Planning the Built Environment and Land Use Towards Deep Decarbonization of the United States

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Abstract

Many governments, businesses, and institutions are committing to net zero greenhouse gas emissions by 2050, a goal and process known as deep decarbonization. Achieving this goal in the United States requires a national, economy-wide transformation in energy production and use in five sectors: electricity, transportation, industry, land-based carbon sinks, and buildings. All of these sectors interact with planning for the built environment and land use, so planning scholars and practitioners have many opportunities to engage policymakers working on national-level decarbonization strategies. This article analyzes the consequences of deep decarbonization for the future speed, scale, scope, role, and relevance of planning.

Introduction

The 2016 Paris Agreement was a landmark international accord intended to limit global warming "preferably to 1.5 degrees Celsius" (UN Climate 2021). Reaching this target and avoiding the most catastrophic effects of climate change requires transitioning to zero carbon energy sources by 2030 and achieving net zero human-related greenhouse gas (GHG) emissions by 2050 (United Nations Intergovernmental Panel on Climate Change 2018). Many governments, businesses, and organizations have committed to this goal (UN Climate 2020).

Deep decarbonization (henceforth, DD) refers to the goal and process of achieving net zero human-related GHG emissions. DD requires reducing GHG emissions by transitioning away from our fossil-fuel based energy system towards renewable and clean energy resources such as solar, wind, geothermal, tidal, and nuclear energy.

This article analyzes the consequences of DD for planning of the built environment and land use (henceforth, BELU) in the US for several reasons. First, DD requires fundamental changes in energy systems that are deeply embedded throughout the economy, society, and BELU of the US. Furthermore, the service life of most physical infrastructure is greater than the time between now and 2050, meaning that new infrastructure investments need to be designed and planned for mid-century climate goals right now (Creutzig et al. 2016; Bennett et al. 2020). We focus on the US as the largest economy and highest historical emitter of GHG emissions, but also because there are a series of well-developed DD strategies for the US. Finally, if planners do not contribute or suggest changes in BELU towards DD, then we risk irrelevance in future policy discussions about climate change.

Planning BELU for DD in the US – still a gigantic topic – required us also to put clear boundaries on the scope of this article. One challenge for us was to decide how to address our analysis and recommendations to the many scales and kinds of governance institutions in which planners work. This paper focuses mostly on planning at the urban, regional, or metropolitan scale, where planners work most often in community groups, city and county governments, and regional planning organizations. There are of course many other possible scales, roles, and mechanisms, because the boundaries between planning practice, action, and research are porous and complex. BELU planning can contribute in many ways to DD, but planners also must deal often with the consequences of policies from higher levels of government, so in turn, DD has many implications for BELU planning. In this paper, we address both how planning can initiate from below as well as deal with policies likely to come from above. Since many of these interactions differ by sector and issue, we therefore address scales and governance separately in each sector and section of the paper.

Of equal importance, this paper articulates DD as a goal and process for planners to engage with *looking forward*. It is similarly not possible in the space of an article to recap all of the ways that planning practice and scholarship could interact with a society-wide transition like DD, since that would draw on the entirety of planning. So, this paper does not explore how urgent DD goals interact with different research cultures in planning (Forsyth 2012); past research topics or themes (Fang and Ewing 2020); or other goals of planning, such as distributional equity, community engagement, deliberative practice, or social and racial justice. We put these themes aside for now because an extensive planning literature already exists on them. Previous work should give planners confidence to contribute our prior experience and scholarship, so in this paper we focus on the nexus of BELU and DD as a significant gap and current opportunity for planners.

A similar outlook is necessary with respect to our current politics. The politics of climate change are rapidly changing as its effects are increasingly felt in everyday life (Sengupta 2021). This paper addresses opportunities for planners to work on DD in the most optimistic and only viable scenario, in which a broad cross-section of the US public and policymakers acknowledge and want to avoid worsening climate change.

The next section describes how economists, engineers, and policymakers have translated DD into ambitious national and economy-wide strategies thus far. Subsequent sections then explain the implications of these DD strategies for BELU related to electricity, transportation, industry, land-based carbon sinks, and buildings. In each section, we describe current planning context, knowledge, and concerns in order to identify new opportunities for planners to address

DD through planning of BELU. We conclude by identifying cross-cutting themes that emerge from these five sectors; summarize the initial implications of DD for the speed, scale, scope, role, and relevance of planning; and exhort planners to engage in this critical policy debate.

Deep decarbonization strategies

Existing DD strategies build on integrated assessment models of climate and energy developed in the energy crises of the 1970's (Nordhaus 2018). These DD strategies integrate many broader exogenous socioeconomic assumptions, including: continuing economic and population growth from Census projections; changes in technology, policy, and behavior; and assumptions about BELU, especially as a constraint on rapid change in the energy system. Non-governmental environmental organizations started the DD Pathways Project in 2013 to show how coordinated public and private sector action can achieve zero carbon emissions by mid-century (Bataille et al. 2016).

Three DD strategies illustrate an emergent consensus among policymakers and academics. The Obama administration first submitted a DD strategy to the Paris Agreement with the goal of achieving an 80% reduction by 2050, known as the Mid-Century Strategy (abbreviated as MCS; White House 2016). An interagency task force produced the MCS considering three scenarios: a benchmark case to 2050; a case that limited carbon capture; and a case with limited available land. Williams et al. (2021) use models and policy scenarios to show how complete (100%) carbon neutrality could be achieved for the US by 2050, taking into account fossil fuel and renewable energy costs, land and energy demand scenarios, and policy and/or behavioral delays. Larson et al. (2021) use models with higher spatial and temporal resolution to identify the many changes to infrastructure and plant, costs, jobs, and land uses necessary to achieve DD. This consensus is reflected in recent federal reports and legislation

(House Select Committee on the Climate Crisis 2020; National Academies of Sciences, Engineering, and Medicine 2021).

All three DD strategies address many topics relevant to planning BELU. Changes in industry, buildings, and transportation will require many changes in patterns of work, dwelling, and mobility, respectively. All of these sectors also interact. For example, electrification of end-uses, renewable energy development, land and ecosystem conservation, and the use of biomass crops as an alternative source of renewable energy all interact within BELU.

The following paragraphs narrate key figures and scenarios from Table 1 from left to right and then top to bottom. The US Energy Information Administration (EIA, 2021b; 2021a) annually reviews and publishes energy data for the US economy, as well as a forecast called the Annual Energy Outlook (AEO). The AEO is cautious about projecting future technological change but provides a useful reference case to indicate how much decarbonization will occur without significant policy changes. Using EIA data from 2019, the most recent available figures that serve as a pre-COVID baseline, the US economy currently consumes approximately 100 quads of primary energy (quadrillion British Thermal Units). In 2019, only 1% came from solar, 3% from wind, 5% from biomass, and 8% from nuclear, for a total of 17% of primary energy coming from renewable and clean resources. The EIA forecasts 10% growth in primary energy use with only a 7% GHG emissions reduction by 2050, with 19% (only a 2% increase) of primary energy coming from clean energy resources.

In contrast, DD strategies all require that total primary energy use goes down and that clean energy resources rapidly replace fossil fuels. In terms of primary energy, solar must grow from the current 1% to 6-29%; wind, from its current 3% to the range of 10-53%; and, biomass must grow from its current 5% to 13-28%. Nuclear could either grow or decline from its current

8% to between 0-32%. In all DD scenarios, energy use in 2019 represents peak energy use in the US, with declines of 8 to 32% largely coming from reductions in fossil fuel use.

Primary energy use must decrease because sufficient clean energy cannot be built quickly enough. The only other option is for end use sectors such as buildings and transportation to become dramatically more efficient. Total energy use in buildings must drop 15-34% and transportation must drop 23-51%. Industrial uses, already considered relatively efficient, could possibly decline (-7%) or increase (17%).

Electrification is the key pathway that connects clean energy resources to end-use sectors. Most DD strategies require growth in electricity generation between 120 and 372%. Put another way, achieving the maximum 100% renewable energy scenario will require an expansion of electricity generation by a factor of 4.7, and even if end-use electrification is assumed to be constrained, electricity generation still must more than double. Use of electricity in buildings increases in most cases by at least 18% except where electrification (-1%) or renewable energy (5%) are limited. Transportation sees the sharpest increases in electricity use: many of the figures in this row indicate four-digit or effectively infinite percentage growth, since the share of electricity used in transportation in 2019 was less than 1%. To enable decarbonization, electricity or fuels derived from renewable resources must expand to become the primary energy source for passenger and freight transport. Even the AEO now forecasts a more than 1000% increase in electricity use in transportation. Use of electricity in industry must grow 26-156% above its current share of 3%.

Expanded renewables and bioenergy crops will have a large aggregate impact on land use in the US. The lowest estimate for both renewable energy and carbon sinks are that these uses impact only 2% of the entire conterminous US (the lower 48 states), while scenarios emphasizing biomass or all renewable energy impact between 14 and 21% of the conterminous US. In comparison, forests are 28% of the lower 48 states, cropland is 15%, and all urbanized areas, roads, and parking spaces combine to less than 4%. The next sections detail key opportunities for planners to influence DD through planning of BELU in the five key areas.

	US EIA		DEEP DECARBONIZATION STRATEGIES						
DATA SOURCE / FORECAST	**EIA 2019**	**EIA 2021**	**MCS 2016**	**Williams et al 2021**			**Princeton NZAP 2020**		
Scenario	Baseline, data released 2021	AEO Ref. Case, 2050 forecast	Bench-mark	Central (least-cost)	100% renew. energy	Low land	E+RE+ (high electrif., high renew.)	E-B+ (slower electrif., high biomass)	E+RE- (high electrif., renew. limited)
GHG reduction goal x Year		7% x 2050	80% x 2050	100% x 2050	100% x 2050	100% x 2050	100% x 2050	100% x 2050	100% x 2050
TOTAL PRIMARY ENERGY									
Clean energy shares:									
Solar	1%	6%	8%	18%	26%	16%	29%	12%	6%
Wind	3%	6%	16%	40%	50%	24%	53%	23%	10%
Nuclear	8%	6%	9%	6%	0%	19%	0%	6%	32%
Biomass	5%	2%	13%	17%	22%	14%	17%	28%	14%
	17%	19%	46%	81%	98%	73%	98%	69%	62%
Fossil fuel shares:									
Oil w/o CCS	37%	35%	19%	0%	0%	0%	0%	0%	0%
Oil w/ CCS	0%	0%	0%	6%	0%	14%	0%	19%	15%
Coal w/o CCS	11%	6%	1%	0%	0%	0%	0%	0%	0%
Coal w/ CCS	0%	0%	5%	0%	0%	0%	0%	1%	0%
Methane w/o CCS	32%	33%	22%	0%	0%	0%	0%	0%	0%
Methane w/ CCS	0%	0%	5%	12%	0%	11%	0%	10%	21%
	80%	75%	52%	18%	0%	26%	0%	30%	36%
CHANGES NEEDED, 2019-50									
Total primary energy consumed	100.4	110.1	68.6	75.0	76.4	75.5	77.1	86.2	92.6
Growth		10%	-32%	-25%	-24%	-25%	-23%	-14%	-8%
Efficiency gains needed									
Buildings		-17%	-15%	-34%	-34%	-34%	-34%	-24%	-34%
Transport		-4%	-30%	-23%	-23%	-23%	-51%	-37%	-51%
Industry		30%	-7%	17%	17%	17%	-2%	3%	-2%
Total electricity delivered	12.8	41.2	28.2	45.7	57.7	36.3	60.4	35.5	33.1
Growth		222%	120%	257%	351%	184%	372%	177%	158%
Growth in use of electricity									
Buildings		26%	18%	21%	21%	21%	22%	-1%	5%
Transport		1067%	2341%	Inf (DIV/0)	Inf (DIV/0)	Inf (DIV/0)	6630%	4951%	6530%
Industry		31%	53%	73%	73%	73%	156%	26%	42%
LAND USE CHANGES									
Renew. energy (% area)	NE	NE	NE	5%	6%	2%	14%	6%	3%
Carbon sinks (% area)	NE	NE	29%	NE	NE	NE	0%	15%	12%
Carbon sinks (-Gt CO2e/yr)	NE	-0.70	-1.20	-1.20	-1.20	-1.20	-0.85	-0.85	-0.85

All numbers measured in quadrillion BTUs (quads).
All % shares measured within reports; all % growth changes measured against EIA 2019 baseline.
Conventional hydropower and geothermal omitted from clean resource shares because they are not expected to grow appreciably.
NE: No estimate provided.
Inf (DIV/0): estimate of growth is essentially infinite because of starting from a zero baseline.
Percentage (% area) is reported as the percentage of the lower 48 states of the US.
Additional carbon sinks estimated in MCS and Williams et al as -0.5 Gt cde/yr; NZAP assumes moderate deployment of sinks.

Table 1. Summary of deep decarbonization strategies (MCS: White House 2016; Williams et al. 2021; Princeton Net Zero America Plan (NZAP): Larson et al. 2021)

Electricity

Expanded electrification has become the main approach to decarbonization for a number of reasons. Continued technological advances, including reduced costs, digitalization, sensing, monitoring, and controls, continue to expand the use of electricity in communications, mobility, and dematerialization of goods and services. Renewable resources are relatively widespread and plentiful worldwide, and electricity can be transmitted over long distances without large losses. As the electric grid decarbonizes, connected end uses will further reduce their carbon emissions over time (Dennis, Colburn, and Lazar 2016). The inefficient alternative is to invest in new fossil-fuel infrastructure now, which will either rapidly become obsolete and/or lock in future emissions (Tong et al. 2019).

Electricity represented just over one-third of all primary energy use in the US in 2019 (37%). In economic and technological terms, electricity is the easiest and quickest sector to decarbonize, since electricity is the preferred way to transmit energy from low-carbon resources like solar, wind, and nuclear; renewable generation of electricity is already competitive with fossil fuels and is expected to continue to become cheaper through 2050 (Wiser, Rand, et al. 2021; Feldman et al. 2021). Lithium-ion battery prices have declined 97% in the last three decades, similar to the cost declines observed for solar photovoltaic cells (Ritchie 2021). Before recent supply chain issues, these economic trends were expected to continue through to 2050. Electricity-related carbon emissions in the US are already one-third or one-half less when compared to projections from 2005 depending on how you measure during the pandemic (Wiser, Millstein, et al. 2021). With continued declines in storage costs, solar and wind power could provide reliable, decarbonized grid power (Ziegler et al. 2019). However, complete replacement of fossil fuels by renewable energy in the electricity sector raises a number of challenges, concerns, and opportunities.

Increase the speed and scale of renewable energy resource development

DD strategies assume that renewable energy will replace fossil fuels, but in all strategies the speed of renewable deployment must increase drastically. For example, in 2021, the US added 28 GW of solar and wind capacity (S&P Global 2022). But almost all DD scenarios require the US to accelerate its deployment of new renewable energy capacity even faster for every year between now and 2050. For example, in Larson et al. (2021), the US must achieve new records of solar and wind deployment of 40 GW annually from 2021-2025, double this to 70-75 GW annually in the period from 2026-2030, and then annually more than 180 GW per year in the 2030s and 2040s. We will discuss the implications and likelihood of such rapid changes in the other sectors below.

Resolve land use conflicts over renewable energy and transmission

Land use conflicts may be the greatest obstacle to rapid deployment of renewable energy. Solar and wind energy are relatively less energy dense than fossil fuels, requiring more land to produce the same amount of energy (Smil 2015). However, local opposition has led to a proliferation of state laws that limit or block renewable development (Marsh, McKee, and Welch 2021). Electric transmission projects are needed to move renewable energy resources, but face many obstacles due to fragmentation of planning authority between local, state, and federal regulators and opposition from utility monopolies (Hurley 2018; Peskoe 2021). Resolving conflicts over the siting and creation of public goods is central to planning research and practice, and planners have much to contribute.

Adapt the electric grid for climate risks

New electricity infrastructure should be built to be "future-proofed", that is, to minimize future climate risks. Infrastructure interdependencies will further amplify climate risks (Jaffe et al. 2019): hurricanes in Puerto Rico, winter storms in Texas, and wildfires in California reveal that the electric grid is more vulnerable to climate risks than previously expected (Zamuda et al. 2018). Infrastructure can be planned for foreseeable risks by updating designs for more extreme weather events; conducting systematic reviews of interdependencies and failure modes; and/or disaggregating or decentralizing complex systems where possible.

Enable local governance of electricity

All the changes suggested above depend on how electricity is governed. Public utility commissions were created more than a hundred years ago to regulate monopolies at the state level, but utilities are now straining from anemic financial returns, increasing business risk and liabilities, rapid shifts towards cleaner resources, and new competing technologies (Utility Dive 2018). Despite efforts in the 1990s to introduce competition to wholesale markets and allow customer choice, distribution of electricity is still dominated by monopolies that have little or no incentive to allow innovation by users at the edge of the grid or behind the meter (Wara 2017). Local governance of energy systems through municipally owned utilities, privately owned cooperatives, community choice aggregations, and/or microgrids may better enable end-use electrification, energy efficiency, and the building of distributed energy resources by allowing integrated planning for energy and BELU (Kristov 2014; Hsu 2022).

Transportation

Transportation accounts for the single largest share of GHG emissions in the US, nearly 29% in 2019, comprised of emissions from passenger cars and light duty vehicles (57%), freight trucks (24%), and air travel (10%) (US Environmental Protection Agency 2021). Most DD plans seek to eliminate transportation emissions by transitioning to electric vehicles and/or those that use clean liquid fuels. Still, integrated modeling suggests that mobility will be the most difficult sector to decarbonize (Pietzcker et al. 2014).

Transportation contributes to accessibility, defined as: "the extent to which the land-use and transportation systems enable (groups of) individuals to reach activities or destinations" (Geurs and Van Wee 2004, 128). Accessibility generates GHG emissions as the product of four determinants, identified in the ASIF framework (Schipper, Liliu, and Landwehr, 1999):

- total activities (A), or the trips made and distances covered to realize accessibility (trips multiplied by distance);
- share (S) of different modes utilized to carry out those activities (% of trip distance);
- intensity (I) of those modes' fuel consumption (energy per trip distance); and,
- type of fuel (F) used (emissions per energy).

Activities (A) most closely correspond to accessibility. Demand for travel is influenced by socioeconomics and demographics, economic structure, and the size, form, and relative location of settlements (Cameron, Kenworthy, and Lyons 2003; Bento et al. 2005). Mode share (S) of the distance traveled for passenger and freight influences carbon emissions, since travel modes have different energy consumption characteristics. Other influencing factors include income, infrastructure provision, service quality, and urban form and design (Rajamani et al. 2003). Technological factors such as engine type, technology, and vehicle age determine fuel intensity (I), i.e. how much fuel is consumed to do the work of moving passengers and freight. Driving conditions also affect fuel intensity, as do vehicle occupancy levels, which again are influenced by urban form and design (Zhang 2004). Fuel choice (F) also influences GHG emissions based on the chemical composition of fuel and vehicle technologies.

Enable changes in technology and mobility demand

With low carbon *accessibility* as the objective, planning must focus on all aspects of ASIF. Working backwards through ASIF, starting with fuel choice (F), transportation DD will almost certainly require massive electrification. Electric passenger vehicles (EVs) are already cleaner than internal combustion-based alternatives in all states (Union of Concerned Scientists 2020) and sales have grown rapidly in recent years (Paoli and Gül 2022). However, EVs still face many adoption challenges, such as: lack of charging infrastructure; consumer "range anxiety"; the slow pace of vehicle stock turnover, and new energy and materials used in their production (Crabtree 2019). At various levels of governance, planners can accelerate EV adoption by siting and developing charging infrastructure, purchasing fleets, incentivizing fleet turnover and scrappage, and prioritizing EVs on roadways and in zones. Fitzgerald (2020) offers many policy examples from European and American cities.

Planning for transport DD can also focus on increasing the efficiency of the energy used for movement (I). In BELU, this translates to smoothing flow and increasing utilization rates. To smooth flow, planners can coordinate traffic signals and try to price congestion by building on efforts such as the Bay Bridge in San Francisco, dynamic pricing for parking and managed lanes, and new efforts in New York City (Cohen 2021). To increase utilization rates, national and state planners can shape financing and investment frameworks to favor high occupancy modes, while regional and local planners can price services such as roads and transit fares, allocate space, and promote urban development and design to increase vehicle loadings. Similar planning and policy approaches can induce a shift in BELU to DD-oriented “active mobility” modes (S) like walking and biking, which have demonstrated decarbonization effects (C. Brand et al. 2021).

Many of the above interventions in BELU will also reduce total demand for travel (A). Local and regional planning for denser, more centralized cities with greater mixed uses can reduce vehicle travel and GHG emissions (Lee and Lee 2020). Designing for compact and dense cities can also reduce infrastructure footprints and sprawl. However, in some cases, reduced accessibility for some segments of society and elements of the economy will raise issues of equitable redistribution.

Speed transportation and land use changes

Rapid changes are needed to meet DD goals, but transportation DD requires BELU changes that typically occur slowly. For example, urbanization and suburbanization processes were fueled by transportation investments that locked in development and mobility patterns for decades (Baum-Snow 2007). Like other sectors in the US’s federal system, a large range of stakeholders play a role, such as government agencies, infrastructure providers, fleet and vehicle operators, real estate developers, financiers, workers, and consumers. Federally mandated and state-empowered metropolitan planning organizations (MPOs) provide an institutional setting for coordinating DD in transportation, a precedent set by air quality regulations, which require MPOs to develop and follow transportation plans to obtain federal funding. However, MPOs have done little to act on climate (Mullin, Feiock, and Niemeier 2020). Additional legislation and/or enforcement at both the state and national level are needed to accelerate focus and coordination towards DD goals.

Implement digitalization and beyond

Digitalization and automation trends could complement electrification and BELU changes towards DD. For example, automated vehicles (AVs) could profoundly change street and parking designs; electrified AVs could merge with building designs to create smart and shared charging facilities; and automated, shared AVs – with intelligent, near real-time, matching of supply and demand – could possibly decrease mobility's carbon footprint, especially when integrated with traditional public transport (Oke et al. 2020). Digitalization also can enable efficient and equitable pricing of roads, parking (Shoup 2021), and transit. Planners can prepare for many possible synergies between local industrial economies and new vehicle types and technologies, service station transitions, and existing buildings, a recurring theme throughout this paper.

Finally, possibilities for replacing long-distance travel appeared to be modest before COVID-19 (Li, Kockelman, and Lee 2021), but as many have experienced during the pandemic, many new possibilities exist for remote and virtual presence to reduce travel if people choose to use them. Aviation and freight remain the most difficult to decarbonize sectors because of the high power densities needed to move people or weight quickly over long distances (Smil 2015).

Industry

Industry accounts for about 23% of GHG emissions in the United States (US Environmental Protection Agency 2021). Decarbonizing industry faces technical and policy challenges in planning for both GHG emission reduction and its aftereffects.

There is considerable debate about whether industrial DD can be accomplished with existing or near-existing technologies, or whether additional innovations are needed (Rissman et al. 2020), but all proposed pathways to industrial DD require significant capital investment (Bataille et al. 2018). Decarbonizing energy-intensive industrial processes requires changes to both fuel sources and raw materials, and new technology to sequester carbon (Åhman, Nilsson, and Johansson 2017). Industrial processes must be switched from fossil fuels to use electricity or biomass, which in some cases will require replacing equipment with remaining useful life (Thiel and Stark 2021). Industrial processes could reduce demand for raw materials by incorporating recycled raw materials and through energy cascading, where waste products from one industry become inputs for another, also known as industrial symbiosis (Fraccascia et al. 2021). Such industrial planning will require global standards because unilateral regulations would reduce global competitiveness and result in carbon leakage to less-regulated countries (Åhman, Nilsson, and Johansson 2017).

Plan for changes in industrial employment and jobs

In terms of land use, communities may experience plant closings, openings, and reconfigurations that will lead to empty industrial properties in need of remediation, as well as demand for new or reconfigured spaces (de Pee et al. 2018; Shum 2017). For example, industrial parks could be redesigned to enable energy cascading networks in clusters of industries (Bataille et al. 2018).

Existing patterns of jobs and wages will be disrupted by DD. Jobs in the oil and gas industry pay higher-than-average wages, and jobs in carbon-intensive industries create between 2-5 additional jobs within local regional economies (Marchand and Weber 2018). As DD shifts the oversized economic impact of these industries, many workers will have to obtain new skills.

Previous economic downturns and industrial shifts suggest that retraining workers can result in less negative economic impacts (Jacobson, LaLonde, and Sullivan 2005), but that older, established workers may be most at risk for long-term displacement or wage losses (Eriksson, Hane-Weijman, and Henning 2018). Without new economic opportunities, businesses relying on economic spillover from carbon-intensive industries will close or relocate. On the positive side, new industrial job opportunities will certainly arise in green technologies and advanced manufacturing (van der Ree 2019; Jaeger et al. 2021). Skills of displaced workers in energy sector jobs impacted by DD may translate well into new green manufacturing jobs (Chen et al. 2020), but there will likely be a geographic mismatch, especially since many new "green-collar" jobs are in the building sector (Knuth 2019). While employment opportunities are expected to be net positive (Ram, Aghahosseini, and Breyer 2020), it remains unclear if new positions will provide the same job quality or pay (García-García, Carpintero, and Buendía 2020). Investment in worker retraining will be important, but evidence from the Great Recession indicates that new green jobs are most likely to grow in places with existing concentrations of green industries (Popp et al. 2020).

Preparing for transformational economic changes therefore requires planning now. Previous industrial shifts led to long downturns well before gains in other industries could compensate for losses (Autor, Dorn, and Hanson 2016). Planners can use tools from our current toolkit to address DD impacts, including regulatory, incentive, and informational policies. However, many local governments that will experience the strongest effects from DD have little planning capacity, making it difficult to address these challenges proactively (Loh 2015).

Redevelop industrial lands

The expertise of planners in brownfield remediation will be critical to reducing the local impact of industrial changes, with the added benefit of providing accessible land for new low-carbon uses (Greenberg et al. 2001). Planners' knowledge about industrial locations and workforce development is complementary to experts in industrial fields (Osland 2013; 2015; Loh and Osland 2016), but if we do not engage in collaborations with those fields, planners may not know how to address fully the challenges and opportunities created by industrial shifts in their communities.

Land-based carbon sinks

There is a significant gap in the planning literature on the use of natural landscapes as carbon sinks. While planners have long studied land preservation and growth management policies for promoting compact development and discouraging suburban sprawl (Hack 2012), few planning researchers have studied how land preservation and growth containment could preserve the ability of natural landscapes to sequester carbon. Within cities, recent evidence shows that urban forests can effectively sequester carbon, but urban lands remain a small portion of total US land area as discussed above (Garvey et al. 2022).

In the carbon cycle, natural landscapes store carbon into stocks, while fluxes are exchanges of carbon between land and atmosphere (US Department of Agriculture Forestry Service 2017). Considerable GHGs are released back into the atmosphere due to land cover changes caused by development, wildfire, and activities such as farming, livestock breeding and feeding, and forestry (Global Carbon Project 2020). The US Environmental Protection Agency (2021) reports that in 2019, 14% of net GHG emissions in the US were removed by forests, cropland, grassland, and wetland, but the net emission stock change decreased by 12% from 1990 levels due to losses from development. Based on projected changes in climate, vegetation, and land uses for 2050, the US Geological Survey estimated that the future carbon sequestration rates of both the Western and the Eastern ecosystem regions will decrease substantially in 2050 from the 2006 baseline (Zhu and Reed 2012; 2014). Continued loss of forest, prairie, farmlands, and wetlands will result in irreversible loss of carbon sinks. The following sections explore policies to avoid these degradations.

Improve forest mitigation

Researchers have called for forest mitigation efforts such as reducing deforestation, promoting afforestation and reforestation, and implementing forest carbon offset programs to create verifiable increases in GHG reduction and sequestration (US Department of Agriculture Forestry Service 2017; Bustamante et al. 2014). However, there is considerable debate about how to implement forest offsets (Kim and Daniels 2019; Temple and Song 2021), and water stress, extreme heat, and wildfires also put forest sequestration potential at risk.

Encourage better agricultural practices

Farmland and food processing are significant sources of GHG emissions. The agricultural sector in 2018 accounted for 11% of total US GHG emissions (US Department of Agriculture Economic Research Service 2020). Climate-smart agricultural practices can reduce emissions from agricultural production and minimize carbon releases from soil, by spreading biochar, manure management from animal production systems, legume inter-seeding, nitrogen management, tillage management to reduce overall emissions from soil, and retiring land from crop production to restore wetland and riparian forests (Pape et al. 2016; Bai et al. 2019).

Conserve existing wetlands and grasslands

Wetlands are also an important carbon sink. Coastal habitats such as salt marshes, mangroves, and seagrass beds store large quantities of carbon, known as coastal blue carbon (US National Oceanic & Atmospheric Administration, Fisheries 2021). Despite this, the lower 48 states in the US between 2004 and 2009 lost about 80,000 acres of coastal wetlands to development, drainage, erosion, subsidence, and sea-level rise (Dahl 2011)https://www.zotero.org/google-docs/?broken=qzssNH. Conservation and rehabilitation of wetlands are necessary to preserve their functioning as effective carbon sinks (Nahlik and Fennessy 2016).

Similarly, grasslands in native prairies with deeper root systems function much better as carbon sinks than non-native prairies. Pendall et al. (2018) estimated that the grasslands of the Great Plains sequestered nearly 35% of the entire carbon stock in the region. Several studies show effective growth management and land preservation reduce GHG emissions substantially. Tomalty (2012) estimates that preserved land in Ontario's Greenbelt in Canada stored more than half of the province's total GHG emissions in 2013. In the US, Han, Daniels, and Kim (2021) found that metropolitan counties in California and Pennsylvania that instituted greenbelt policies lost less land-based carbon sinks to new development compared to counties that did not. Urban growth boundaries, county-level agricultural zoning, and market-based land preservation tools can all promote compact development and preserve land-based carbon sink capacity.

Manage sprawl and growth to preserve carbon sinks

Development has a direct impact on the land's ability to sink carbon. The literature reviewed above suggests that achieving land-based carbon sinks requires comprehensive growth management planning, land preservation, habitat conservation, and climate-smart agricultural practices. Increasing loss of wildlife habitat, farmland, and forests are among the substantial costs of sprawl (Burchell et al. 2005).

Emerging research on land-based carbon sinks reinforces the costs-of-sprawl argument calling for enhanced planning to promote more compact, less sprawling development. Land-based carbon sinks could be part of local and regional growth management policies. Evidence shows that implementation of land preservation tools (Daniels 2005) such as urban growth boundaries, priority funding areas, and greenbelts can be used to protect land and habitats for carbon sequestration. California's Environmental Quality Act amendment shows how state government can help protect land-based carbon sinks by requiring an impact assessment of GHG emissions for development projects (State of California 2021). Thus, planners at the state, regional, and local-level all have important roles to play in preserving land-based carbon sinks.

Buildings

Buildings are a primary focus of DD strategies because they are significant users of energy and sources of GHG emissions, directly accounting for 11% of US total GHG emissions, which does not include associated electricity use (US Environmental Protection Agency 2021). Previous efforts in building energy efficiency indicate some of the challenges and opportunities. Decades of energy efficiency policies have improved the energy performance of the building stock, but not at the rate that many analysts predicted (Shove 2018). It is worth unpacking the reasons for this disappointing result. First, many older buildings already make intrinsic tradeoffs between thermal comfort, indoor air quality, and energy performance, since they were designed to optimize objectives other than energy efficiency (Wells et al. 2015). Second, the construction industry is inherently risk averse (World Economic Forum 2016). Third, the use of buildings is tightly embedded in social practices that do not quickly yield to technical innovations (Shove, Walker, and Brown 2014).

As in the other sections, building energy efficiency faces a variety of institutional, technological and behavioral obstacles, such as: aligning local, state and federal regulations and incentives more effectively; persuading individual building owners to adopt carbon-free technologies; learning how new technologies compete in the marketplace; identifying the barriers to widespread adoption; and figuring out who pays. The following subsections detail several potential pathways to improvement.

Understand building stocks

DD in buildings requires study and strategy at several levels. Energy epidemiology distinguishes between population-level studies of diverse buildings, detailed diagnoses of how to make a specific building perform better, and overall policy recommendations (Hamilton et al. 2017). Econometric models highlight human behavioral responses to prices and information (Giraudet 2020), whereas engineering-economic models indicate relative technology performance in varied contexts (Reyna and Chester 2017). Both dimensions are essential for managing change and integrated assessments are now the state of the art (Colelli and Cian 2020).

Design more effective building policies

A reductionist engineering approach to energy efficiency seeks to characterize changes as pairwise technology substitutions, such as replacing a “dirty” natural gas-fired water heater with a “clean” electric heat-pump water heater (Mai et al. 2018). This strategy is limited because it attempts to solve a society-wide problem (climate change) by influencing an individual choice (“buy a new water heater”), without calibrating other incentives throughout the economy (such as the carbon intensity of electricity), which is why economists call for broader solutions such as carbon taxes.

Building energy efficiency experts have advanced several partial solutions to this suboptimization problem, including ranking investments in energy-efficient retrofits; advocating for changes in tariff structures to encourage demand management, energy storage, and distributed solar energy production; and using shadow prices to approximate the effect of carbon taxes. Energy benchmarking, audits, and performance standards are examples of relatively low-cost policies that can create data and incentives to drive further energy use reductions (Marasco and Kontokosta 2016; Meng, Hsu, and Han 2017). Local planning agencies often have jurisdiction to implement integrated policies to reduce GHG emissions in local building codes (Hsu et al. 2017). Other examples of local policy innovation include mandated stretch building codes that are more stringent than base code, such as in Santa Monica, California (New Buildings Institute 2020). Many local governments are seeking to use regulatory tools to require mandatory integration of new technologies, such as requirements for solar installations, electrification, and electric vehicle charger-ready installations to their building codes, local ordinances and zoning requirements (Cook et al. 2016; Salcido, Tillou, and Franconi 2021), although many of these efforts face opposition from industry groups and state governments through pre-emption (Leber 2021). Finally, achieving more holistic building energy policies may require significant policy and business model innovation, such as in the 'Energiesprong' energy efficiency retrofit model in Europe (Brown, Kivimaa, and Sorrell 2019; Fitzgerald 2020), which is now being tried in New York State.

Design innovations for adoption

The innovation diffusion literature tells us that adopted innovations must be cost-competitive, integrate into existing building systems, and be simple to understand (Andrews and Krogmann 2009). Planners and other government agencies can reduce the risks associated with adoption by subsidizing trials to gain experience, avoid unintended consequences, and support regional demonstration projects that make innovations widely and locally observable (Späth and Rohracher 2010). Larger scales such as districts and campuses allow experimentation with new technologies such as ground source ("geothermal") heat pumps that can then be generalized to wider urban applications (Shaffer et al. 2018; Revesz et al. 2020).

Brand (1995) also reminds us that different elements of a building such as the site, structure, skin, services, space plans, and occupants all have different lifetimes. Empirical studies of innovation diffusion show that lags of many decades between invention and widespread adoption are typical (Grubler and Wilson 2014). Mazzucato (2011) argues that the role of governments is to take long-term risks by investing where the private sector will not. While this role has mostly been played by states and the federal government, local institutions and technology ecosystems play an important role in innovation (Geels 2002).

Target opportunities for action

Buildings are parts of multi-level systems in which many parties can act. Successful decarbonization of buildings depends in part on accommodating human occupants and changing their behaviors (Heydarian et al. 2020; Sovacool et al. 2021). This places a premium on the usability of building systems, positive engagement, and the design of interfaces connecting building systems to occupants (Day et al. 2020; O'Brien et al. 2020). As buildings become smarter, they can play a greater role in balancing the supply and demand of electricity by shifting the timing and intensity of building operations (Kolokotsa 2016).

Opportunities exist for planners to transform the energy use of buildings, and in turn, larger settlements, private property, and the public realm. Physical strategies for DD extend beyond individual buildings to include planning for district energy systems, microgrids, community solar installations, and co-housing with shared amenities. Social and political strategies enacted by planners similarly play out at the settlement level, including energy awareness campaigns, building code amendments and enforcement, energy auditing, technical assistance, and public expenditures for affordable housing and public buildings. Public policymaking at the state level influences building codes and energy prices. Policymaking at the national level additionally sets energy performance standards for appliances and equipment used in buildings, as well as encouraging the development of new technologies.

Conclusion

Many cross-cutting themes and common problems emerge from the five major sectors for DD. We present a few examples in consecutive order. Electricity and transportation require planners to speed and facilitate necessary changes in BELU within larger systems, especially technologies, markets, and behaviors. Transportation and industry both require the early retirement of existing capital stock and coordination between stakeholders at different levels. Industry and agricultural practices are not usually thought of as part of planning, but planners can enable improved practices through proactive planning of BELU, as well as directing new development towards existing lands to preserve natural habitats. Similarly, high-density and high-efficiency buildings can encourage land preservation. To complete the cycle, buildings can help to stabilize the electric grid. All of these potential opportunities build on existing planning knowledge and expertise; BELU is a core area for planning; and yet there is much more to do to in order to enable DD, so readers will undoubtedly think of many more opportunities.

Implications for practice

Experiences to date with other large societal transitions suggests that planning processes for DD will be contentious, urgent, and require much education. Planners have critical roles to play, especially at the local level, in training and re-training the workforce, crafting policy incentives and regulations for efficient buildings, developing settlement patterns to encourage non-motorized transport, ensuring land preservation for carbon sinks, re-using industrial land, and siting renewable energy facilities and network elements. Planners need to identify which DD interventions are most cost-effective across such divergent spheres as the supply of clean energy by utilities, the demand for convenient energy by households, and the uses of land and other resources.

Implications for research

Research gaps and emerging phenomena make DD a rich area for future scholarship. Much comparative research is needed to determine how well different approaches – top-down versus bottom-up, directed investment versus market-driven, etc. – enable faster and persistent decarbonization. The scale of change needed requires understanding of federal interactions – both horizontal and vertical – as they relate to private sector supply chains, locally available resources, and economic tradeoffs between mass production of, say, solar panels, and size of, say, nuclear power plants. Planners can act to harness, encourage, spread, and assess innovations emerging at all scales.

New challenges for planning

Planners must also grapple with several new challenges raised by DD, namely the speed, scope, scale, role, and relevance of BELU planning. First, in almost all sectors, we will have to work much faster to anticipate and enable the massive changes needed by DD within the next thirty years and beyond. We must analyze why planning for BELU is so slow. Planners need to learn how to drive faster action while working proactively to resolve foreseeable conflicts.

Second, both the scale and scope of the changes needed for DD are large. Local planners will have to engage various stakeholders and communities within contexts that are determined by dynamic technological, economic, social, and political change at multiple regional, national, and international levels. Spatial scale is one relevant dimension, but DD will change the basic architecture of large-scale networks that deliver energy, and move people, goods, money, and information. Many factors will be beyond our control. Coordination across sectors and levels has become an essential planning skill, and planners need to be equally comfortable using the languages of markets, public policy, design, and visioning.

Third, the practical role of planners in shaping BELU is central, but not total, fixed, or complete. In the absence of coordinated national land-use policies, planning and planners currently have authority over local BELU, but this jurisdiction has been preempted in the past by Congress when local planners and processes could not provide networked infrastructure of national importance such as natural gas in the 1950s and cellphone towers in the 1990s (Klass 2014). New York State passed legislation in 2020 to consolidate environmental permitting and incentivize communities to accept renewable energy (Wiseman 2020), and environmental review itself is being reconsidered in light of the need to build more renewables (Farah 2021). State legislatures are also attempting to restrain the leadership of local governments on multiple environmental issues through preemption (Fitzgerald 2021). If solutions do merge from technological innovation, sweeping public policy, and political consensus, implementation at the local level could still make or break DD. Planners therefore need to engage, complement, and collaborate with other disciplines and professions towards DD.

Our fifth and final point about relevance summarizes the previous challenges of speed, scale and scope, and role. In this article we have proposed many ways that planning BELU is critical and relevant to averting further climate catastrophe. The general public understands that climate action is necessary and the importance of planning BELU. Planners have an important role to play if we can act quickly, at all scales, and engage broader climate policy communities and discussions. Are we ready to act?

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