and Evaluation	Case Study/ Report	Environmental Politics, Taylor & Francis Online	A climate governance study that presents a new analytical framework to explore the politics of invention, diffusion, and evaluation in specific areas of mitigation and adaptation policy.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Interim Implementation Guidance for the Justice40 Initiative	Case Study/ Report	United States Executive Office of the President, Office of Management and Budget	Justice40 is a whole-of-government effort to ensure that US Federal agencies work with states and local communities to deliver at least 40% of the overall benefits from Federal investments in climate and clean energy to disadvantaged communities. The Interim Implementation Guidance provides the initial recommendations and a set of actions required of agencies that manage covered Justice40 programs to achieve this goal.
National	Managing Agricultural Land for Greenhouse Gas Mitigation within the United States	Case Study/ Report	United States Department of Agriculture	An analysis of the GHG mitigation potential associated with changes in US agricultural management practices, including animal production, nutrient management, tillage management, land retirement, and legume interseeding.
National	Meeting the Dual Challenge: A Roadmap to At-Scale Deployment of Carbon Capture, Use, and Storage	Case Study/ Report	United States National Petroleum Council	A report delivered to the US Secretary of Energy that describes a pathway to scale the deployment of carbon capture, utilization, and storage (CCUS) across the US over the next 25 years with detailed recommendations.
National	Model Laws for Deep Decarbonization in the United States	Database/ Resource Hub	Columbia Law School and Widener University Commonwealth Law School	A database of over 2,000 legal tools, more than 300 pathways, and 50 model laws that can be adopted by all levels of government and the private sector to drastically reduce fossil fuel use and greenhouse gas emissions.
National	Net-Zero America: Potential Pathways, Infrastructure, and Impacts	Tool	Princeton University	"Data explorer" that allows users to dig deeply into the quantification of five distinct technological pathways to reach net-zero by 2050.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Opportunities to Reduce Greenhouse Gas Emissions through Materials and Land Management Practices	Case Study/ Report	Office of Solid Waste and Emergency Response, United States Environmental Protection Agency	A report that presents the link between materials and land management and GHG emissions, as well as several scenarios to identify areas of opportunity to reduce emissions via materials and land management across the US.
National	Project Sunroof	Tool	Google Earth Engine	A personalized solar savings estimator that uses Google Earth imagery to analyze users' roof shape and local weather patterns to allow them to create a personalized solar plan.
National	PVMapper	Tool	United States Department of Energy	An open-source GIS-based PV project planning tool for energy siting that allows utility-scale solar developers to compare multiple potential sites with reducing balance of systems soft costs.
National	Regulatory Solutions for Building Decarbonization	Database/ Resource Hub, Case Study/ Report	Rocky Mountain Institute	A library of 10 key strategies to support building decarbonization, with resources from commissions, nonprofits, and media.
National	RE-Powering America's Land Initiative Mapper	Tool	United States Environmental Protection Agency	An interactive web application that provides federal and state data for over 190,000 brownfields, Superfund, landfill, mine sites and other contaminated lands to help users identify sites for renewable energy development.
National	RE-Powering's Electronic Decision Tree	Tool	United States Environmental Protection Agency	Developed by US EPA's RE-Powering America's Land Initiative, this tool guides interested parties through a process to screen sites for their suitability for solar photovoltaics or wind installations.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Role of Long-Duration Energy Storage in Variable Renewable Electricity Systems	Case Study/ Report	Joule, ScienceDirect	An examination of capacities and dispatch in least cost, 100% reliable electricity systems with wind and solar generation supported by long-duration storage (LDS; 10 hours or greater) and battery storage, based on 39 years of hourly US weather data and a macro-scale energy model.
National	Site Renewables Right Map	Tool	The Nature Conservancy	A map that synthesizes more than 100 layers of engineering, land-use, and wildlife data to identify where wind and solar energy sites can be developed in the central US, while still conserving important wildlife habitats and natural areas.
National	Future System Scenarios Analysis	Case Study/ Report	United Stations National Renewable Energy Laboratory	An array of future energy system scenarios and analyses of their cost, operability, and sustainability. Studies include those on power systems and electrification, electric system flexibility and storage, high renewable generation, and transmission infrastructure across the US.
National	State Renewable Portfolio Standards and Goals	Database/ Resource Hub	National Conference of State Legislature	Lists of renewable portfolio standards or voluntary targets across the US.
National	Tools and Resources for Sustainable Communities	Database/ Resource Hub	United States Environmental Protection Agency	List of useful tools and key resources to help communities address climate change, develop and support neighborhoods that provide transportation choices and affordable housing, increase economic competitiveness, and direct resources toward places with existing infrastructure.

Scope	Title and URL	Type	Creator/Host Institution	Description
National	Tribal Green Building Toolkit	Case Study/ Report	United States Environmental Protection Agency	Provides information on how tribes and other communities can prioritize and implement green building codes, policies, and practices. Includes sections on land use, energy efficiency and renewable energy, and resilience and adaptability.
National	US Climate Regulation Database	Database/ Resource Hub	Columbia Climate School and Sabin Center for Climate Change Law at Columbia University	Database of regulations and other actions by federal agencies that are relevant to climate change mitigation and adaptation across the US.
National	US Climate Resilience Toolkit	Database/ Resource Hub	United States Global Change Research Program and United States National Oceanic and Atmospheric Administration	A website designed to help people find and use tools, information, and subject matter expertise to build climate resilience. The Toolkit offers information from all across the US federal government in one easy-to-use location.
National	US Municipal OpenSDG Dashboard	Database/ Resource Hub	UC San Diego School of Global Policy and Strategy at University of California San Diego	Open source, free-to-reuse platform for managing and publishing data and statistics related to the UN Sustainable Development Goals (SDGs).
National	Utility Carbon-Reduction Tracker	Tool	Smart Electric Power Alliance	Map that displays carbon reduction targets adopted by individual electric utilities, and those subject to a state-level 100% requirement. It also displays carbon reduction targets adopted voluntarily by parent companies of utilities that provide retail electric distribution service in the US.
National	Waste Reduction Model (WARM)	Tool	United States Environmental Protection Agency	A tool that estimates the potential GHG emissions, energy savings, and economic impacts of baseline and alternative waste management practices, such as recycling, combustion, composting, and landfilling.

Scope	Title and URL	Type	Creator/Host Institution	Description
International	A Blueprint for Blue Carbon: Toward an Improved Understanding of the Role of Vegetated Coastal Habitats in Sequestering CO_2	Case Study/ Report	Frontiers in Ecology and the Environment, The Ecology Society of America	A synthesis of evidence of the carbon sequestration potential of vegetated coastal habitats that also identifies uncertainties to address to improve the scientific understanding of what controls carbon sequestration in these ecosystems.
International	A Comprehensive Review on Energy Efficient CO_2 Breakthrough Technologies for Sustainable Green Iron and Steel Manufacturing	Case Study/ Report	Renewable and Sustainable Energy Reviews, Elsevier	A comprehensive overview of the worldwide carbon reduction programs and new CO_2 breakthrough technologies for energy saving and carbon capture and storage in iron and steel making processes, including a description of selecting the most appropriate technology, barriers, development, and deployment.
International	A Framework for Sustainable Materials Management	Case Study/ Report	Journal of The Minerals, Metals & Materials Society, SpringerLink	A study that presents an integrated framework for sustainable materials management to decouple material consumption from economic value creation.
International	Agrisolar Best Practices Guidelines Version 1.0	Case Study/ Report	SolarPower Europe	Guidance for farmers, regulators, photovoltaic developers, and other stakeholders to develop high quality and sustainable agrisolar projects in Europe and across the world, including case studies and key actions needed from an agronomical, ecological, and financial perspective.

Scope	Title and URL	Type	Creator/Host Institution	Description
International	A Techno-Economic Analysis and Systematic Review of Carbon Capture and Storage (CCS) Applied to the Iron and Steel, Cement, Oil Refining and Pulp and Paper Industries, as well as Other High Purity Sources	Case Study/ Report	International Journal of Greenhouse Gas Control, Elsevier	A systematic assessment of the applicability of different CCS technologies in the iron and steel, cement, petroleum refining, and pulp and paper industries, as well as certain high-purity sources of CO_2 from other industries. The study also includes a projection of costs per ton of CO_2 avoided over the time period extending from first deployment until 2050.
International	Carbon Lock-In: Types, Causes, and Policy Implications	Case Study/ Report	Annual Review of Environment and Resources	A systematic literature review that presents what is known about the types and causes of carbon lock-in, as well as strategies for advancing transitions toward less carbon-intensive emissions trajectories.
International	CCUS in Clean Energy Transitions Part of Energy Technology Perspectives	Case Study/ Report	International Energy Agency	As the most comprehensive global study on carbon capture, utilization, and storage (CCUS), the report analyzes the role of CCUS technologies in clean energy transitions.
International	Clean Energy Innovation: Part of Energy Technology Perspectives	Case Study/ Report	International Energy Agency	A quantification of the needs for technology innovation and investment to obtain a net-zero emissions energy sector, which also offers key innovation principles governments should follow.
International	Climate Action Planning Resource Centre	Tool, Database/ Resource Hub	C40	A wide range of resources and tools to support city climate planners in the process of delivering action consistent with the objectives of the Paris Agreement.
International	Climate Action Tracker	Tool	Climate Analytics and NewClimate Institute	An independent scientific analysis that tracks progress towards the globally agreed aim of holding warming well below 2°C, and pursuing efforts to limit warming to 1.5°C.

Scope	Title and URL	Type	Creator/Host Institution	Description
International	Climate & Disaster Risk Screening Tools	Database/ Resource Hub	World Bank	A variety of resources that provide information on climate data, climate change impacts and adaptation, and other useful information that can help stakeholders better understand climate and disaster risks to national- or project-level activities.
International	Climate Policy Database	Database/ Resource Hub	NewClimate Institute	A collaborative effort to track climate policy adoption and identify global and national policy coverage gaps.
International	Climate Tools	Tool	Climate Analytics	Several open access, user-friendly, and interactive tools that make climate projections easily available to policymakers and researchers dealing with climate-related questions in fields such as agriculture, energy, and human health.
International	Climate Watch Data	Database/ Resource Hub	World Resources Institute	Open data, visualizations, and analysis to help policymakers, researchers, and other stakeholders gather insights on countries' climate progress.
International	Comprehensive Offerings for Municipal Climate Action	Tool, Database/ Resource Hub	Climate Alliance	Tools and methods for a variety of needs in municipal climate action, from general instruments to those with a regional focus, and from guides for beginners to support for climate action role model communities.
International	Deep Decarbonization Pathways Project	Case Study/ Report	Institute for Sustainable Development and International Relations and Sustainable Development Solutions Network	A global collaboration of energy research teams charting practical pathways to deeply reducing GHG emissions in Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan Mexico, Russia, South Africa, South Korea, the UK, and the US. The consortium also developed a cross-cutting analysis, the 2015 synthesis report.

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International	Direct Air Capture 2022: A Key Technology for Net Zero	Case Study/ Report	International Energy Agency	A report that analyzes the opportunities and challenges for scaling up direct air capture technologies to reach net-zero goals.
International	Early Retirement of Power Plants in Climate Mitigation Scenarios	Case Study/ Report	Environmental Research Letters, IOP Science	A study that examines future fossil fuel electricity demand in 171 energy emissions scenarios from Integrated Assessment Models to evaluate the implicit retirements and/or reduced operation of coal- and gas-fired power plants worldwide.
International	Earth Engine Data Catalog	Database/ Resource Hub	Google Earth Engine	Earth Engine's public data catalog is the world's largest archive of open Earth data, including more than 700 Earth science raster datasets, curated geospatial datasets, and near-real-time satellite imagery.
International	Embodied Carbon Policy Toolkit	Case Study/ Report	Carbon Leadership Forum	An array of resources to support the crafting of policies to radically reduce embodied carbon.
International	End-of-Life Management: Solar Photovoltaic Panels	Case Study/ Report	International Renewable Energy Agency	A report that presents the first global projections for future photovoltaic panel waste volumes to 2050 and summarizes the existing technological and regulatory knowledge and best practices for photovoltaic panel end-of-life waste management. The report also includes case studies, analyses of associated environmental and socio-economic benefits, and specific recommendations for industry, governments, and other stakeholders.

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International	Energy Access Explorer (EAE)	Tool	World Resources Institute	An interactive, geospatial platform that provides visualizations of the state of energy access in unserved and underserved areas. It analyzes credible and public data to make the connection between the demand and supply of energy, so that users can identify and prioritize areas where energy markets can be expanded.
International	EnergyData Platform	Tool	World Bank Group	An open data platform providing access to datasets and data analytics relevant to the energy sector across the world, with the aim to share over 800 datasets and 23 apps that can help achieve the United Nations' Sustainable Development Goal 7 of ensuring access to affordable, reliable, sustainable, and modern energy for all.
International	Energy Policy Simulator	Tool, Database/ Resource Hub	Energy Innovation	A free, open-source tool that evaluates decarbonization policies and visualizes cash flow, job growth, emissions, power plants, and more.
International	Energy Policy Tracker	Tool, Database/ Resource Hub	International Institute for Sustainable Development, Institute for Global Environmental Strategies, Oil Change International, Overseas Development Institute, Stockholm Environment Institute, and Columbia University	Tracking of real-time data on approved public finance and policy measures targeting energy generation and consumption to stimulate economies in response to the COVID-19 pandemic.

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International	ENERGY STAR® Portfolio Manager®	Tool	ENERGY STAR®	An interactive resource management tool that enables users to benchmark the energy use of any type of building in a secure online environment.
International	Energy Sprawl Tool	Tool	The Nature Conservancy	An interactive tool that allows users to visualize the trade-offs between energy, carbon emissions, and land use based on the world's projected energy needs.
International	Energy Tools	Tool, Database/ Resource Hub	Energy and Environmental Economics, Inc.	A variety of tools to help utilities, regulators, policymakers, developers, and investors in the electricity industry make the best strategic decisions possible. These tools include an avoided cost model, electric vehicle grid impacts model, and renewable energy capacity model, among others.
International	Engineering, & Construction Procurement Best Practice Guidelines Version 2.0	Case Study/ Report	SolarPower Europe	A report that presents guidelines that systematically go through the engineering, procurement, and construction phases of a solar power plant, including minimum requirements and best practices for Europe and other regions abroad.
International	Enhancing Nationally Determined Contributions through Urban Climate Action	Case Study/ Report	UN-Habitat	A guide for incorporating urban climate action and human settlement issues into the Nationally Determined Contributions enhancement process.
International	Environmental Insights Explorer (EIE)	Tool, Database/ Resource Hub	Google	A freely available platform that helps cities and regions measure emission sources, run analyses, identify strategies to reduce emissions, as well as access air quality and tree canopy datasets.

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International	Equity Tools and Guides	Database/ Resource Hub	Urban Sustainability Directors Network	A variety of tools and guides to inform developing programs regarding equity.
International	Floating Wind Joint Industry Project Summary Reports	Case Study/ Report	Carbon Trust	Findings from the Floating Wind Joint Industry Project, a world leading collaborative research and development initiative that aims to overcome the challenges and investigate opportunities for the deployment of large-scale commercial floating wind farms.
International	From Community Engagement to Ownership: Tools for the Field with Case Studies of Four Municipal Community-Driven Environmental & Racial Equity Committees	Case Study/ Report	Urban Sustainability Directors Network, Facilitating Power, Movement Strategy Center, and National Association of Climate Resilience Planners	This report identifies useful, high-impact practices across multiple places and sectors to support new and existing collaborative governance efforts dedicated to advancing racial and environmental justice solutions.
International	Global Atlas for Renewable Energy	Tool, Database/ Resource Hub	International Renewable Energy Agency	An online platform intended to help users (policymakers and investors) find renewable energy resources maps and assess renewable energy potential in locations across the world.
International	Global Climate Policy and Deep Decarbonization of Energy-Intensive Industries	Case Study/ Report	Climate Policy, Taylor & Francis Online	An analysis of how the global climate framework has impacted national policy responses to reduce emissions in energy-intensive industries, and how the framework should be developed after the Paris Agreement in order to support the transition to zero emissions in these industries.

Scope	Title and URL	Type	Creator/Host Institution	Description
International	Global Electrification Platform (GEP)	Tool, Database/ Resource Hub	Energy Sector Management Assistance Program and World Bank Group	An open access, interactive, online platform for exploring least cost electrification strategies around the world, interacting with country contextual data and 96 different investment scenarios.
International	Global Solar Atlas	Tool, Database/ Resource Hub	Solargis s.r.o., World Bank Group, and Energy Sector Management Assistance Program	A free, online map-based application that provides data on solar resource and photovoltaic power potential globally at multiple levels.
International	Global Wind Atlas	Tool, Database/ Resource Hub	Technical University of Denmark, World Bank Group, Vortex, and Energy Sector Management Assistance Program	A free, web-based application developed to help policymakers, planners, and investors identify high-wind areas for wind power generation virtually anywhere in the world, and then perform preliminary calculations by providing tools and high-resolution wind resource data at multiple levels.
International	Global Toolkits	Tool, Database/ Resource Hub	United States Agency for International Development and National Renewable Energy Laboratory	Free toolkits that offer state-of-the-art support on common and critical challenges countries face when scaling up advanced energy systems, such as grid integration and distributed photovoltaics.
International	Industry Transition Tracker	Tool, Database/ Resource Hub	Stockholm Environment Institute	Users can find industry transition roadmaps in one place and identify the demands in a particular country and industry sector to reach net-zero emissions across the globe.
International	International Map of Emissions Trading Systems (ETS)	Tool, Database/ Resource Hub	International Carbon Action Partnership	Global map that allows viewers to visualize the status of ETS worldwide and access information on individual ETS of interest.

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International	Low-Carbon Heat Solutions for Heavy Industry: Sources, Options, and Costs Today	Case Study/ Report	Center on Global Energy Policy, Columbia University	An analysis of the costs, application concerns, and policy implications of options for low-carbon heat in heavy industries, including biomass and biofuel combustion, hydrogen combustion, electrical heating, nuclear heat production, and post- combustion carbon capture, utilization, and storage (CCUS).
International	Mapping Global Urban Land for the 21st Century with Data-Driven Simulations and Shared Socioeconomic Pathways	Case Study/ Report	Jing Gao and Brian C. O'Neill	A study of the first empirically-grounded set of global, spatial urban land projections over the 21st century.
International	Material Efficiency in Clean Energy Transitions	Case Study/ Report	International Energy Agency	An analysis of the potential for material efficiency and the resulting energy and emissions impact for steel, cement, and aluminum, including a description of key policy and stakeholder actions needed.
International	Mitigation of Climate Change in Agriculture Programme Tools	Tool	Food and Agriculture Organization of the United Nations	Agriculture, forestry, and other land use climate mitigation analysis tools.
International	Modeling Tools for Sustainable Development	Tool, Database/ Resource Hub	United Nations Department of Economic and Social Affairs and United Nations Development Programme	Five quantitative modeling tools to help countries assess sustainable development policy options: The Climate, Land-use, Energy and Water Systems analysis and model (CLEWS), economy-wide models, socioeconomic microsimulations, energy systems models, and geospatial electrification access modeling.

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International	Natural Climate Solutions World Atlas	Tool	Nature4Climate and The Nature Conservancy	An online tool designed to help users understand nature's role in mitigating climate change through 16 "pathways," activities that enhance the protection, restoration, and management of natural and working lands at the country level.
International	Net Zero by 2050–A Roadmap for the Global Energy Sector	Case Study/ Report	International Energy Agency	This flagship report is the world's first comprehensive analysis of how to transition to a net-zero energy system by 2050. It describes the roadmap to ensuring stable and affordable energy supplies, universal energy access, and enabling economic growth, while also examining uncertainties.
International	Open Source Spatial Electrification Tool (OnSSET)	Tool, Database/ Resource Hub	KTH Royal Institute of Technology	GIS-based optimization tool that has been developed to support electrification planning and decision making for the achievement of energy access goals in currently unserved locations.
International	Operations & Maintenance Best Practice Guidelines Version 5.0	Case Study/ Report	SolarPower Europe	A report that presents guidelines and best practices for operations and maintenance service providers, investors, financiers, asset owners, asset managers, monitoring tool providers, technical consultants, and all interested stakeholders in the solar industry in Europe and beyond.
International	Partnership for Resilience and Preparedness (PREP) Data	Database/ Resource Hub	Partnership for Resilience and Preparedness, Future Earth, and World Resources Institute	A map-based, open data online platform that allows users to access and visualize spatial data reflecting past and future climate, as well as the physical and socioeconomic landscape for climate adaptation and resilience planning.

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International	Photovoltaic Geographical Information System (PVGIS)	Tool	EU Science Hub, European Commission	A tool that provides information about solar radiation and photovoltaic system performance for any location in Europe and Africa, as well as a large part of Asia and America.
International	Plastic & Climate: The Hidden Costs of a Plastic Planet	Case Study/ Report	Center for International Environmental Law	A report that analyzes the major and uncounted sources of GHG emissions in the plastic lifecycle, compares GHG emissions estimates against global carbon budgets and emissions commitments, and compiles data that has not been accounted for in widely used climate models, including downstream emissions and future growth rates.
International	Policies and Measures Database	Database/ Resource Hub	International Energy Agency and International Renewable Energy Agency	Database that provides access to information on past, existing, or planned government policies and measures to reduce greenhouse gas emissions, improve energy efficiency and support the development and deployment of renewables and other clean energy technologies.
International	Policy Brief on Public Charging Infrastructure	Case Study/ Report	International Energy Agency	A report to provide policymakers with a comprehensive overview of the ecosystem of public charging infrastructure and key recommendations for its efficient deployment.
International	Python for Power System Analysis (PyPSA)	Tool, Database/ Resource Hub	Department of Digital Transformation in Energy Systems at Technical University of Berlin	An open-source toolbox for simulating and optimizing modern power systems that can conduct both economic analysis and grid analysis.

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International	Recent Progress in Green Cement Technology Utilizing Low-Carbon Emission Fuels and Raw Materials: A Review	Case Study/ Report	Sustainability, Multidisciplinary Digital Publishing Institute	A study that presents a comprehensive analysis of options for future cements, an updated review of alternative fuels and binders that can be used to mitigate CO_2 emissions in cement production, and a discussion of the benefits of producing the low-cost materials to meet the increasing cement demand.
International	Respecting the Human Rights of Project-Affected Communities in Wind and Solar Energy Project Deployment: Business Guide and Legal Primer	Case Study/ Report	Columbia Center on Sustainable Investment at Columbia Law School	A business guide and legal primer for commercial wind and solar project development that provide strategies and resources for addressing community-related human rights impacts.
International	Renewable Energy Zoning (REZoning) Tool	Tool	World Bank Group, UC Santa Barbara, Energy Sector Management Assistance Program, and Development Seed	An interactive, web-based platform designed to identify, visualize, and rank zones that are most suitable for the development of solar, wind, or offshore wind projects across the world. Custom spatial filters and economic parameters can be applied to meet users' needs or to represent a specific country context.
International	Sharing in the Benefits of a Greening City	Case Study/ Report	CREATE Initiative	A toolkit drawing from academic research, lessons from planning practice, and the lived experiences of affected communities to equip readers with the tools needed to evaluate gentrification risks and advocate for equitable access to healthy environments and green spaces.

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International	SolarCity Simulator	Tool	International Renewable Energy Agency	Web-based simulator application created to help households, businesses, and municipal authorities evaluate their prospects for generating electricity using rooftop-mounted solar photovoltaic systems.
International	Sustainability Aspects of the Lithium Ion Battery Supply Chain	Case Study/ Report	Electric Power Research Institute	A report that summarizes key resource, environmental sustainability, and labor standards issues associated with the production of lithium ion batteries, an important technology for decarbonizing the transport and power sectors.
International	Technology Roadmap: Low-Carbon Transition in the Cement Industry	Case Study/ Report	International Energy Agency	A report that presents the global pathway to reducing direct CO_2 emissions from the cement industry, including an action plan to 2050 for specific stakeholders and policymakers to support evidence-based decisions and regulations.
International	The Future of Hydrogen: Seizing Today's Opportunities	Case Study/ Report	International Energy Agency	A landmark report that examines the current state of play for hydrogen with actionable recommendations to governments and industry for its future development.
International	The Impact of Climate Targets on Future Steel Production – An Analysis Based on a Global Energy System Model	Case Study/ Report	Journal of Cleaner Production, Elsevier	A study that examines how global climate targets may influence future technology choices for iron and steel production, especially steel demand patterns and scrap availability.
International	Tracking Clean Energy Progress	Case Study/ Report	International Energy Agency	Reports that assess the status of 46 critical energy technologies and sectors and provide recommendations on how they can get on track with reaching net-zero emissions by 2050.

Scope	Title and URL	Type	Creator/Host Institution	Description
International	United Nations High-Level Dialogue on Energy 2021 Theme Reports	Case Study/ Report	United Nations	Five theme reports written by multistakeholder technical working groups in support of the United Nations High-level Dialogue on Energy: 1) Energy Access; 2) Energy Transition; 3) Enabling Sustainable Development Goals through Inclusive, Just Energy Transitions; 4) Innovation, Technology and Data; and 5) Finance and Investment. These reports present priority recommendations, action areas, stakeholder actions, and milestones through 2050.