How Dynamic Pricing Models Influence the Economic Attractiveness and Acceptance of Energy Sharing in Rural and Urban Regions

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Abstract: - Germany's energy transition goals represent a fundamental transformation of the national energy supply, closely tied to the expansion of renewable energies and increased energy efficiency. Dynamic pricing models are considered promising tools to support the shift to a more sustainable and decentralized energy system by adjusting demand to fluctuating renewable energy production through flexible pricing structures. At the same time, the concept of energy sharing allows communities—ranging from neighborhoods to municipalities and entire districts—to collectively use locally generated energy, thus promoting self-sufficiency and sustainable grid relief. This study examines the potentials and challenges arising from the combination of dynamic pricing models and energy sharing, particularly focusing on economic efficiency, consumer acceptance, and the specific requirements in urban and rural areas. The goal is to analyze best practices and challenges to highlight how dynamic pricing models can optimize energy use in decentralized community systems and accelerate the energy transition at the municipal level.

Key-Words: - Dynamic pricing models, decentralized energy supply, energy sharing, prosumer, renewable energies, smart grids

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1 Introduction

With the implementation of the energy transition, Germany has set ambitious goals to establish a sustainable and largely decarbonized energy supply. Key pillars of this transformation are the expansion of renewable energy sources and the promotion of energy efficiency. However, the fluctuating production from sources like solar and wind power presents significant challenges to the previously centralized energy system. Here, new concepts like energy sharing and dynamic pricing models offer potential solutions, enabling active consumer participation and strengthening decentralized self-sufficiency. Dynamic pricing models provide flexible rates that vary according to supply and demand, encouraging consumers to adapt their consumption patterns.

Energy sharing enables communities to use locally generated energy collectively, offering significant advantages for energy supply at the municipal level. This study explores how dynamic pricing models can support the success of such communal models by improving economic efficiency and creating additional incentives for sustainable energy use. Furthermore, it examines regional differences in acceptance and feasibility in urban and rural areas to shed light on the diverse challenges and opportunities.

2 Dynamic Pricing Models: Basic and Implementation Approaches

Dynamic pricing models offer rates that reflect current market conditions and net-work requirements, making the price structure flexible in response to supply and demand. These models generally fall into three main categories:

- Time-of-Use (ToU) tariffs: Prices vary during specific times of the day in predefined blocks. Typically, prices are higher during peak demand times and lower during off-peak periods like nighttime
- Real-Time Pricing (RTP): Prices change in short intervals, often hourly, based on the current network load and production costs, providing

consumers with high flexibility and reflecting market prices.

- Demand Response: Consumers are incentivized to reduce or shift their energy consumption during peak network demand times, usually through dis-counts or rewards.

The implementation of dynamic pricing models requires technology infrastructure for accurate, real-time measurement and billing of energy consumption, especially through smart meters and smart grids.

3 Energy Sharing: Definition, Mechanisms, and Opportunities

Energy sharing involves the collective use of locally produced energy within defined groups, such as neighborhoods or municipalities. The aim is to optimize decentralized generation, such as photovoltaic or wind installations, and reduce grid stress by distributing locally produced electricity. This concept promotes self-sufficiency and increases awareness of sustainable energy use. Energy sharing mechanisms typically include:

- Cooperative usage: Collective ownership and use of energy systems reduce investment costs for individuals, making renewable energy accessible even to those with limited financial resources.
- Self-consumption optimization: Communities can lower their energy costs by maximizing self-consumption and feeding excess energy back into the grid at favorable terms.
- Flexibility distribution: Energy sharing communities rely on systems that allow flexible distribution and storage of energy, supported by technologies like battery storage and time-varying tariffs.

3.1 Potentials of Dynamic Pricing Models in Energy Sharing

When Dynamic pricing models and energy sharing complement each other in several ways, helping to maximize both financial and ecological benefits by encouraging consumption when prices are low and renewable energy availability is high. Specific benefits include:

- Cost reduction through flexible usage: Dynamic pricing enables consumers to use cheap energy during off-peak times, which is particularly relevant for communities with high self-consumption.
- Efficiency increase through grid integration: Energy sharing depends on local renewable energy, which is variable. Dynamic prices help adjust consumption to the availability of this energy, leading to more stable grid usage and reducing the need for grid upgrades
- Increased participation willingness: Consumers are more likely to accept sustainable energy solutions when they can see direct financial benefits. Dynamic pricing offers clear incentives for participants to shift their consumption to lower tariff periods.

3.2 Regional Differences in Implementation: A Comparsion of Urban and Rural Areas

The implementation of dynamic pricing models and energy sharing varies significantly depending on the regional context:

- Urban areas: Cities often have dense populations and high energy density, facilitating the introduction of dynamic pricing models and energy sharing. Urban areas typically have well-developed networks and the infrastructure necessary for smart metering, making dynamic pricing easier to implement. Additionally, short transport distances and opportunities for battery storage at multiple locations support urban energy-sharing models.
- Rural areas: These regions often have a higher presence of renewable generation sources, like wind and solar farms, making them particularly suited for energy sharing. Dynamic pricing models can work effectively here as consumers can adjust their usage to match energy availability. However, challenges include less developed grid infrastructure, higher costs for

individual investments, and sometimes a lack of smart metering systems.

3.2.1 Urban Area

Figure 1
Multifamily House in an Urban Area (house 1)

Figure 2
Multifamily House in an Urban Area (house 1,2)

Table 1 Assumption: Multifamily House

Assumption: Multifamily House	
Electricity consumption:	159077,548 kWh
Number of people:	45
House size:	3980 qm²
Battery capacity:	0
PV system capacity:	0
EVCI:	196,734 kWh
Gas:	117781,178 kWh

The multi-family house, built in 2020 to the highest energy standards, provides living space for 45 residents across a total area of 3,980 m². Despite its modern construction, the building has a considerable annual energy consumption: electricity usage stands at 159,077.548 kWh, while gas consumption is also significant at 117,781.178 kWh. Since no photovoltaic (PV) system is installed, the entire electricity demand is covered by the public grid, which has both economic and environmental implications.

The building is equipped with an electric vehicle charging infrastructure (EVCI), but its annual consumption is relatively low at 196.34 kWh. This suggests that few residents currently use electric vehicles or that the charging points are only used sporadically.

As the building was constructed to the highest energy efficiency standards, further energy-saving measures are somewhat limited but still possible. One potential improvement could be the implementation of an intelligent energy management system that monitors energy consumption in real time and helps reduce peak loads. Additionally, the use of energy-efficient household appliances, smart lighting systems, and raising residents' awareness of energy-conscious behavior could contribute to further reducing electricity usage.

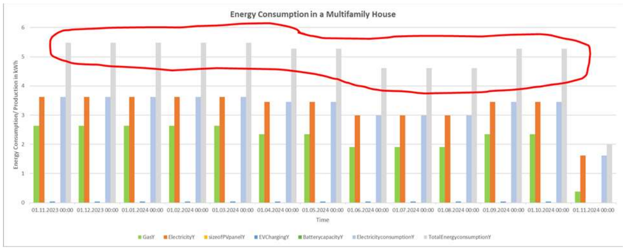

Figure 3
Energy Consumption Multifamily House in an Urban Area (house 1)

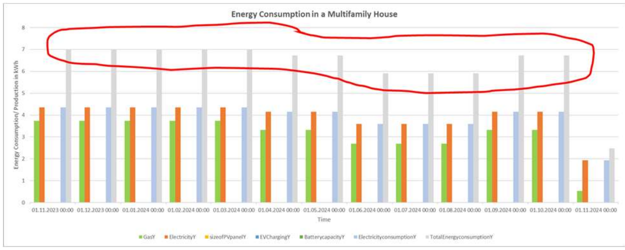

Figure 4
Energy Consumption Multifamily House in an Urban Area (house 2)

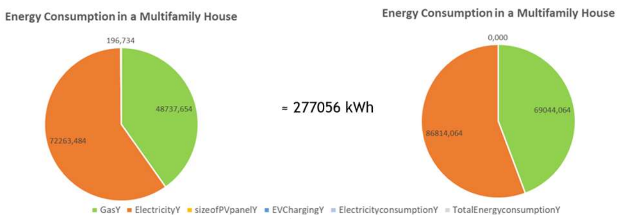

Figure 5
Energy Consumption Multifamily House in Comparison
green: Gas orange: Electricity

These two residential buildings, which together form the multi-family house, have approximately the same energy consumption in relation to their size. This suggests that energy usage is evenly distributed across both buildings, with no significant differences in consumption patterns.

One important factor is the structural design of the roofs, particularly the presence of roof windows. Due to this construction, installing a photovoltaic (PV) system on the building would not be economically viable. The available space is insufficient for a PV system large enough to provide a noticeable benefit in terms of self-generated electricity. Even if some roof areas were utilized, the energy yield would be too low to justify the investment costs.

Since there is no PV system, investing in a battery storage unit would also make little sense at this time. A battery storage system is most effective when paired with self-generated electricity, maximizing self-consumption and reducing reliance on the public grid. Without a PV system, the battery would need to be charged primarily with grid electricity, limiting both its financial advantages and environmental benefits.

However, a potential future optimization could be achieved through the implementation of an intelligent energy management system. Such a system would allow for the effective use of dynamic electricity tariffs. Dynamic tariffs enable electricity consumption to be shifted to periods when prices are lower, such as at night or when there is a high share of renewable energy in the grid. Over time, this could significantly reduce energy costs.

In a well-developed urban infrastructure, where modern energy networks and smart control systems are becoming increasingly common, the use of smart meter gateways presents a highly effective solution. These gateways allow for more precise monitoring and control of energy consumption within individual residential units. Through automation, household appliances or heating systems could be operated during periods of lower electricity prices without requiring active intervention from residents.

In summary, while the multi-family house already meets high energy standards, there is still potential for further optimization through the targeted use of intelligent technologies. The adoption of dynamic tariffs and smart energy consumption management could lead to more efficient and cost-effective energy use, even without a PV system or battery storage.

3.2.2 Rural Area

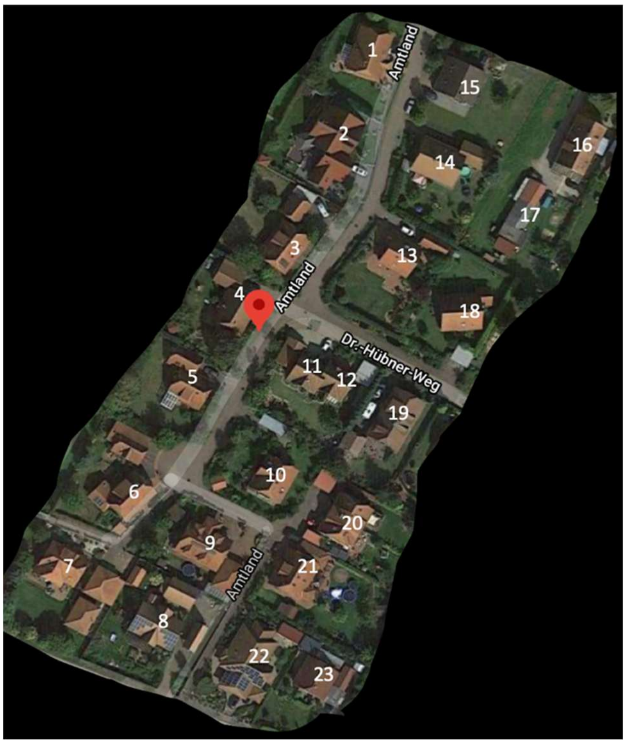

Figure 6
Overview Neighbourhood Amtland

The Amtland neighborhood consists of 23 single-family homes with a total of 45 residents. The houses were built between 1995 and 2000, meaning that the average age of the buildings is approximately 25 years. This construction period falls within a time when energy efficiency standards were already a consideration but were not yet as strongly focused on renewable energy sources as they are today.

The heating systems in the houses are entirely gas-powered, which was a common solution for buildings of that era. Gas heating was considered efficient and economically attractive, especially in well-developed residential areas with direct access to the gas network. The electricity supply for the households comes exclusively from the public grid, with no on-site generation systems such as photovoltaic (PV) systems or other decentralized energy sources.

In the late 1990s and early 2000s, the installation of photovoltaic systems and solar thermal systems for hot water production was associated with very high investment costs. At that time, solar technology was not yet widely adopted, and the costs of purchasing solar panels, inverters, and storage technologies were significantly higher compared to today. Additionally, government incentive programs for renewable energy were not as attractive as they are now. In many cases, the economic feasibility and profitability of such systems were uncertain or only marginal, leading many homeowners to decide against investing in them.

Table 2 Assumption: Neighbourhood Amtland old

Assumption: Neigbhourhood old	
Electricity consumption:	89187,856 kWh
Number of people:	45
House size:	3980 qm²
Battery capacity:	0
PV system capacity:	0
EVCI:	196,734 kWh
Gas:	363421,026 kWh

Table 3 Assumption: Neighbourhood Amtland new

Assumption: Neigbhourhood new	
Electricity consumption:	60587,094 kWh
Number of people:	45
House size:	3980 qm²
Battery capacity:	274 kWh
PV system capacity:	135140,620 kWh
EVCI:	196,734 kWh
Heatpump:	96017,705 kWh

The Amtland neighborhood consists of 23 single-family homes with a total of 45 residents. The buildings were constructed between 1995 and 2000, meaning their average age is approximately 25 years.

In their original design, heating was provided entirely by gas, while electricity was sourced directly from the public grid. At that time, renewable energy solutions such as photovoltaic (PV) systems or solar thermal installations played a minor role due to high investment costs and a lack of attractive subsidies.

A comparison between the original energy supply and the modernized system reveals significant improvements. Before renovation, the annual electricity consumption of the entire neighborhood was 89,187.856 kWh, while gas consumption for heating amounted to 363,421.026 kWh. Following modernization, gas heating systems were completely replaced with heat pumps, eliminating gas consumption entirely. Instead, the heat pumps now require 96,017.705 kWh of electricity. Combined with improved building insulation, this enables a far more energy-efficient and sustainable heating solution. Despite the additional electricity demand for heat pumps, overall electricity consumption was reduced to 60,587.094 kWh—a reduction of 32.1% compared to the original state.

A key factor in this increased energy efficiency is the installation of a high-performance photovoltaic system with a capacity of 135,140.620 kWh. This allows a substantial portion of the electricity demand to be met through renewable sources, significantly reducing dependency on the public grid. Additionally, a battery storage system with a capacity of 274 kWh was installed to store excess solar energy, ensuring availability during periods of low sunlight.

Thanks to the combination of PV generation and battery storage, the total electricity demand from the public grid for the renovated homes has been reduced to just 21,660.374 kWh. In comparison to the original situation, where the entire electricity demand of 89,187.856 kWh was drawn from the grid, this represents a remarkable 75.7% reduction. This drastic decrease demonstrates the effectiveness of modern energy management with renewable technologies.

Beyond environmental sustainability, residents also benefit financially. The reduced reliance on grid electricity lowers exposure to rising energy prices, leading to long-term cost savings. Combined with the integration of heat pumps and improved energy efficiency, this comprehensive modernization optimizes overall energy consumption and positions the Amtland neighborhood for a more sustainable and future-proof energy supply.

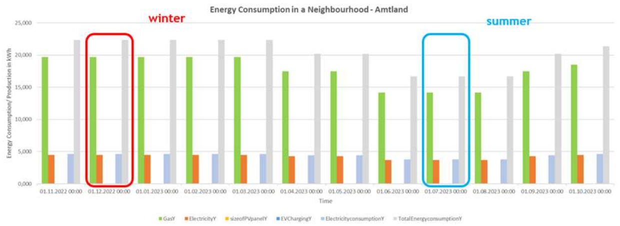

Figure 7
Energy Consumption Multifamily House in an Urban Area (house 1)

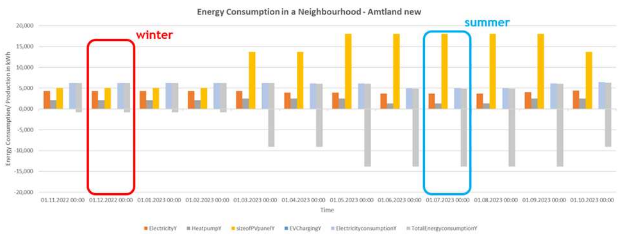

Figure 8
Energy Consumption Multifamily House in an Urban Area (house 1)

Energy consumption is higher in winter than in summer, as shown in Figures 7 and 8. It is important to mention that, despite the well-developed renewable energy infrastructure in Amtland, the houses achieve an autonomy of approximately 60% during the winter months. This means that while a significant portion of the required electricity can be generated locally, some energy still needs to be drawn from the public grid, especially during peak consumption periods.

In contrast, during the summer months, the photovoltaic (PV) system generates a surplus of energy. Due to the high solar power production, more electricity is generated than consumed, allowing the excess energy to be fed into the grid. These seasonal fluctuations highlight the benefits of a battery storage system, which helps balance supply and demand more effectively.

In the old Amtland energy system, there was complete dependence on external energy sources. Without the integration of renewable energies, both electricity and heating had to be entirely supplied through the public grid and gas infrastructure. This made the neighbourhood fully reliant on fluctuating energy prices and fossil fuels. Through modernization measures, energy independence has been significantly increased, and supply security has been improved, particularly during the high-demand winter months.

3.2.3 Comparison Urban and Rural Area

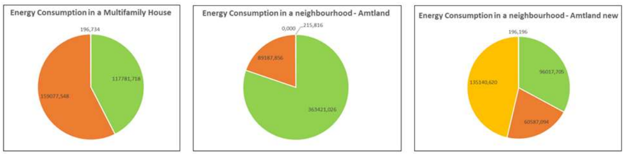

Figure 9
Energy Consumption Multifamily House (1/ 2), Single Family House (old/ new) green: Heating orange: Electricity Consumoption yellow: PV Production

A comparison between the multi-family house in the city and the old and modernized single-family homes in Amtland reveals significant differences in energy supply, driven by both structural and infrastructural factors. The urban multi-family house, with 45 residents and a total area of 3,980 m², has an annual electricity consumption of 159,077.548 kWh and a gas consumption of 117,781.178 kWh. Since no photovoltaic (PV) system is installed, the entire electricity demand is covered by the public grid, making the residents fully dependent on energy prices and grid fluctuations.

In its original construction, the rural Amtland neighbourhood was also highly dependent on the grid. The annual electricity consumption was 89,187.856 kWh, while heating with gas required 363,421.026 kWh. Through comprehensive energy modernization, gas heating systems were replaced with modern heat pumps, which now consume 96,017.705 kWh of electricity. At the same time, a high-performance photovoltaic system with a capacity of 135,140.620 kWh was installed, supplemented by a 274 kWh battery storage unit. This led to a drastic reduction in grid electricity consumption to only 21,660.374 kWh, as most of the required energy can now be covered by self-generated power.

During the summer months, the Amtland homes generate more energy than they consume, allowing surplus electricity to be fed into the grid. In contrast, energy consumption is significantly higher in winter due to increased heating demand, preventing full self-sufficiency. However, even in colder months, the modernized homes achieve an autonomy rate of around 60%. Meanwhile, the multi-family house in the city remains fully dependent on the electricity and gas grid throughout the year, as it lacks its own energy generation system.

The key difference between urban and rural areas lies in energy infrastructure and the feasibility of renewable energy utilization. Cities benefit from a stable grid supply, but due to limited roof space and higher energy demand per square meter, the expansion of PV systems is often less economical or technically feasible. In contrast, rural areas offer larger spaces for solar installations, allowing for a higher degree of self-sufficiency. Additionally, urban areas often face complex approval procedures and regulatory restrictions that hinder energy-efficient renovations.

The modernization of the Amtland neighbourhood demonstrates that targeted investments in renewable energy not only drastically reduce grid electricity consumption but also lower long-term energy costs. While urban multi-family homes remain more reliant on external energy sources, rural regions benefit from decentralized generation and storage technologies, leading to greater independence from rising energy prices. This highlights the need for tailored solutions for both urban and rural areas to ensure a successful energy transition that accommodates specific infrastructural conditions.

3.3 Challenges in Implementing Dynamic Prices in Energy Sharing

The combination of dynamic pricing models with energy sharing presents several challenges:

- Infrastructure requirements: Widespread implementation of dynamic pricing models requires a robust infrastructure, particularly smart meters and grids, which can be costly and hindered by regulatory barriers.
- Regulatory framework: Clear rules are needed for price setting and consumer protection to ensure fair conditions and prevent exploitation.
- Technological barriers: Digitalization of households is essential for dynamic pricing models to function effectively, but rural areas may lack the necessary network and communication infrastructure.
- Acceptance issues and social inequality: Dynamic pricing may disadvantage low-income households that cannot easily adjust their consumption patterns, leading to acceptance problems. Support programs or social tariffs could address these issues.
- Complexity and user-friendliness: Dynamic tariffs can be confusing for consumers, requiring new understanding and technical equipment. User-friendly platforms and educational campaigns can help improve acceptance.
- Interoperability and privacy: Ensuring compatibility between systems from different providers and protecting consumer data in accordance with the GDPR is crucial for successful implementation.

4 Case Studies and Examples of Successful Implementation

Several national and international case studies highlight how dynamic pricing models can be successfully integrated into energy sharing systems:

- Energiegemeinschaft Oberland (Germany): A rural energy community that uses a combination of local wind and solar power with battery storage, optimizing self-consumption and feeding excess energy into the grid at peak times. Dynamic pricing helps increase efficiency and convenience for members.
- Quartier Vauban in Freiburg (Germany): An urban district that combines energy sharing and dynamic pricing to achieve a CO_2-neutral energy supply. By linking photovoltaic systems, battery storage, and heating networks, residents can adjust their energy use to match production, benefiting from financial incentives to consume energy when it's abundant.
- Brooklyn Microgrid (USA): A blockchain-based platform that allows residents to buy and sell locally generated energy. Dynamic pricing helps manage demand, while blockchain ensures transparency and security.

5 Recommandations and Solutions for Introducting Dynmaic Pricing Models in Energery Sharing

Based on the identified potentials and challenges, the following recommendations can help promote the implementation of dynamic pricing models in energy sharing:

1) Promotion and expansion of technological infrastructure: A nationwide rollout of smart meters and grids is critical for the success of dynamic pricing. Government funding could accelerate this process, especially in rural areas.
2) Regulatory support and clear frameworks: A transparent legal framework is needed to ensure fairness and encourage investment in energy-sharing models.
3) User-friendly platforms and education: To improve acceptance, user-friendly applications should be developed that help consumers manage their energy use and take advantage of dynamic pricing.
4) Social fairness considerations: Dynamic pricing models should be designed to ensure that low-

income households also benefit, through reduced tariffs or targeted subsidies.

5) Pilot projects and stakeholder collaboration: Pilot projects and cooperation between local authorities, energy providers, and consumers will provide valuable insights and increase acceptance.

6 Conclusion

Germany's energy transition requires innovative approaches to enable sustainable, decentralized energy supply. Dynamic pricing models combined with energy sharing can play a central role in promoting more efficient energy use and greater consumer responsibility. The benefits, including cost savings, grid stability, and increased acceptance, are substantial. However, addressing the necessary technological and regulatory conditions, as well as ensuring social fairness, remains a challenge. Pilot pro-jects like the Energiegemeinschaft Oberland and Quartier Vauban show that successful examples already exist and can serve as models for broader implementation. The integration of advanced technologies like blockchain and artificial intelligence could further increase efficiency and acceptance, providing more precise control over energy consumption. Ultimately, the involvement of consumers and the promotion of acceptance will be critical to the success of these new approaches, contributing significantly to Germany’s energy transition and sustainable energy future.

Urban and rural areas each present unique challenges and opportunities when it comes to the energy transition, which requires a balance between renewable energy generation, infrastructure, and consumption patterns.

Urban Areas:

In urban areas, there is limited space for installing renewable energy components such as solar panels or wind turbines due to the high population density and constrained building structures. This results in a higher energy consumption relative to generation. However, urban environments are particularly well-suited for the implementation of smart technologies, as the relatively short transport distances allow for efficient energy distribution.

Dynamic pricing and energy-sharing models work particularly well in urban multi-family buildings, where the energy consumption patterns of many households can be optimized collectively. Smart meters and advanced infrastructure enable these solutions to be deployed effectively. These technologies allow for more efficient energy use and cost savings, helping to reduce the strain on the grid while promoting consumer responsibility.

Rural Areas:

Rural areas, in contrast, typically have a higher availability of renewable energy sources, such as wind and solar power, making them more favorable for energy generation. These areas often have a more balanced ratio of energy generation to consumption, which makes decentralized energy systems more viable. However, rural regions face challenges in terms of grid infrastructure, which is often less developed and can be a barrier to energy distribution. The high costs of implementing decentralized systems, such as energy storage and the necessary infrastructure, make it more expensive to fully integrate renewable energy sources.

Despite these challenges, rural areas offer significant potential for larger investments in renewable energy, as the natural resources for energy generation are more abundant. The investment required to upgrade the grid and establish decentralized systems could result in long-term benefits, both in terms of energy security and sustainability.

Conclusion:

Both urban and rural areas have distinct advantages and limitations when it comes to the energy transition. Urban areas benefit from smart technologies and shorter transport distances, making them ideal for solutions like dynamic pricing and energy-sharing in multi-family buildings. However, space limitations and high consumption relative to generation pose challenges.

Rural areas, on the other hand, benefit from a more favorable energy generation-to-consumption ratio and abundant renewable resources. However, they face significant challenges due to underdeveloped grid infrastructure and high decentralization costs.

To achieve a successful energy transition, both areas require technological innovation, appropriate infrastructure investment, and a fair distribution of resources. By tailoring solutions to the specific needs of each area, it is possible to create an energy system that is both sustainable and equitable.

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