<u>Annotated Bibliography; Behavioral and Societal Changes to Reduce Energy Consumption by Sector</u>

1. Cross Sectoral

Grubler, A., et al. (2018). "A low energy demand scenario for meeting the 1.5 °C target and sustainable development goals without negative emission technologies." https://www.nature.com/articles/s41560-018-0172-6

This article provides a comprehensive statistical analysis of the LED scenario, projecting future energy demands using a bottom-up approach. It details 2050 energy projections based on activity levels and sectoral transformations, adjusting estimates from the Global Energy Assessment (GEA) Efficiency scenario.
The study analyzes the Low Energy Demand (LED) scenario for 2020–2050, highlighting significant sectoral changes and solutions.

The analysis of Mobility in this study suggests that "increasing vehicle occupancy by 25% and vehicle usage per day by 75% delivers **<u>the same intra-urban mobility with 50% of the vehicle fleet</u>**. By 2050, the total vehicle numbers halve to around 850 million light-duty vehicles." It then goes on to indicate that this reduction in vehicle density encourages the repurposing of the extra road space for walking, cycling etc.

In industry, it poses that a shift from ownership to service-based models, supported by digitalization, promotes the use of longer-lasting, higher-quality products. This change reduces overall resource use by extending product lifespans, increasing reuse rates, and decreasing turnover rates. In depth analysis of this shows that halving private vehicle stock by 2050 could lower global steel demand by 14 Mt and save 3 EJ of energy. Additionally, consumer preferences for sustainable environments decrease the use of single-use plastics, reducing global petrochemical demand by 600 Mt and saving 17 EJ of energy.

Other key solutions include retrofitting buildings at a doubled rate to 3% per year in the North and expanding urban and vertical farming systems. Additionally, adopting smart, multifunctional devices and integrating renewables are crucial.

In addition to key solutions, this study also considers the caveat of the rebound effect—where efficiency gains may lead to increased demand— a phenomenon the study deems is "not inevitable and can be managed by policy, for example, by adjusting taxation levels to offset efficiency improvements and so hold energy-service prices roughly constant (though this might be difficult to implement)."

However, in an instance where policy is hard to implement, the study finds that LED's projections for staying within a 1.5°C limit are robust even with a 50% increase in demand, indicating resilience to potential rebound effects.

Amory Lovins "How big is the energy efficiency resource?"https://rmi.org/insight/how-big-is-the-energy-efficiency-resource/

This text discusses ways of Reducing Energy Demand through Changes in Behaviors and Habits

1. Building Systems and Lighting: Changes in how we approach lighting systems can significantly reduce energy demand. While upgrading to energy-efficient lighting like LEDs is beneficial, it should not be the first priority. The Illuminating Engineering Society (IES) Handbook of Fundamentals suggests that addressing usually ignored steps before upgrading lighting equipment can save over 90% of lighting energy. By rethinking daylighting - the practice of using natural sunlight to illuminate indoor spaces and reduce the need for energy-consuming artificial light - and reducing lighting power density, offices can cut nominal energy use by 4 to 10 times, depending on the level of natural light available. Focusing on the integration of daylighting strategies and optimizing existing lighting infrastructure before considering high-efficiency equipment like LEDs can lead to greater savings at lower costs. Behavioral changes like relying more on natural light, adjusting workspace layouts to make better use of daylight, and reducing unnecessary artificial lighting could significantly reduce energy demand in commercial and residential settings.

2. Air Conditioning and Space Cooling: More efficient air conditioners or chillers are often viewed as the go-to solution for reducing cooling energy demand. However, focusing on upstream factors—like reducing heat loads in buildings and improving thermal comfort through non-mechanical means—can reduce cooling demand by 90–100%, sometimes eliminating the need for air conditioning altogether. Simple behavioral changes, such as shading windows, using fans for ventilation, and adjusting clothing based on temperature, can enhance thermal comfort without relying heavily on energy-intensive air conditioning systems. These habit changes can create immediate savings, reduce equipment size, and cut costs.
3. HVAC Systems and Building Renovations: Timing deep retrofits with routine building renovations, such as replacing heating, ventilation, and air-conditioning (HVAC) systems or renewing façades, can lead to substantial energy savings. For example, in one case study of a Chicago office tower, a redesign led to a 76% energy-saving potential and a 4x reduction in cooling load by making minor adjustments in construction practices. Implementing behavioral changes like scheduling energy-efficient retrofits during major upgrades, instead of postponing, can reduce overall capital costs while achieving significant energy reductions. Property owners should also prioritize energy efficiency during routine upgrades to avoid missing valuable opportunities for long-term savings.
4. Motor and Drive Systems: About half of the world's electricity powers motors, mostly in industrial applications. Behavior changes in how these motors are used, such as adjusting drive systems to reduce unnecessary friction in pumps and fans, can dramatically cut energy demand. For example, making pipes and ducts fat, short, and straight—rather than thin, long, and crooked—can save 80–90% of friction energy in retrofits, typically paying back in under a year. These changes, which require a shift in how engineers and operators think about energy efficiency in their systems, can reduce motor energy demand by shrinking the system size and minimizing friction losses.
5. Industrial Integrative Design: The use of integrative design in industrial processes shows how changing habits can unlock deeper energy savings. For instance, Texas Instruments saved 40% of energy and 30% of capital costs by optimizing the design of their microchip-making facility, while Tesla's Gigafactory replaced 1 MW of gas boilers with 15 kW of heat pumps for solvent redistillation, achieving a 98.5% site energy savings. These outcomes stem from habit changes that prioritize whole-system designs and efficiency over traditional, dis-integrated approaches. Applying integrative design principles—such as minimizing energy losses through improved system layout and equipment choice—requires a shift in both mindset and behavior across industrial sectors, but can result in major reductions in energy demand.

Rocky Mountain Institute. Ben Holland et al. (2023) "Urban Land Use Reform: The Missing Key to Climate Action Strategies for Lowering Emissions, Increasing Housing Supply, and Conserving Land"
https://rmi.org/insight/urban-land-use-reform/
This study explores land use policy reforms in cities like Austin, Charlotte, and Denver, recommending strategies to reduce energy use. It advocates for developing housing closer to daily needs, promoting multifamily housing, and curbing urban sprawl to lower vehicle miles traveled (VMT) and building energy use. The report suggests that successful land use reforms could cut VMT by 13%, building energy use by 16%, and local greenhouse gas emissions by 14%, but notes challenges such as zoning restrictions and planning processes. Specifically in the housing sector, it reports that "Over 70% of new housing takes the form of detached single-family homes, which use 64% more energy per occupant on average than attached and multifamily homes."

The study also includes a striking estimate that 1/3 of global GHG emissions can be directly or indirectly attributed to urban sprawl. On the underwhelming side, they estimated that greater urban density and land-use planning in 49 states (not including Alaska) could reduce CO_2 emissions by 70 million tons.

In terms of policy recommendations, it suggests encouraging multifamily development in traditionally single-family residential areas, especially through upzoning and Transit-Oriented Development (TOD), can significantly reduce emissions and improve housing equity. By redeveloping underutilized parcels of land near transit stops with high-density, mixed-use buildings, cities can reduce car dependence and promote sustainable growth. Improvements in transportation infrastructure, such as expanding sidewalks, creating protected bike lanes, and offering e-bike rebates, encourage more sustainable commuting alternatives, while converting general lanes to express bus lanes further incentivizes public transit use. Additionally, unbundling parking from housing and businesses, offering cash-back incentives for non-use of parking, and implementing pay-as-you-drive insurance schemes can discourage driving and reduce emissions. Redirecting funds from highway expansion to transit and pedestrian infrastructure helps align investments with climate-friendly goals. These changes in urban planning and transportation habits foster more walkable, bike-friendly, and transit-accessible communities, contributing to lower energy demand and more equitable urban environments.

Steven Nadel and Lowell Ungar (2019) "Halfway There: Energy Efficiency Can Cut Energy Use and Greenhouse Gas Emissions in Half by 2050"
https://www.aceee.org/research-report/u1907
This paper suggests that to effectively reduce energy demand, a multi-pronged approach is essential. Building retrofits and energy efficiency improvements are crucial, starting with enhanced transparency and benchmarking through tools like ENERGY STAR Portfolio Manager, which have already led to energy savings of 3–8% in commercial buildings. The DOE's Home Energy Score tool for residential properties also plays a vital role by offering efficiency ratings and improvement suggestions. Effective retrofitting requires a combination of strategies including contractor training, owner education, incentives, and ongoing research and development. For low-income households, increased grant funding and long-term financing are needed to facilitate upgrades. In the realm of appliances and equipment, federal efficiency standards have saved over 130 quads of energy by 2030 and reduced bills by nearly $2 trillion. The additional impact of ENERGY STAR specifications further boosts efficiency, though at a smaller scale compared to minimum standards. The industrial sector has made significant strides, with energy intensity declining by 38% from 1980 to 2013, and further reductions can be achieved through expanded use of strategic energy management and emerging technologies. Lastly, urban planning and transit-oriented development play a pivotal role in reducing energy demand by promoting higher-density, mixed-use developments near transit hubs, improving bike and pedestrian infrastructure, and implementing policy measures like e-bike rebates and equitable parking fees. Collectively, these strategies offer a comprehensive path to substantial reductions in energy consumption and emissions.

Niamir, L., Verdolini, E., & Nemet, G. (2024) "Social innovation enablers to unlock a low energy demand future." https://iopscience.iop.org/article/10.1088/1748-9326/ad2021/pdf
This article discusses the potential of additive manufacturing (AM) - a process also known as 3D printing that builds objects layer by layer, using only the material needed.
This reduces waste and allows for energy-efficient production, particularly when creating complex or customized parts. By enabling local, on-demand manufacturing, AM can lower energy demand associated with transportation and large-scale production processes to reduce energy demand significantly across sectors. It highlights that AM could decrease primary energy use in aerospace and medical equipment production. The authors stress the need for substantial public support, new business models, and effective governance to realize these benefits. Additionally, the article examines shared mobility and solar photovoltaics (SP), noting that shared mobility's success varies by region and that SP adoption requires supportive policies and improved finance access.

Nan Zhou, International Institute for Applied Systems Analysis. (2022). "EDITS at UNFCCC COP27: High services with low energy and resource demand for low-carbon pathways and the SDGs."
Prefabricated construction methods help reduce energy use by making building parts in factories instead of on-site, which is faster and more efficient. At the 2022 UNFCCC COP, Nan Zhou, Senior Scientist at Lawrence Berkeley National Laboratory and Speaker at the event, emphasized the benefits of using prefabricated parts in construction, which can reduce project timelines by 30-50% and costs by up to 20%. This approach also lowers energy use and emissions by incorporating alternative materials with lower embodied energy compared to traditional cement and steel. The focus is on minimizing energy consumption and emissions in the building process through innovative construction methods.

2. Buildings

Dietz et al. (2019) “Halving energy demand from buildings: The impact of low consumption practices”

https://www.sciencedirect.com/science/article/abs/pii/S0040162518311818

Some analyses exploring the potential for reduction of energy demand already considered technological and behavioral approaches together. Taking an individual perspective, Dietz et al. (2009) considered all the interventions that US households could take to reduce their emissions, and therefore their energy demand, covering changes in technology purchase patterns as well as usage habits. According to them, residential emissions could decrease by 20% within ten years if all these measures were implemented. In other words, they claim that energy consumption from activities in buildings at the end of the century would decrease by 11% compared to the 2015 level, instead of a 126% increase. The decrease in energy demand is driven by new practices for hot water usage, insulation and by the increased use of efficient air conditioners and heat pumps.

The changes in consumer practices in the Low and Very Low energy demand scenarios illustrate a significant potential for reducing energy use compared to the Reference case. In these scenarios, energy demand growth is greatly subdued, with the Low scenario showing a 33% decrease and the Very Low scenario a 44% decrease by 2050. By 2100, these reductions become even more substantial, reaching 47% and 61%, respectively. This indicates that adjusting practices can lead to considerable energy savings. For indoor heating, the Very Low scenario involves setting the thermostat to 19°C in winter and 26°C in summer, while the Low scenario uses 20°C and 25°C, respectively, compared to the Reference level of 23°C year-round. Improvements in insulation, such as applying window tape to block out hot or cold air, also play a crucial role. The majority of the reduction in energy demand is attributed to enhanced space heating and cooling measures, including better building insulation and the use of efficient HVAC systems. Water conservation measures and changes in habits further contribute, albeit to a lesser extent. Overall, adopting these changes in consumer practices can lead to significant decreases in energy demand.

Mastrucci, A., Niamir, et al. (2023) “Modeling Low Energy Demand Futures for Buildings: Current State and Research Needs.” https://www.annualreviews.org/content/journals/10.1146/annurev-environ-112321-102921

This paper highlights the importance of community-centered approaches in reducing energy demand through tailored spatial planning and housing solutions. It advocates for engaging local residents in the design and implementation of energy efficiency programs to address challenges such as access to technology, affordability, and cultural relevance. The paper underscores the role of equitable spatial planning in reducing energy poverty and enhancing living conditions, promoting a sustainable and socially just approach to energy efficiency.

Joana Ortiz, Juli Carrere, Jaume Salom, Ana M. Novoa, (2023) “Energy consumption and indoor environmental quality evaluation of a cooperative housing nZEB in Mediterranean climate”https://www.sciencedirect.com/science/article/pii/S0360132322010253

LaBorda is a cooperative housing in Barcelona, Spain. The analysis of La Borda's energy performance in this paper highlights the significant impact of building orientation and design on energy consumption:

Thermal and Electricity Consumption:

- Average Thermal Energy Demand: La Borda's average heating and domestic hot water (DHW) demand is 11.6 kWh/m²·yr, which is substantially lower than the Spanish average and well below the typical heating demand of 29 nearly zero-energy buildings (nZEBs) analyzed in the European ZEBRA2020 project.

- Heating Demand: South-oriented apartments have an exceptionally low heating demand of under 2.2 kWh/m²·yr, reflecting their efficient passive solar heating. In contrast, north-oriented apartments have a higher heating demand, up to 20.0 kWh/m²·yr, which is above the average for nZEBs and corresponds to a C label on the energy certificate.

- Electricity Consumption: La Borda's average annual electricity consumption is around 1,000 kWh/yr, significantly lower than the Spanish average of 2,500 kWh/yr. This efficiency is attributed to communal resources and active community involvement.

It also talks about the Impact of Orientation and Design:

- Orientation: South-facing apartments benefit from reduced heating needs due to greater solar gain, while north-facing units require more heating to maintain comfort. This difference in demand is mitigated by high-quality construction and improved insulation in the north-facing units.

- Size and Occupancy: Larger households generally have higher energy needs. La Borda's design integrates strategies to balance energy consumption with the number of occupants and their patterns.

The paper then touches on Energy Efficiency Strategies as a mindful tactic to reduce energy consumption/demand.

- Design and Orientation: The orientation of buildings plays a crucial role in energy efficiency. South-facing units leverage passive solar heating, reducing their energy demand. In contrast, north-facing units, despite increased heating needs, benefit from enhanced insulation and window performance.
- Community and Shared Resources: Shared communal spaces, such as kitchens, and collective learning initiatives contribute to lower overall energy use. The cooperative housing model promotes efficient use of resources and encourages behavioral changes that support energy savings.
- Affordability and Equity: To maintain affordability, La Borda distributes heating costs among residents based on their apartment's orientation, addressing the higher heating demands of north-facing units.

Minjin Kong, Changyoon Ji, Taehoon Hong, Hyuna Kang, (2022) "Impact of the use of recycled materials on the energy conservation and energy transition of buildings using life cycle assessment: A case study in South Korea"

https://www.sciencedirect.com/science/article/pii/S1364032121011588?casa_token=B_vIH0wfeaAAAAAA:w_vbC5pcQ1Zj21G7pFqvsgOA0CY3v_ncffndC4H00fpdX8tp_TzuhNGpSgzMFREh4vcvNPYFF04

This study looked at how using recycled materials instead of new ones affects the installation of renewable energy systems in buildings. Researchers used a method called Life Cycle Assessment (LCA) to estimate energy use and greenhouse gas (GHG) emissions over the lifetime of buildings and their energy systems. They focused on a public building and four types of solar panel systems. The findings showed that using recycled materials generally reduced GHG emissions more than energy use. For the building studied, using recycled materials lowered overall energy use by 4.9% and GHG emissions by 3.3%. Among the solar panel systems, the biggest impact was seen in single crystalline-silicon (sC-Si) panels, where energy use dropped by 44.5% and GHG emissions by 41.3%.

Overall, the study showed that using recycled materials can significantly reduce both energy use and emissions in buildings and solar energy systems.

Fecheyr-Lippens, D., & Bhiwapurkar, P. (2017). Applying biomimicry to design building envelopes that lower energy consumption in a hot-humid climate. Architectural Science Review, 60(5), 360–370
https://www.researchgate.net/publication/319239529_Applying_biomimicry_to_design_building_envelopes_that_lower_energy_consumption_in_a_hot-humid_climate

Based on biomimicry examples from the African reed frog and Hercules beetle, innovative design strategies for thermoregulation in hot-humid climates can lead to significant energy savings. The African reed frog's heat management techniques inspired the use of high-albedo surfaces, phase change materials (PCMs), and adaptive thermal comfort strategies like mixed-mode (MM) and natural ventilation (NV). Meanwhile, the Hercules beetle's humidity-responsive camouflage informed the idea of preconditioning outside air through dehumidification using hydrogels. By combining these biomimetic strategies, and utilizing an energy simulation tool, a building envelope was developed that could achieve a 66% reduction in HVAC-related energy use intensity (EUI), or 39% of total building energy consumption.

Li, W., Cui, Z. & Han, F. (2015)“Methods for assessing the energy-saving efficiency of industrial symbiosis in industrial parks. Environ Sci Pollut Res 22, 275–285”

https://link.springer.com/content/pdf/10.1007/s11356-014-3327-4.pdf

The depletion of global energy resources has prompted interest in Industrial Symbiosis (IS) as a strategy to improve energy efficiency. This paper introduces an index system to evaluate IS's energy-saving efficiency, including energy-saving and financial indicators. Energy-saving indicators include the IS energy-saving index, contribution rate of energy saved, fractional energy savings, and energy consumption reduction per total output value. Financial indicators include the IS payback period, input-output ratio, net present value (NPV), and internal rate of return (IRR).

The index system was applied to the XF Industrial Park (XF IP) in Liaocheng, China, identifying three IS channels for energy savings: (a) utilizing high-temperature materials between processes, (b) recovering waste heat and steam, and (c) sharing infrastructures. Results showed that IS contributed to 34.6% of the total energy savings in 2011, with a fractional savings rate of 12.42%. The energy consumption per output value dropped by 43.42%. The IS input-output ratio was 57.2% lower than coal prices, and the payback period was 8.5 months. Both NPV and IRR were positive, with values of 1,789.96 MRMB and 140.96%, respectively. These findings demonstrate IS's capacity to enhance energy efficiency and reduce financial burdens, supporting its potential for broader application in industrial and eco-industrial parks.

Hobman, E., et al.(2017) “Exploring Everyday Energy Usage Practices in Australian Households: A Qualitative Analysis.” Energies, vol. 10. https://www.mdpi.com/1996-1073/10/9/1332

This article investigates energy usage practices in Australian households, noting that habitual behaviors and societal myths impact energy consumption.

It offers insights into how behavioral interventions could promote energy efficiency. Practitioners should focus on functional benefits of efficient practices, such as how washing in cold water can still produce clean clothes. Interventions should capitalize on natural moments for change, such as extreme weather days (e.g, using these as an opportunity to illicit energy conscious behavior through avenues like alerts to householders with tips on how to manage energy use), or by altering default settings (e.g., cold wash as the norm). The effectiveness of social influence strategies, such as social proof and peer influence, is also noted, although caution is advised in cases where strong personal preferences, such as hot showers, may resist change.

The study suggests that effective interventions should focus on the broader meanings people ascribe to their energy usage, beyond just energy or monetary savings. By shaping new technologies and practices that make energy-efficient actions easier or more attractive, there is potential to transform resistant behaviors into more sustainable ones.

Statistics reveal significant savings from switching to cold washes—using 8.4 kWh less per load compared to hot washes.

Brown, J. (2005) "Comparative Analysis of Energy Consumption Trends in Cohousing and Alternate Housing Arrangements." Massachusetts Institute of Technology.https://dspace.mit.edu/handle/1721.1/30142

This paper examines cohousing as an energy-efficient alternative to single-family homes. It highlights that shared spaces and reduced individual home footprints in cohousing can lower energy use and foster community. The paper provides data on cost savings, showing a minimum of $200 per month in savings per household, with some residents saving over $2,000 annually. Despite its potential, cohousing faces scalability challenges for broader adoption.

Since the above article is dated, here's a more recent publication that further validates the capacity forshared housing to reduce energy demand;

Peter Berrill, Kenneth T. Gillingham, and Edgar G. Hertwich. Environmental Science & Technology (2021)

"Linking Housing Policy, Housing Typology, and Residential Energy Demand in the United States"
https://pubs.acs.org/doi/10.1021/acs.est.0c05696

The text argues that U.S. housing policies, particularly those favoring single-family homeownership, are misaligned with climate mitigation goals. Single-family homes, often associated with the "American Dream," are more energy-intensive compared to multifamily homes, largely due to older construction standards and less efficient energy systems. Multifamily housing tends to have lower energy consumption due to characteristics like higher urban heat island effects, less exposed surface area, and more efficient heating systems.

The analysis suggests that encouraging the construction of multifamily housing, through changes to federal taxes, subsidies, and local land-use regulations, could significantly reduce residential energy demand and greenhouse gas (GHG) emissions. Federal policies that favor single-family homes also contribute to higher property taxes and land-use restrictions on multifamily housing, further discouraging its development.

The paper highlights that newer multifamily homes have greater potential for energy efficiency improvements and would also help reduce the demand for air conditioning, which is rising due to climate change. A shift towards multifamily housing could provide significant energy and GHG savings, even without changes in household income or floor area. The authors propose reforms that equalize housing subsidies, expand access to financing for multifamily housing, and relax local land-use regulations to enable more energy-efficient housing development. This shift is critical for achieving U.S. climate goals and addressing housing needs.

"Within each cohort, single-family detached houses require 13−39 GJ more space heating annually than multifamily high units. Energy for space cooling follows the same pattern, higher in single-family and older houses, but the magnitude is much smaller, with single family homes requiring 3−4 GJ more space cooling within each cohort.", "Single-family detached homes use 5−10 GJ more energy for other end-uses, compared to multifamily high homes of the same cohort."

Sharp, F., et al. (2014) "The use and environmental impact of daylighting."

https://www.sciencedirect.com/science/article/abs/pii/S0959652614003254#:~:text=Once%20a%20daylighting%20system%20is,the%20life%20of%20the%20product.
This article explores the energy savings achieved through daylighting, which uses natural sunlight to reduce reliance on artificial lighting. Properly designed daylighting systems, such as skylights and tubular daylighting devices, can cut lighting energy use by up to 46% as noted by Rutten [2]. However, effective implementation is crucial; poor design can lead to reverting to more energy-intensive lighting methods. Daylighting aligns with LEED certification goals by providing efficient, environmentally friendly lighting solutions.

Woo Moon, et al. (2021). "Thermostat strategies impact on energy consumption in residential buildings."https://www.sciencedirect.com/science/article/abs/pii/S0378778810003440
This paper examines how different thermostat settings affect energy consumption in both cold (Detroit) and hot-humid (Miami) climates. The study reveals that higher thermostat settings lead to increased energy consumption, especially for heating in cold climates. It emphasizes that lower thermostat settings during winter can maintain comfort while reducing energy demand, highlighting the importance of proper thermostat management for energy efficiency.

Pisharoty D. et al., (2015). "ThermoCoach: Reducing Home Energy Consumption with Personalized Thermostat Recommendations" [(PDF) ThermoCoach: Reducing Home Energy Consumption with Personalized Thermostat Recommendations (researchgate.net)]()
This article shows how thermostats can have significant potential to reduce global energy consumption, but their effectiveness is often limited by user engagement. This paper introduces ThermoCoach, a system designed to enhance thermostat usability by providing personalized, actionable recommendations based on human occupancy patterns. The system sends suggested setpoint schedules via email, which users can easily modify or activate with a click.

In a randomized controlled trial involving over 600 devices in 40 homes over 12 weeks, ThermoCoach demonstrated impressive results: it saved 4.7% more energy compared to manually programmable thermostats and 12.4% more than the Nest learning thermostat, while also improving user comfort.

This study highlights the potential for innovative thermostat systems like ThermoCoach to significantly reduce energy consumption in homes, demonstrating that personalized and user-friendly approaches can lead to more effective energy management.

Brown, L., & Williams, J. (2023). "Thermostat strategies for energy savings in residential buildings." Energy Efficiency Journal.
Brown and Williams investigate various thermostat strategies for energy savings, demonstrating that lowering thermostat temperatures during inactivity or when away from home leads to substantial reductions in energy consumption. The paper reinforces that managing thermostat settings effectively is a key strategy for balancing comfort and energy efficiency.

Subdivision of "Buildings"- Land Use

Haiqian Ke,1 Bo Yang,2 and Shangze Dai (2022? "Does Intensive Land Use Contribute to Energy Efficiency?—Evidence Based on a Spatial Durbin Model"
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9102805/#:~:text=This%20paper%20finds%20that%3A%20

This paper shows that the intensive use of land can contribute to the energy efficiency positively, as each percentage point increase in the level of intensive land use will increase energy efficiency by 1.3 percentage points. (2) Although the intensive use of land can improve the local energy efficiency of the region, it will have a negative effect on energy efficiency of the surrounding areas because of the transfer of energy-intensive industries to the surrounding areas. Space integration can solve this problem to a large extent."

Mostafavi, N.; Heris, M.P.; Gándara, F.; Hoque, S. The Relationship between Urban Density and Building Energy Consumption. *Buildings* 2021, *11*, 455. https://doi.org/10.3390/buildings11100455

This paper shows
1. That urban canyon form reduces energy consumption by up to 19% and 30% for residential and office buildings.
2. Evidence of a study in Singapore showed that height of building can potentially reduce energy use by up to 5%.

3. **Industrial**

Edgar G Hertwich, Saleem Ali, Luca Ciacci, Tomer Fishman, Niko Heeren, Eric Masanet, Farnaz Nojavan Asghari, Elsa Olivetti, Stefan Pauliuk, Qingshi Tu (2019) "Material efficiency strategies to reducing greenhouse gas emissions associated with buildings, vehicles, and electronics—a review"
https://iopscience.iop.org/article/10.1088/1748-9326/ab0fe3
Material production accounted for 56% of the construction sector's carbon footprint, which amounted to 3.3 gigatons of CO2 emissions. The long lifespans of buildings and infrastructure—lasting decades to centuries—require ongoing materials and energy for maintenance, potentially leading to inefficient use patterns and outdated energy practices.

Reducing Material and Energy Demand in Construction
Future building material demand and related emissions can be minimized through several strategies, including more intensive use of buildings (reducing per capita floor area), extending building lifetimes, adopting lighter and less carbon-intensive materials (such as wood-based construction in place of steel and cement), minimizing construction waste, using prefabrication, reusing structural elements, and recycling building materials.

The potential of these strategies varies based on a region's development stage, local building material resources, and existing building stock. In developing countries, measures focusing on new construction are more critical, whereas in regions with a large existing stock, efforts related to lifetime extension, reuse, and recycling are more pertinent.

More Intensive Building Use
Scenarios for future residential buildings often assume more spacious living spaces, which negatively impacts material efficiency (ME). In Switzerland, projections show that a 20% growth in floor area by 2050 could increase cumulative material-related greenhouse gas emissions by 8% compared to a baseline scenario. Similarly, Swilling et al. (2013) anticipate a threefold increase in global urban land area from 2010 to 2050 to accommodate housing for an additional 2.4 billion people, following trends of decreasing urban density.

Reversing the trend of increasing floor area through better-designed and furnished residences with less space per capita has significant potential for emission reductions. For example, a "more intense use" scenario for future residential buildings in Norway suggests that climate impacts could be reduced by 50% compared to the baseline, owing to decreased material demand and reduced energy required for heating a smaller area.

Hessam Golmohamadi (2022) "Demand-side management in industrial sector: A review of heavy industries" https://www.sciencedirect.com/science/article/pii/S1364032121012284

In the food industry, hygro-thermal models estimate potential demand response benefits from optimizing refrigerated display cabinets. Pulp and paper mills with electric boilers can offer primary frequency reserves to power systems while reducing energy costs by up to 7.4% in summer and 2.3% in winter. Dynamic optimization in glass furnaces and joint heat-power flexibilities in oil refineries further illustrate how adjusting operations in response to fluctuating electricity prices can lead to energy and cost savings.
Overall, these studies highlight that integrating demand response strategies and optimizing energy use in industrial processes can significantly lower energy consumption and costs. This underscores the need for more research and review in the industrial sector to better understand and enhance these flexibility potentials.

Alexander Otto, Martin Robinius, Thomas Grube, Sebastian Schiebahn, Aaron Praktiknjo, Detlef Stolten (2017) "Power-to-Steel: Reducing CO2 through the Integration of Renewable Energy and Hydrogen into the German Steel Industry"
https://www.mdpi.com/1996-1073/10/4/451
The paper explores ways to integrate renewable power into the steel manufacturing process, highlighting techniques such as blast furnace gas recirculation (BF-GR), carbon capture furnaces, increased use of electric arc furnaces (EAFs), and direct reduced iron production with hydrogen (H-DR). These methods could

significantly reduce or eliminate coal dependence in steelmaking, enabling the industry to be powered by renewable energy. Using Germany as an example, the study shows that these technologies could achieve a 47–95% reduction in CO_2 emissions (compared to 1990 levels) and a 27–95% reduction in primary energy demand (relative to 2008), depending on the integration of 12–274 TWh of renewable electricity. While these changes would contribute substantially to reducing CO_2 emissions and fuel demand, they would not fully meet Germany's target of a 50% reduction in power consumption by 2050.

This represents a societal change as it encourages industries to adopt cleaner technologies and rethink their energy strategies, ultimately leading to significant reductions in CO_2 emissions and primary energy demand.

G.P. Hammond, J.B. Norman,
(2014) Heat recovery opportunities in UK industry, Applied Energy.
https://www.sciencedirect.com/science/article/abs/pii/S030626191300901X
The study assessed the potential to reduce energy demand in the United Kingdom's industrial sector by analyzing surplus heat from sites involved in the European Union Emissions Trading System. Several heat recovery technologies were considered: on-site recovery using heat exchangers, heat upgrading via heat pumps, conversion to chilling using absorption chillers, conversion to electricity using Rankine cycles, and transport to off-site heat demands. The analysis provided an indicative assessment of overall potential.

The most significant potential for surplus heat reuse was found in low-temperature recovery using heat exchangers and conversion to electricity via organic Rankine cycles. Both technologies are commercially available but not widely established, suggesting a need for further support and development to increase adoption. By capturing and reusing waste heat, industries can lower their need to generate additional heat or electricity, directly reducing energy consumption. For example, on-site heat recovery using heat exchangers captures waste heat for reuse within the facility, reducing the need for new energy generation. Heat upgrading with heat pumps elevates captured waste heat to higher temperatures, minimizing the demand for new heat sources. Similarly, converting surplus heat into cooling energy using absorption chillers shifts energy use from electricity to recovered thermal energy. Waste heat can also be converted into electricity through Rankine cycles, offsetting some of the facility's power needs and lowering demand on external sources. Additionally, exporting surplus heat to other users through district heating systems allows facilities or residential areas to use this heat instead of generating their own. The total estimated recoverable surplus heat was 52 PJ/year, potentially reducing emissions by 2.2 $MtCO_2e$/year.
Establishing heat trading networks and district heating systems could facilitate the export of heat from industrial sites, further decreasing energy demand.

Howland Daphne (2023) "How good is secondhand apparel for the planet, really?"

Howland's report reveals that if every consumer bought just one second hand garment instead of a new one this year, it could reduce CO_2 emissions by over 2 billion pounds, save 23 billion gallons of water, and cut 4 billion kilowatt-hours of energy. This statistic highlights the significant environmental benefits of purchasing second hand clothing.

Dami Moon, (2024) Promoting sustainable practices: "Exploring secondhand clothing consumption patterns and reductions in greenhouse gas emissions in Japan,
Sustainable Production and
Consumption,"https://www.sciencedirect.com/science/article/pii/S2352550924000071

The study highlights the potential reduction in greenhouse gas (GHG) emissions achievable by replacing new clothing purchases with secondhand clothing in Japan. It analyzed the effects of selling 10 million secondhand clothing items on an online platform. Based on consumer survey data, it estimated that about 8.5 million new clothing items could be replaced by these secondhand transactions. From a life-cycle assessment (LCA) perspective, the GHG emissions associated with a secondhand clothing item are roughly 33% of those of a new piece. Consequently, substituting 10 million new clothing transactions with secondhand alternatives could result in a GHG emissions reduction of approximately 9.6 thousand tons of CO2 equivalent.

Replacing 10 million new clothing items with secondhand ones could reduce emissions by around 9.6 thousand tons of CO2, underscoring thrifting as a sustainable consumer behavior that can contribute to lowering overall energy demand in the fashion industry.

Chang Su, et al. "Circular economy for clean energy transitions: A new opportunity under the COVID-19 pandemic." **(PDF) Circular economy for clean energy transitions: A new opportunity under the COVID-19 pandemic (researchgate.net)**
This study, based on a sample of 140,000 people in China, shows that implementing circular economy measures could result in significant savings in energy use, CO2 emissions, and PM2.5 emissions compared to new policy scenarios focusing solely on energy efficiency. The study estimates a 7% reduction in final energy use, a 10% reduction in CO2 emissions, and a 17% reduction in PM2.5 emissions from 2020 to 2040.

Ellen MacArthur Foundation. (n.d.). "The circular economy in detail."https://www.ellenmacarthurfoundation.org/the-circular-economy-in-detail-deep-dive
The Ellen MacArthur Foundation estimates that adopting a circular economy could reduce primary material consumption by 32% by 2030. This reduction in material use would significantly lower energy consumption and environmental impacts across various sectors.

Fashion Innovation (2024) THE DARK SIDE OF THRIFTING AS A SUSTAINABLE FASHION TREND AND SOLUTIONS: Commercializing Thrift: A Sustainable Solution to the Fashion Industry's Carbon Footprint."

https://fashinnovation.nyc/sustainable-fashion-trend/#:~:text=Thrifting%20shopping%20reduces%20carbon%20emissions,about%201%2C800%20gallons%20of%20water.
This article explores the benefits of thrift shopping in reducing the environmental impacts of the fashion industry. It argues that secondhand markets and curated thrift stores can decrease energy demand associated with new clothing production, which is energy-intensive.

Jamili, et al. (2022) "Quantifying the Impact of Sharing Resources in a Collaborative Warehouse." European Journal of Operational Research. https://www.sciencedirect.com/science/article/pii/S0377221722000078
This paper evaluates how resource sharing in industrial settings, such as collaborative warehouses, can reduce energy use. It reports that sharing resources can improve efficiency by up to 84%, highlighting the potential for collaborative practices to lower overall energy consumption in the industrial sector.

Marketing The Conscious Club. (2019) "Clothing & Energy — The Conscious Challenge." The Conscious Challenge.https://www.theconsciouschallenge.org/ecologicalfootprintbibleoverview/clothing-energy
This article discusses the significant environmental impact of the fashion industry, noting its position as the world's second-largest polluter after oil. It highlights the high energy consumption associated with textile production and suggests choosing fabrics with lower environmental impacts, such as organic cotton or recycled polyester, to reduce energy use and greenhouse gas emissions.

Green America. (n.d.). "Pros and cons of online thrifting." Green America.
This article evaluates the environmental impact of online thrifting. It notes that Americans travel an average of 14 miles per shopping trip, with each trip leading to one package delivery. For those in rural areas, online thrifting may be more energy-efficient compared to traditional shopping. The article underscores the potential of online thrifting to reduce energy consumption related to transportation.

4. **Agricultural**

Mohammad, J., et al. (2019). *Effects of crop rotation on energy use efficiency of irrigated potato with cereals, canola, and alfalfa over a 14-year period in Manitoba, Canada.* Agricultural Systems, 167, 1-10.https://www.sciencedirect.com/science/article/abs/pii/S0167198719300182

This study reveals that longer crop rotations, particularly those incorporating legumes like alfalfa, can significantly improve energy use efficiency in agriculture. Rotations that include legumes enhance soil fertility, reduce greenhouse gas emissions, and lower energy inputs, making farming more sustainable and energy-efficient over time.

Energy Study Institute. (2023). *No-till farming improves soil health and mitigates climate change*. Environmental and Energy Study Institute. https://www.eesi.org/articles/view/no-till-farming-improves-soil-health-and-mitigates-climate-change

This article explores the benefits of no-till farming, which reduces energy use by minimizing mechanical soil disruption. By preserving soil structure and reducing the need for chemical inputs, no-till farming significantly lowers fuel consumption and greenhouse gas emissions, making it a more energy-efficient practice.

In terms of relevant energy-use reduction statistics, a study consolidated into an article shows that " **no-till farming can slash fuel usage by 50 to 80 percent**, saving farms money". This reduction in fuel usage can be directly linked to a reduction in energy demand.

Goland, C. (2008). *Community supported agriculture, food consumption patterns, and member commitment.* Culture & Agriculture, 24(1), 1-10.

https://www.researchgate.net/publication/229466951_Community_Supported_Agriculture_Food_Consumption_Patterns_and_Member_Commitment

This paper examines how Community Supported Agriculture (CSA) programs can reduce energy use by promoting local food systems. CSAs shorten supply chains and reduce the energy required for transportation and industrial processing, creating a more sustainable agricultural model that supports small farmers and environmentally friendly practices.

According to a U.K. study by Egli Lucas et al. (2023), CSA can reduce energy demand by a significant percentage, with some research indicating a decrease of up to 28% compared to conventional farming practices. This reduction is primarily due to reduced transportation distances and more sustainable farming methods employed by CSAs.

Anon. (2023). *Energy use in livestock and crop production.* Environmental Research Letters, 19, 1-18.

This article highlights how reducing the use of energy-intensive inputs in livestock and arable farming can lower energy consumption. The study discusses the benefits of shifting livestock to pasture-based systems and reducing synthetic fertilizers in cropping systems, though these changes may involve trade-offs such as yield variability or increased herbicide use.

Shifting livestock to pasture-based systems and reducing synthetic fertilizers in cropping systems can significantly reduce energy demand, with studies indicating potential reductions of 20-50% in overall energy use within an agricultural system. Additional sources supporting these findings include the National Center for Appropriate Technology (n.d.) and Monteiro et al. (2023), which explore the benefits of reducing synthetic fertilizer use and integrating crop-livestock-forestry systems, respectively**.**

Sanderson MA, Archer D, Hendrickson J, et al. Diversification and ecosystem services for conservation agriculture: Outcomes from pastures and integrated crop–livestock systems. *Renewable Agriculture and Food Systems*. 2013;28(2):129-144. doi:10.1017/S1742170512000312
https://www.cambridge.org/core/journals/renewable-agriculture-and-food-systems/article/diversification-and-ecosystem-services-for-conservation-agriculture-outcomes-from-pastures-and-integrated-croplivestock-systems/C29F7658818F1EC373A4F00B6E845032

The study provides evidence that pasture-based farming systems can be more energy efficient than traditional livestock farming systems. Specifically, the rice-pasture rotations, which included grazing animals on pasture, had lower energy consumption and comparable or higher energy returns compared to the other rotations. This suggests that pasture-based systems, by allowing livestock to graze on pasture, can eliminate the need for farmers to acquire costly machinery such as feed mixers, grinders, and pellet mills. This not only reduces energy consumption but also lowers maintenance costs and reduces the environmental impact associated with these machines.

***Implementing integrated crop- livestock management systems Overview*. (n.d.).**
https://foodforwardndcs.panda.org/content/uploads/2024/08/Implementing-integrated-crop-livestock-management-systems-Food-Forward-NDCs.pdf

Integrated crop-livestock systems (ICLS) are mutually supportive systems where crops and livestock production work together, reducing reliance on external inputs. Unlike specialized systems, ICLS close nutrient and energy cycles by using livestock byproducts as fertilizer for crops and vice versa. This helps to reduce environmental externalities like greenhouse gas emissions from mineral fertilizers and increases the resilience of smallholder farmers. By diversifying income and diet, ICLS can also enhance agricultural biodiversity at the landscape level. Farmers can reduce energy demand and use by implementing ICLS, as these systems often require less machinery and energy-intensive inputs. However, it's important to note that ICLS requires an initial investment of USD 863/ha (estimation made between 2005-2012, so needs to be corrected for inflation), which is higher than specialized systems. While operational and input costs are lower for ICLS compared to specialized soy and corn farms, they are higher than those of specialized cattle farms.

Rabes, A., et al. (2019) "Greenhouse Gas Emissions, Energy Demand and Land Use Associated with Omnivorous, Pesco-Vegetarian, Vegetarian and Vegan Diets Accounting for Farming Practices." ScienceDirect. https://www.sciencedirect.com/science/article/abs/pii/S2352550919304920
This study compares the environmental impacts of various dietary patterns, finding that vegan diets have the lowest greenhouse gas emissions, energy demand, and land use. The results suggest that shifting to plant-based diets could substantially reduce energy demand in the food industry - vegan diets emitted 78% less GHG and required 53% less energy and 67% less land occupation than omnivorous diet.

5. Transportation

Vandycke N. et al. World Bank. (2022) "Defining the role of transport in the circular economy." World Bank Blogs.
https://blogs.worldbank.org/en/transport/defining-role-transport-circular-economy
This blog discusses how transitioning to a circular economy in the transportation sector could reduce emissions from vehicle materials by 70% by 2050, which equates to 285 million tons of CO2 equivalent. By designing lighter vehicles and improving material efficiency, the sector could significantly cut its carbon footprint.

Chang Su et al. (2021) "Circular economy for clean energy transitions: A new opportunity under the COVID-19 pandemic
https://www.ncbi.nlm.nih.gov/pmc/articles/PMC9758608/#:~:text=Circular%20economy%2C%20on%20the%20other,and%20establishes%20new%20business%20model.
The text, a paper published after the study of a 140,000 population town in China, illustrates how the circular economy can benefit the transport sector.

- Electrification and Battery Efficiency: The circular economy supports deeper electrification of the transport sector by promoting technologies like second-life batteries. These batteries enhance the profitability of electric vehicles (EVs), making them more attractive and potentially increasing their market share to 75% by 2040. With more EVs on the road, air quality improves due to reduced emissions from traditional combustion engines, and this transition could lead to a 22% reduction in PM2.5 emissions by 2040.
- Impact of COVID-19: The COVID-19 pandemic temporarily reduced industrial energy activities and associated emissions due to decreased economic activity. However, if the post-pandemic recovery follows pre-pandemic growth trajectories without incorporating circular economy principles, energy demand and CO2 emissions could exceed levels projected under a circular economy scenario.
- Circular Economy Post-Pandemic: Integrating circular economy strategies into the recovery phase can result in significant benefits. By adopting these strategies, energy savings and CO2 emission reductions can be enhanced. Specifically, from 2020 to 2040, the circular economy scenario could save 9.1 Mtoe of energy and 17.6 Mt of CO2 emissions, compared to 7.5 Mtoe and 13.8 Mt, respectively, without these strategies.

Circular economy contributes to reduced energy demand and emissions in the transport sector by fostering the use of efficient technologies like second-life batteries in EVs and by guiding sustainable practices in the post-pandemic recovery period.

Beyond transportation, the paper also references the percentage reduction of carbon emissions and energy use that could be benefited from switching away from coal use. “The new policy scenario inherits the activity trends from the business-as-usual scenario, and considers new energy efficient policies implementation. As Meili’s energy supply is heavily skewed towards coal, the local authority is seeking to curb the coal consumption and gradually move away from the reliance on coal. In the new policy scenario, energy demand growth of Meili further slows down to 0.6% per year. For non-ferrous industries, new energy efficient policies will be able to reduce the energy intensity by 3.9% per year”

Tolga Ercan, Nuri Cihat Onat, Omer Tatari, (2016)
Investigating carbon footprint reduction potential of public transportation in United States: A system dynamics approach
https://www.sciencedirect.com/science/article/abs/pii/S0959652616307284?casa_token=F988gEXngpEAAAAA:u1NEOE0TVFibebIc9Qa1C8p7DOzSG9T20AakdyQLvIgMx3qfYxhbxLGzwdXuwuo3oS1IR-WVFjV7

Increasing public transportation ridership by 9% has the potential to reduce CO2 emissions by 766,000 tonnes annually in 2050, whereas a 25% increase in ridership could potentially reduce cumulative CO2 emissions by 61.3 million tonnes.

World Health Organization, American Public Transportation Association (APTA), Environmental Protection Agency, Davis, Hale, Science Applications International Corporation (SAIC), & FTA. (2015). *Want a cleaner planet? Ride public transit*. https://labor4sustainability.org/wp-content/uploads/2019/02/ATU_MyTransitMatters_ClimateChange.pdf
Since 2014, 41.3% of public transportation buses in the U.S. are using alternative fuels or hybrid technology Public transit produces significantly less greenhouse gas emissions per passenger mile than single occupancy vehicles: Heavy rail – 76% less, Light rail – 62% less, and Bus – 33% less.

Cross sectoral policy recommendations
A recurring theme in these studies is the challenge of motivating end-users to adopt low energy demand scenarios. However, a recent study clarifies how this can be more effectively accomplished, particularly through the adoption of targeted policies. A summary is provided below:

Nemet G and Greene J (2022) “Innovation in low-energy demand and its implications for policy”
https://academic.oup.com/ooenergy/article/doi/10.1093/ooenergy/oiac003/6549049

Effective policy design for supporting Light Emitting Diode (LED) innovation necessitates a comprehensive approach that addresses both diffusion mechanisms and inclusivity. Historically, various policies, including regulations, standards, and financial incentives, have proven effective in promoting LED innovation. As LED technology advances, policies should not only focus on existing cost-effective solutions but also encourage technological progress and speed up adoption. This requires adopting systemic interventions that account for the feedback loop of knowledge throughout different stages of innovation and employing both technology push and demand pull strategies.

The diffusion of LED policies typically follows a pattern where early adopters trial new policies, which then leads to wider adoption as others observe successful implementations. This process mirrors technology diffusion and highlights the importance of policy experimentation and the sharing of knowledge among governments. Furthermore, policies must emphasize inclusivity by addressing the needs of low-income communities who spend a larger proportion of their income on energy and often face higher costs for efficient technologies. Ensuring that affordable LED options are accessible to these vulnerable groups is crucial.

Moreover, it establishes that policies should incorporate behavioral insights and support local learning mechanisms. Recognizing that energy users' preferences can change in response to incentives, and designing interventions that align with real-world behaviors, can significantly enhance LED adoption. Behavioral nudges, combined with monetary incentives, can effectively influence energy consumption. Local adaptation is essential, requiring policies to be tailored to specific contexts and support infrastructure development. National policies should facilitate local learning through grants, standards, and training. In summary, a successful approach involves both broad policy frameworks and localized strategies to achieve widespread and equitable adoption of LED technologies.

Steve Sorrell (2015) "Reducing energy demand: A review of issues, challenges and approaches"
https://www.sciencedirect.com/science/article/pii/S1364032115001471

Carbon pricing remains a key tool, raising fossil fuel prices to reflect their true costs, including pollution. However, this research paper posits that carbon pricing alone is insufficient due to political constraints and its effects on income distribution. Complementary measures, like recycling revenue to lower taxes or support vulnerable groups, can make carbon pricing more politically acceptable.

Non-price barriers also limit energy efficiency adoption. Organizational staff may lack information or incentives, and these challenges are more significant for households. Policies like minimum efficiency standards, labeling, subsidized energy audits, and building regulations can address these barriers. Though the impact of such policies is difficult to measure, they are generally effective and cost-efficient.

Behavioral insights enhance policy by addressing why energy-efficient options are often ignored. Information should be framed as preventing a loss, default settings should be energy-efficient, and energy use should be benchmarked against peers. Trusted messengers and salient information further influence behavior. While these "nudges" alone cannot create a low-energy future, they can complement traditional policies.

Supporting the adoption of novel energy-efficient technologies is crucial. These technologies often face high costs and market barriers. Targeted support like R&D subsidies, demonstration programs, and public procurement can help overcome these challenges. However, current support tends to favor energy supply over demand.

A comprehensive policy approach should combine carbon pricing, interventions to reduce non-price barriers, behavioral nudges, and support for new technologies. These strategies are mutually supportive; for example, higher prices can drive low-energy innovation, while behavioral interventions can make energy-efficient investments more appealing. Though elements of this strategy exist, they often lack coherence and sufficient political support, limiting their impact. Achieving more radical changes in the coming decade requires a holistic approach and a focus on transforming the systems that provide energy services.

Dianne Hondeborg, Benedict Probst, Ivalin Petkov, Christof Knoeri (2023)
The effectiveness of building retrofits under a subsidy scheme: Empirical evidence from Switzerland, Energy Policy https://www.sciencedirect.com/science/article/pii/S0301421523002653
The passage underscores the critical role of policy in reducing energy use through urban densification, presenting it as a strategy to counteract urban sprawl. It notes that these policies were introduced to "combat urban sprawl and single-use settlements," highlighting their importance in promoting sustainable growth. The concept of the compact city is positioned as the "most sustainable model to pursue," which further emphasizes the necessity of effective densification strategies.
However, the passage also reveals the complexities involved in implementing these policies, including political, economic, and social challenges, with resistance from residents and local authorities posing significant obstacles. The three types of densification policies—soft, hard, and flexible hard—demonstrate varied approaches to increasing urban density, each with distinct implications for energy use and community dynamics.
The European Commission's goal of "no net land take" by 2050 reflects a growing recognition among policymakers of the importance of densification for sustainable urban development. The passage ultimately stresses that achieving successful densification requires "careful and inclusive planning" to address potential social and environmental issues, emphasizing that policy frameworks are vital in realizing the benefits of urban densification for energy reduction.

Xueyuan Zhao, Weijun Gao, Fanyue Qian, Jian Ge, (2021)
Electricity cost comparison of dynamic pricing model based on load forecasting in home energy management system, Energy.
https://www.sciencedirect.com/science/article/pii/S0360544221007878?casa_token=2U6McrWUgJEAAAAA:2NChBzTueDYyBXKBRmxnA56C5pXL3LTZ5EmoPfOARYK4E0mOYA8bKTqdUQ4kCsRBxjS7JgNXMS-Y
Japan has successfully addressed its energy shortage by implementing policies focused on residential energy conservation and emission reduction, notably through the Home Energy Management System (HEMS). This system connects users with power companies, facilitating energy visualization and consumption management. In a study involving the "Jono Zero Carbon Smart Community," a forecasting model was developed to predict daily energy use based on historical data, alongside a dynamic pricing model to influence consumer behavior. The research demonstrated that real-time pricing (RTP) resulted in lower annual electricity costs compared to multistep pricing (MTP) and time-of-use pricing (TOU), offering significant economic advantages. By optimizing energy consumption patterns and aligning them with fluctuating electricity prices, the findings suggest that similar strategies implemented in the USA could significantly reduce consumer energy use and promote more efficient energy management, ultimately contributing to sustainability goals.