ESTABLISHING A UTILITY-SCALE ENERGY COMMUNITY IN SINES

Jorge Paraíba

Dissertação apresentada para cumprimento parcial dos requisitos para a obtenção do grau de Mestre em Mestrado Executivo em Inovação e Transformação Digital (Innovation and Digital Transformation) na Universidade Católica Portuguesa.

Abril de 2025

Dissertação escrita sob a supervisão do Professor Paulo Cardoso do Amaral.

INDEX

Acknowledgements 3

CASE STUDY

Abstract 4

Introduction 5

Background and Context 6

Business Model and Financial Structure 10

Challenges and Solutions 11

Municipality's Role and Long-Term Strategy 13

Conclusion 14

References 16

Appendices 19

TECHNICALL ANNEX

Case Synopsis 22

Classroom Implementation Guide 22

Recommended Teaching Approach 23

Analysis and Application of Theories 24

Selected Discussion Questions 26

Financial Structure and Potential Results 30

Required Additional Information 31

Conclusions 32

Glossary of Technical Terms (teaching handout) 34

Acknowledgments

I sincerely thank everyone who supported me in completing this executive master's thesis. My deepest gratitude goes to my thesis advisor for their expert guidance and patience. Special thanks to Professor Doutor Paulo Cardoso do Amaral for his inspiring and disruptive approach, and to Mr. Afonso Salema for his invaluable insights in the early stages and to Mr. João Manso Neto for his visionary influence. Heartfelt thanks to my professors, colleagues, friends, and family for their encouragement and understanding. Lastly, I acknowledge the broader academic community for providing the theoretical foundation that shaped my research. Your contributions have been invaluable to my academic and professional growth.

Case Study: Establishing a Utility-Scale Energy Community in Sines

Abstract

This case study investigates the strategic and operational feasibility of establishing a Utility-Scale Energy Community (USEC) in the Municipality of Sines, Portugal—a region undergoing rapid industrial growth and an accompanying surge in energy demand. Traditionally known as a pivotal industrial and maritime hub, Sines is now the site of major infrastructure investments, including large-scale data centers, battery production facilities, hydrogen and green steel plants, and expanded port operations. In parallel, the region is witnessing significant deployment of renewable energy assets, such as solar parks and offshore wind projects, which present a timely opportunity to reimagine its energy system.

A USEC presents an innovative approach to energy governance by decentralizing production, promoting local consumption, and integrating renewable energy through smart grid infrastructure. Unlike conventional centralized systems, this model enhances local energy resilience, improves economic circularity, and empowers municipalities to directly influence energy pricing, access, and sustainability outcomes. The closure of the country's largest coal-fired power station in Sines in 2021 has further accelerated the region's transition toward a cleaner, more distributed energy paradigm.

Drawing on the context of Sines, this thesis explores the potential role of municipal leadership in spearheading a USEC. It examines governance models, financing mechanisms, stakeholder engagement strategies, and regulatory barriers. The study also considers broader questions around equitable energy access, long-term affordability, and integration with national and European climate goals. By presenting a structured decision-making framework and highlighting key trade-offs, the case study offers practical insights for policymakers and energy planners seeking to scale utility-scale energy communities in industrialized regions.

Introduction

As global energy systems transition toward decarbonization and decentralization, municipalities are increasingly taking a critical role in energy governance. The shift from centralized fossil fuel grids to localized renewable energy production has accelerated the need for innovative, sustainable, and resilient energy models.

A Utility-Scale Energy Community (USEC) is a self-sustaining energy ecosystem that enables municipalities, renewable energy producers, and industrial consumers to collaborate in energy generation, storage, and consumption. Unlike small community energy projects that primarily serve residential prosumers, a USEC operates at an industrial scale, integrating solar farms, offshore wind, hydrogen production, battery storage, and smart grids. This model reduces reliance on national utilities, stabilizes prices, and strengthens local economic resilience by ensuring that energy is produced and consumed locally while keeping economic benefits within the region.

For Sines, a municipality experiencing rapid industrial expansion, a USEC provides a forward-thinking energy strategy that aligns economic growth with sustainability goals. The closure of the 1.2 GW coal-fired power plant in 2021 was a major step toward Portugal's decarbonization objectives, significantly improving environmental conditions. However, this transition also resulted in significant workforce displacement and economic uncertainty. At the same time, energy demand is surging, driven by industrial expansion in data centers, hydrogen hubs, steel manufacturing, and logistics infrastructure. Without a structured energy governance model, Sines risks rising energy costs, supply instability, and missed economic opportunities.

To effectively implement a USEC, the Municipality of Sines must consider several key dimensions:

- Policy and regulatory frameworks: Ensuring compliance with Portuguese and EU energy regulations (such as RED II) while advocating for favorable policies that support decentralized energy communities.
- Infrastructure and investment planning: Developing grid modernization strategies, energy storage solutions, and smart grid technologies to ensure efficiency and long-term scalability.
- Public-private partnerships: Engaging industrial stakeholders, energy producers, and technology providers to share costs, risks, and benefits.
- Land-use and zoning policies: Allocating space for renewable energy projects, transmission infrastructure, and industrial expansion while maintaining environmental sustainability.
- Community and workforce development: Providing training programs, incentives for new residents, and housing expansion to accommodate the growing workforce driven by new energy-intensive industries.

By leveraging these strategic dimensions, Sines can establish a USEC that not only addresses rising energy demand but also fosters economic stability, job creation, and long-term sustainability.

Background and Context

Energy communities have emerged as a critical component of the global transition toward decentralized energy systems. Initially introduced in response to rising energy costs, grid inefficiencies, and the need for sustainable local solutions, energy communities have become increasingly prevalent across Europe. These models, supported by EU policies such as the Renewable Energy Directive (RED II), allow consumers to generate, share, and store energy within defined geographical areas. Over time, energy communities have evolved from small residential collectives into large-scale, industrial-oriented ecosystems, now known as Utility-Scale Energy Communities (USECs).

Energy Communities in Portugal

In Portugal, the adoption of energy communities has accelerated in recent years, driven by regulatory incentives, advancements in smart grid technology, and corporate sustainability commitments. Many municipalities and industrial hubs have embraced energy communities as a way to lower costs, improve energy independence, and enhance local economic resilience. The decentralization of energy markets has allowed regions to reduce reliance on national grid operators and volatile wholesale electricity pricing, ensuring a more stable and predictable energy supply.

Portugal has been rapidly expanding its energy communities, with a growing number of projects being developed under the regulatory framework set by Decree-Law No. 162/2019. According to the latest reports:

- Over 100 energy communities are currently operational or in development across the country.
- The regions with the highest concentration of energy communities include Lisbon, Porto, and Évora, with new initiatives emerging in industrial zones like Sines.

Sines has historically been a key energy hub in Portugal, with its coal-fired power plant playing a major role in national electricity supply. Following its decommissioning in 2021, the municipality has shifted its focus toward renewable energy and industrial sustainability. Investments in solar farms, offshore wind projects, hydrogen production, and battery storage have created new opportunities for a decentralized energy model, ensuring that economic and environmental benefits remain within the region.

A Utility-Scale Energy Community (USEC) in Sines would integrate these renewable energy assets into a cohesive framework, reducing dependence on the national grid, stabilizing electricity prices, and promoting direct energy transactions between local producers and consumers. This model maximizes energy efficiency, cost reductions, and local reinvestment, reinforcing economic circularity by keeping energy revenues within the local economy.

Smart Cities and Energy Optimization

The Smart City concept integrates digital infrastructure, IoT solutions, and automated energy management to improve energy efficiency and sustainability. The Évora Smart City project, led by EDP, serves as a reference model, showcasing:

- A 15% reduction in energy consumption through real-time monitoring.

- Integration of microgrids, enabling localized energy balancing and resilience.
- Adoption of demand-side response technologies, allowing users to adjust consumption based on grid signals.

These elements could be adapted to the Sines USEC, leveraging smart grid capabilities to optimize energy flow and enhance stability in the industrial region.

The Role of Microgrids in Energy Decentralization

Microgrids are small-scale energy systems that operate either independently or in connection with the main grid. Their benefits include:

- Enhanced energy resilience, ensuring industrial and residential consumers have a stable power supply.
- Optimization of renewable energy use, integrating solar and wind power efficiently.
- Reduced transmission losses, as energy is consumed closer to where it is generated.

By implementing microgrids within the USEC, Sines can improve grid stability, reduce dependency on external sources, and enhance energy autonomy.

Renewable Energy Growth in Portugal (APREN & REN Data)

Year	Solar (MW)	Wind (MW)	Hydro (MW)	Total Renewable (MW)
2020	1 000	5 400	7 100	13 500
2025	3 500	6 200	7 200	16 900
2030	6 000	7 000	7 500	20 500
2035	8 500	7 500	7 800	23 800

The expected growth in renewable capacity aligns with Portugal's National Energy and Climate Plan (PNEC 2030), reinforcing the viability of the USEC model.

Energy Consumption Growth in Sines (Projected 2024-2034)

Year	Energy Consumption (GWh)
2024	350
2025	1 500
2026	3 200
2027	5 500
2028	8 400
2029	11 800
2030	14 500
2031	16 200
2032	18 000
2033	19 500
2034	20 000

Environmental and Licensing Considerations (APA & DGEG Data)

Licensing for Renewable Projects in Sines

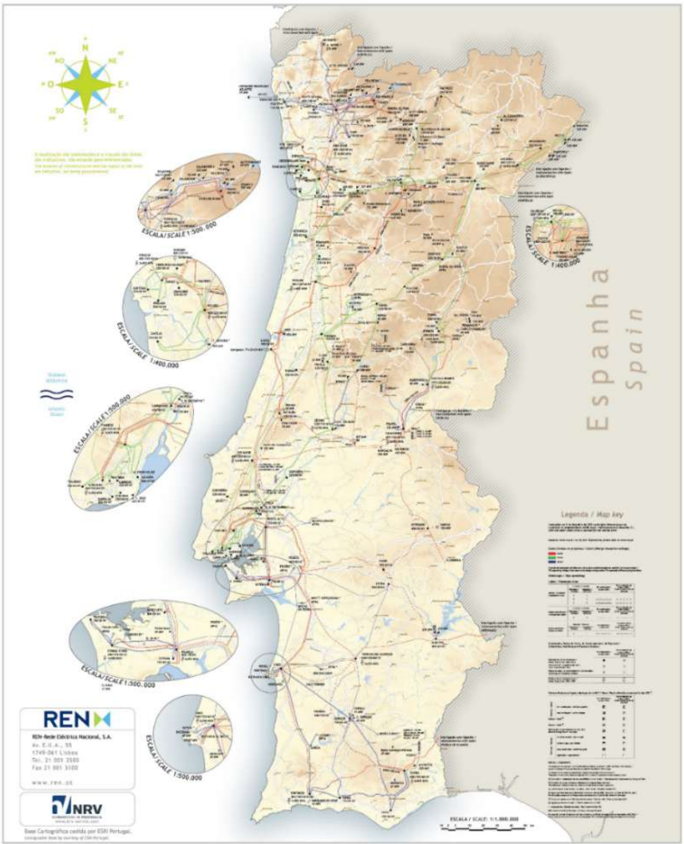
- According to the Portuguese Environmental Agency (APA), Sines has 12 active renewable energy licenses, including solar, wind, and hydrogen projects.
- The DGEG (Directorate-General for Energy and Geology) has identified Sines as a priority region for grid reinforcement, with new high-voltage 400kV transmission lines planned to accommodate increased production.

Energy Transport Infrastructure Expansion (REN Data)

The expansion of the 400kV transmission network is a key enabler for renewable energy development in Sines. REN (Redes Energéticas Nacionais) has planned significant upgrades to ensure the region can handle increased energy flow:

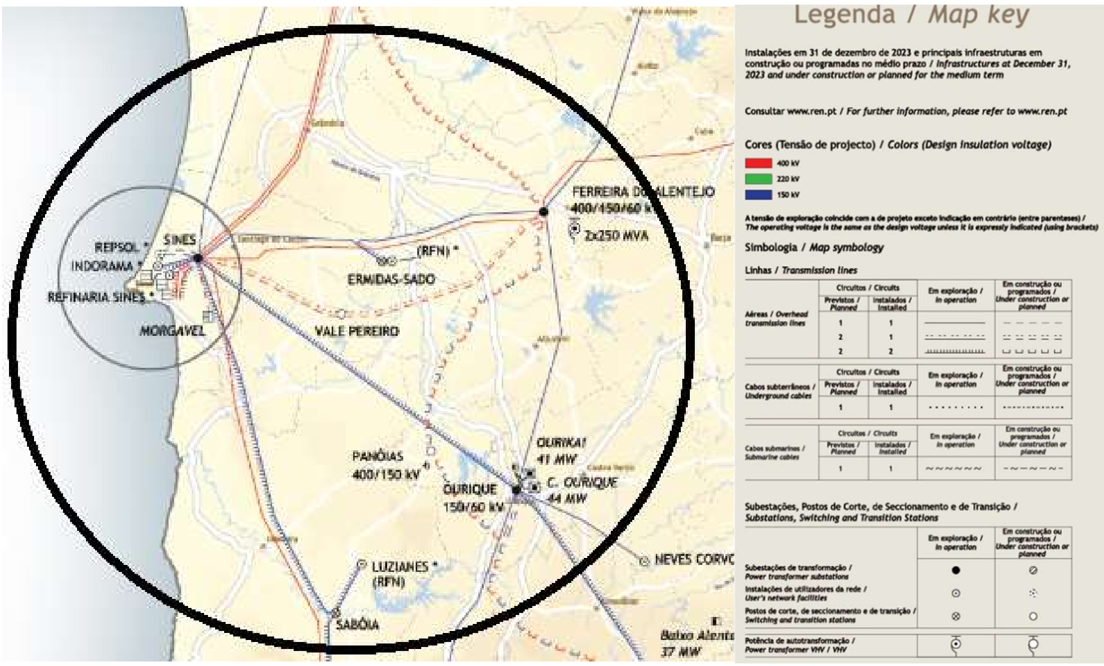
- New 400kV lines connecting Sines to the national grid, facilitating the evacuation of renewable energy production.
- Expansion of existing substations to support additional capacity.
- Grid reinforcements to accommodate offshore wind and large-scale hydrogen projects.

Below is the REN Map for Grid Upgrades, showing the expansion plans for high-voltage transmission lines in the Sines region:



(REN's official grid upgrade map highlighting new 400kV connections, substation reinforcements, and key transmission corridors)

Zooming and describing the Sines region:



Sines Region will have a new 400kV substation and a new switching/transition station in Vale Pereiro, and several key transmission corridors to increase reliability and stability of the power grid.

RNT connection capacity allocated in the Sines GGPZ

In compliance with the provisions of Order no. 1/2025 of the Secretary of State for Energy, which determines the end of the exceptional procedure for the allocation of connection capacity to the public service electricity grid for electricity consumption facilities in the Sines High Demand Zone, as communicated by the Directorate-General for Energy and Geology, it is announced that the connection capacity to the National Transmission Network allocated under this procedure is **4,892.4 MVA**.

The Municipality of Sines plays a crucial role in ensuring affordable energy for public infrastructure, while also benefiting from renewable project fees. Industrial consumers, such as data centers and manufacturing plants, would gain stable and predictable energy pricing, while renewable energy producers could sell electricity at more competitive rates than the wholesale market (OMIE). Additionally, local businesses and residents would benefit from lower energy costs, making Sines a more attractive and competitive economic region.

With proper governance, investment planning, and regulatory alignment, a USEC in Sines could serve as a benchmark for decentralized industrial energy communities, ensuring long-term energy resilience, economic growth, and sustainability.

Business Model and Financial Structure

For a Utility-Scale Energy Community (USEC) to be successful, it must be designed with a sustainable financial structure, easy accessibility for all stakeholders, and strict regulatory compliance. Ensuring these elements is essential for maintaining economic viability, operational efficiency, and stakeholder trust, all of which contribute to the long-term success of the model.

A financially sustainable USEC must generate consistent revenue streams while keeping energy costs competitive and predictable for consumers. Its design must allow for long-term reinvestment in infrastructure, workforce development, and expansion projects. Sustainability also means that the USEC must be scalable, growing alongside industrial energy demand while ensuring grid stability and energy security.

Accessibility is another critical dimension of a well-functioning USEC. The model must be structured to ensure that all stakeholders, including industrial consumers, local businesses, municipal infrastructure, and residents, have fair access to energy resources. To achieve this, the governance structure should be transparent, providing equal participation opportunities while maintaining price stability and supply security. The Municipality of Sines, as a facilitator of the USEC, plays a crucial role in ensuring that economic and social benefits are widely distributed.

Regulatory compliance is another foundational pillar. The USEC must align with national and European energy laws, ensuring that operations are legally sound and in line with decarbonization goals. Adhering to compliance rules minimizes risks related to licensing, grid connection approvals, and financial audits, ensuring that the model is legally robust and attractive to investors and energy consumers.

Structural Requirements for the USEC

To establish a successful USEC in Sines, the following components must be integrated:

- **Smart Grid Infrastructure**: Digital monitoring systems to balance supply and demand in real-time.
- **Energy Storage Solutions**: Large-scale battery installations to mitigate fluctuations in renewable energy generation.
- **Municipal Energy Hubs**: Public buildings and infrastructures acting as anchor consumers to stabilize demand.
- **Automated Trading Platforms**: Digital platforms facilitating peer-to-peer energy transactions between community members.
- **Expansion of Grid Infrastructure**: New energy transport lines to accommodate the expected increase in production and consumption, supported by DGEG plans.

The Sines USEC would operate under a hybrid governance model, integrating public and private sector collaboration. Its revenue streams would include:

- **Energy Sales**: Renewable electricity generated within the USEC would be sold to members at competitive rates, reducing dependency on national utilities and securing stable electricity prices.
- **Grid Services**: The USEC would offer ancillary services, such as frequency regulation, demand-side management, and energy storage solutions, creating an additional revenue stream.
- **Participation Fees**: Industrial participants and large consumers would contribute service fees to support infrastructure maintenance and expansion.
- **Public Incentives**: Funding from European sustainability programs, national energy transition policies, and private investments would help cover initial development costs and encourage renewable energy adoption.

By structuring energy generation, distribution, and pricing within a self-sustaining ecosystem, the Sines USEC ensures that the economic value of renewable energy remains within the municipality. This reinforces economic circularity, ensures long-term municipal financial stability, and allows for reinvestment in infrastructure and workforce expansion, ultimately benefiting all stakeholders involved.

Challenges and Solutions

The successful implementation of a Utility-Scale Energy Community (USEC) in Sines presents several challenges that must be carefully managed to ensure regulatory compliance, grid stability, investment feasibility, and long-term operational success. While the USEC model offers a viable pathway for decentralized and sustainable energy management, addressing these challenges proactively will determine its effectiveness and scalability.

Regulatory and Policy Compliance

One of the most significant challenges in establishing a USEC is navigating the complex regulatory environment. The USEC in Sines must align with both Portuguese national policies and European Union directives, particularly the Renewable Energy Directive (RED II), which supports the integration of renewable energy communities into existing markets.

Ensuring regulatory compliance while securing government incentives and approvals will be critical for the feasibility of the project. The municipality must work closely with the Portuguese energy regulatory authority (ERSE) to establish clear legal and operational frameworks for local energy trading, self-consumption, and grid interconnection policies. In addition, the DGEG (Direção-Geral de Energia e Geologia) must approve grid integration plans, ensuring that the USEC aligns with national decarbonization and energy transition goals.

Another aspect of regulatory compliance is the contractual framework for energy transactions. Unlike traditional centralized energy supply models, a USEC enables direct peer-to-peer energy trading, where industrial consumers, public institutions, and local businesses can purchase electricity directly from renewable energy producers within the USEC ecosystem. This requires structured agreements on pricing mechanisms, energy dispatch priorities, and fair competition principles, all of which must comply with Portuguese energy market laws.

Furthermore, securing public incentives from the European Union and national energy transition programs will provide essential financial support. Policies under the European Green Deal, Horizon Europe, and Portugal's National Energy and Climate Plan (PNEC 2030) offer various subsidies, grants, and tax benefits for decentralized renewable energy projects, all of which must be strategically leveraged by the municipality to enhance the USEC's financial sustainability.

Energy Storage and Grid Stability

Given the intermittent nature of renewable energy sources, such as solar and wind power, ensuring a stable and reliable energy supply within the USEC is a primary technical challenge. Energy storage solutions must be integrated into the system to compensate for fluctuations in generation and ensure uninterrupted electricity supply to industrial consumers, public facilities, and local businesses.

A successful USEC in Sines must incorporate a diverse mix of energy storage technologies, including:

- **Battery Energy Storage Systems (BESS)**: Large-scale lithium-ion and flow batteries that can store excess electricity generated during peak production periods and discharge it when needed.
- **Hydrogen Storage Solutions**: Electrolyzers that convert excess electricity into hydrogen, which can be stored and later converted back into power when needed.
- **Demand-Side Management (DSM)**: A strategy that optimizes energy consumption by shifting demand to align with peak renewable generation, reducing stress on the grid.

Additionally, smart grid technologies will be critical in optimizing energy flow and balancing supply and demand dynamically. Smart grids enable real-time monitoring of energy production and consumption, allowing the USEC to respond flexibly to fluctuations in demand. By integrating AI-driven energy management systems, the municipality can predict energy consumption patterns, optimize storage deployment, and ensure that electricity distribution remains cost-effective and stable.

A key role of the municipality will be collaborating with grid operators, such as REN (Redes Energéticas Nacionais) and E-REDES, to ensure that the USEC is properly connected to Portugal's high-voltage transmission network. The ongoing expansion of 400 kV transmission lines in the region provides a strategic opportunity to integrate larger-scale renewable energy projects, reinforcing the long-term grid stability of the USEC.

Investment Requirements and Financial Strategy

The development of a USEC requires substantial upfront investment in infrastructure, including grid enhancements, energy storage facilities, digital management systems, and transmission upgrades. Ensuring the financial viability of the project will depend on securing diverse funding sources, including public-private partnerships (PPPs), EU grants, and municipal budget allocations.

Potential funding mechanisms for the Sines USEC include:

- European Green Deal and Horizon Europe Grants for innovation in renewable energy communities.
- Public-private partnerships (PPPs) with large industrial consumers who can invest in on-site energy storage and localized grid infrastructure.
- Municipal incentives and tax benefits to encourage businesses and households to join the USEC, ensuring strong participation rates.

A sustainable financial model must also include long-term revenue generation mechanisms, such as:

- **Energy sales**: Direct transactions between producers and consumers at competitive rates.
- **Grid services**: Ancillary services, such as voltage regulation, frequency balancing, and demand-response programs, generating additional income.
- **Participation fees**: Large industrial consumers contributing to infrastructure maintenance and expansion.

A crucial aspect of the municipality's role is ensuring that the financial structure remains inclusive and equitable, allowing small businesses and public institutions to access affordable energy rates alongside large industrial participants.

Municipality's Role and Long-Term Strategy

The Municipality of Sines will play a central role in ensuring the successful implementation and long-term sustainability of the USEC. By facilitating partnerships, securing policy incentives, and ensuring regulatory compliance, the municipality can create a strong governance framework that encourages widespread participation and investment.

The municipality can use land-use planning tools to allocate dedicated zones for renewable energy projects, ensuring that expansion efforts align with industrial development strategies. Additionally, municipal policies can incentivize businesses and residential consumers to participate in the USEC, ensuring a broad and stable consumer base.

<u>Economic Impact Estimation</u>

A comparative analysis of USEC versus traditional energy suppliers indicates significant savings and revenue potential:

- Energy price reduction for consumers: Estimated savings of 25-35% compared to retail market prices.
- Increased profitability for renewable producers: Sales prices 15-20% above the OMIE wholesale market average.
- Revenue potential for the municipality: Annual earnings from infrastructure fees and surplus energy sales projected at €15-€25 million due to the expected industrial energy consumption growth.

Looking ahead, the expansion of the USEC model to include new renewable energy projects and emerging technologies could further enhance operational efficiency and economic competitiveness. The adoption of blockchain-enabled peer-to-peer energy trading could revolutionize local energy transactions, ensuring transparency and efficiency in pricing mechanisms.

Aligning the USEC's objectives with Portugal's National Energy and Climate Plan (PNEC 2030) will also provide strategic coherence, ensuring that the project remains aligned with national decarbonization goals and eligible for long-term policy incentives and regulatory support.

The municipality must also engage in active communication and stakeholder coordination, ensuring that all participants understand the benefits of the USEC and are incentivized to participate. Educational programs, community outreach, and policy workshops can strengthen public support and increase adoption rates among businesses and residents.

By strategically planning for growth, securing long-term investment, and leveraging regulatory support, Sines can position itself as a global leader in decentralized energy governance, ensuring energy security, economic prosperity, and environmental sustainability for years to come.

Conclusion

The establishment of a Utility-Scale Energy Community (USEC) in Sines represents a transformational shift in municipal energy governance, providing a sustainable, cost-effective, and resilient solution for the industrial and economic expansion currently underway. As industrial activity intensifies and energy demand continues to rise, the Municipality of Sines must take a proactive role in ensuring that energy supply remains stable, affordable, and aligned with national and European decarbonization goals.

This case study has explored the opportunities and challenges associated with implementing a USEC in Sines, examining its technical, financial, and regulatory dimensions. The transition toward a decentralized energy system, where renewable energy assets, smart grid solutions, and local energy transactions replace traditional fossil-fuel-based centralization, ensures that economic benefits remain within the region. The USEC model reduces reliance on national grid pricing fluctuations, enhances energy security, and fosters economic circularity, whereby renewable energy revenues are reinvested into local infrastructure, workforce development, and municipal services.

The Municipality of Sines stands at a crossroads, where its role in energy governance can determine long-term economic resilience and competitiveness. By establishing a hybrid governance model that integrates public-private partnerships, digital energy management technologies, and structured investment strategies, the municipality can position itself as a national and international benchmark for decentralized energy communities. A successful USEC requires strong municipal leadership, ensuring that regulatory frameworks support local energy trading, infrastructure expansion, and smart grid optimization while remaining compliant with European energy market directives.

The success of a USEC in Sines is contingent on several key factors, including:

- Regulatory compliance and policy alignment with Portuguese and European energy transition strategies.
- Investment in grid modernization, energy storage, and AI-driven energy management technologies.
- Engagement with industrial stakeholders, renewable energy producers, and financial institutions to ensure long-term funding and stability.
- Incentive programs for local businesses, residents, and industries to foster broad participation in the USEC.

Furthermore, the Municipality of Sines must ensure that the USEC remains accessible and inclusive, offering equal opportunities for small businesses, local enterprises, and public institutions to benefit from stable and lower-cost energy. By integrating advanced digital solutions such as blockchain for peer-to-peer energy trading, the USEC can increase transparency, efficiency, and scalability, further solidifying its role as a pioneering model for decentralized industrial energy communities.

A Strategic Path Forward

Looking ahead, the municipality must facilitate the transition from planning to execution, ensuring that policy frameworks, investment roadmaps, and community engagement strategies are well-defined and actionable. The implementation of a USEC in Sines presents a unique opportunity to secure energy sovereignty, attract foreign direct investment, and establish a green industrial economy that is globally competitive and locally resilient.

The next step involves technical validation and financial structuring, which will be explored in the Technical Annex. This annex provides detailed data, projections, and regulatory frameworks to support decision-making and address key questions related to feasibility, cost-efficiency, and long-term sustainability.

How can the Municipality of Sines ensure that the USEC model is financially viable, legally compliant, and capable of scaling to meet future energy demands while remaining a benchmark for sustainable industrial growth?

References

Below is a comprehensive list of references cited in the thesis, organized by type and formatted in Harvard referencing style:

Reference Papers for the EU Energy Transition

1. D'Aprile, P., Rouch, P., & Yiangou, J. (Coords.). (2024). *The future of European competitiveness: A competitiveness strategy for Europe* (Part A). European Commission. Available in: https://commission.europa.eu/document/download/97e481fd-2dc3-412d-be4c-f152a8232961_en?filename=The%20future%20of%20European%20competitiveness%20_%20A%20competitiveness%20strategy%20for%20Europe.pdf

2. European Commission. (2024). *The future of European competitiveness: In-depth analysis and recommendations (Part B)*. European Commission. Available in: https://commission.europa.eu/document/download/ec1409c1-d4b4-4882-8bdd-3519f86bbb92_en?filename=The%20future%20of%20European%20competitiveness_%20In-depth%20analysis%20and%20recommendations_0.pdf

Academic Papers

3. Amir, R., & Lazzati, N. (2011). Network effects, market structure and industry performance. *Journal of Economic Theory*, *146*(6), 2389–2419. Available in: https://doi.org/10.1016/j.jet.2011.10.002

4. Rapp, C. (2020). Hypothesis and theory: Collaborative governance, natural resource management, and the trust environment. *Frontiers in Communication*, *5*, Article 28, 1–12. Available in: https://doi.org/10.3389/fcomm.2020.00028

5. Adner, R., & Kapoor, R. (2010). Value creation in innovation ecosystems: How the structure of technological interdependence affects firm performance in new technology generations. *Strategic Management Journal*, *31*(3), 306–333. Available in: https://doi.org/10.1002/smj.821

6. Ellen MacArthur Foundation. (2013). *Towards the Circular Economy: Economic and business rationale for an accelerated transition*. Ellen MacArthur Foundation. https://ellenmacarthurfoundation.org

7. Ikenami, R. K., Garnica, L. A., & Ringer, J. M. (2016). Ecossistemas de inovação: Uma abordagem analítica. *Espacios*, *37*(33), 11–23. Available in: https://www.revistaespacios.com/a16v37n33/16373311.html

8. Gupta, S., & Godwin, J. (2022). Michelin: Digital transformation and data-driven services. *Harvard Business School Case*, 9-520-061, 1–23. Retrieved from Harvard Business Publishing website. Available in: Michelin: Building a Digital Service Platform - Case - Faculty & Research - Harvard Business School

9. Chai, R., & Amaral, P. (2022). *Is Grab, the Asian Superapp, Leveraging Digital Innovation for Good?* SAGE Business Cases Originals. https://doi.org/10.4135/9781529797312:contentReference[oaicite:0]{index=0}

10. Koo, W. W.-Y., & Madhavji, A. (2022). *Binance: Ecosystem Leadership in Uncertain Times*. INSEAD. Available in: Binance: Ecosystem Leadership in Uncertain Times | INSEAD Publishing

11. Biehl, K. e Drewyer, H. (2024) *Carbon Free Data Centers Through Solar Photovoltaic Generation, Battery Energy Storage, and Medium Voltage DC Power Distribution*. Master's Project, Nicholas School of the Environment, Duke University. Available in: https://hdl.handle.net/10161/30574

12. Daou, A., Mallat, C., Chammas, G., Cerantola, N., Kayed, S., & Saliba, N. A. (2020). 'The Ecocanvas as a business model canvas for a circular economy'. Journal of Cleaner Production, 258, 120938. Available in: https://doi.org/10.1016/j.jclepro.2020.120938

13. Carlisle, N., Elling, J. e Penney, T. (2008) *A Renewable Energy Community: Key Elements*. National Renewable Energy Laboratory. NREL Technical Report TP-540-42774. Available in: https://www.nrel.gov/docs/fy08osti/42774.pdf

14. Fàbrega Ferrer, E., 2022. *Exploration of the Next Generation of Green Electricity Procurement Strategies*. KTH Royal Institute of Technology, MSc Energy for Smart Cities. Available in: https://www.diva-portal.org/smash/get/diva2:1724528/FULLTEXT01.pdf

15. Lage, M., Castro, R., Manzolini, G., Casalicchio, V. e Sousa, T. (2024) 'Techno-economic analysis of self-consumption schemes and energy communities in Italy and Portugal', *Solar Energy*, 270, artigo 112407. Available in: https://doi.org/10.1016/j.solener.2024.112407.

16. Mendicino, L., Menniti, D., Pinnarelli, A., Sorrentino, N. & Vizza, P., 2021. *DSO Flexibility Market Framework for Renewable Energy Community of Nanogrids*. Energies, 14(3460). Available in: https://doi.org/10.3390/en14123460.

17. Romero-Castro, N., Ribeiro-Soriano, D., Lopez-Cabarcos, M. A. & Miramontes-Vina, V., 2022. *Sustainable energy transition and circular economy: The heterogeneity of potential investors in rural community renewable energy projects*. Environment, Development and Sustainability, https://doi.org/10.1007/s10668-022-02898-z.

Industry Reports

18. Nouicer, A. e Meeus, L. (2019) *The EU Clean Energy Package (2019 ed.)*. Technical Report. Florence School of Regulation, European University Institute. Disponível em: https://doi.org/10.2870/33236

19. European Commission, 2019. *Directive 2019/944/EU on common rules for the internal market for electricity (IEM)*. Official Journal of the European Union. Available in: Directive - 2019/944 - EN - EUR-Lex

20. European Commission, 2019. *Electricity Market Regulation (EU) 2019/943*. Official Journal of the European Union. Available in: Regulation - 2019/943 - EN - EUR-Lex

21. APREN (2024) *Renewable Electricity in Review: Portugal Needs Our Energy*. Lisboa: Associação Portuguesa de Energias Renováveis (APREN). Available in: http://www.apren.pt.

Government Policies

22. Portuguese Government, 2019. *Decree-Law No. 162/2019*. Establishing the legal framework for renewable energy self-consumption and energy communities. Available in: Decree Law No. 162/2019 | DR

23. Portuguese Government, 2020. *Ordinance No. 43/2020*. Licensing requirements for renewable energy producers and energy communities.

24. Portuguese Government, 2021. *National Energy and Climate Plan (PNEC) 2030*. Ministry of Environment and Climate Action. Available in: pt_final_necp_main_en_0.pdf

Technical and Project Data

25. Greenvolt, 2024. *Performance Metrics and Case Studies*. Available at: Greenvolt website.

26. EGAC, 2024. *Annual Report on Collective Self-Consumption Programs*. Available through the Portuguese Ministry of Energy. Available in: bridge_tf_energy_communities_report_2020-2021_0.pdf

Books

27. Padilla-Rivera, A., Russo-Garrido, S. & Merveille, N., 2020. *Addressing the Social Aspects of a Circular Economy: A Systematic Literature Review*. Sustainability Journal, 12(7912), doi:10.3390/su12197912. Available in: Addressing the Social Aspects of a Circular Economy: A Systematic Literature Review

Online Sources

28. Ribeiro, M. G. C., Luke, J., Martin, S. & Balogun, E., 2024. *Towards a 24/7 Carbon-Free Electric Fleet: A Digital Twin Framework*. Available at: ResearchGate.

29. REScoop.eu, 2023. *Community Energy Guide*. Available at: REScoop.

Notes on Referencing

Each reference has been chosen to ensure comprehensiveness, covering theoretical frameworks, regulatory analyses, and real-world applications. These sources provide a solid foundation for understanding the development, challenges, and future potential of utility-scale energy communities.

Appendices

Appendix A: Project Maps and Visuals

Figure A1: Map REN's Portuguese Grid for Electricity ([mapa-2025-eletricidade.jpg (2917×3602)](mapa-2025-eletricidade.jpg))

Figure A2: Zoom of the Sines Region regarding the National Grid Map (REN)

Appendix B: Technical Schematics

Figure B1: Diagram of a Microgrid Architecture in USECs

- Demonstrates the interconnectivity of local production and consumption.

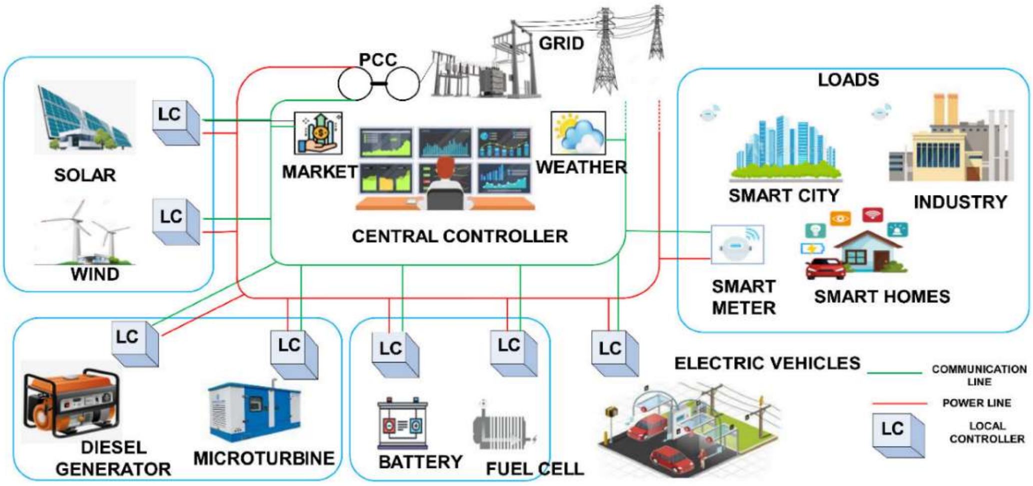
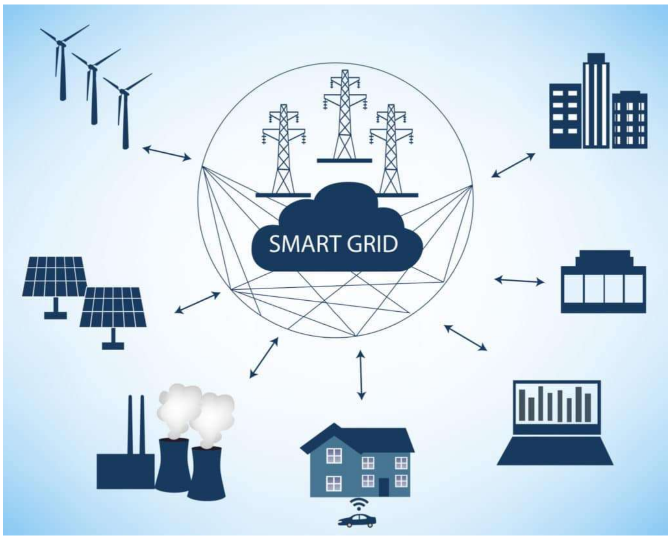


Figure B2: Configuration of Smart Grids for Real-Time Energy Management

- Details energy optimization tools such as AI-driven forecasting and demand-side response mechanisms.



Appendix C: Financial Models

Table C1: Cost Breakdown of Utility-Scale Energy Communities in Portugal

Expense Type	Amount (€)	Notes
Initial Capital Investment	€10,000,000	Includes solar PV installation and grid updates.
Operational Costs	€500,000/year	Maintenance of infrastructure and energy management systems.
Regulatory Compliance	€200,000/year	Licensing and administrative costs.

Table C2: Revenue Streams for Greenvolt's Energy Communities

Revenue Source	Annual Income (€)	Notes
Energy Sales	€8,000,000	From solar and wind energy production.
Grid Services	€1,000,000	Includes peak shaving and frequency regulation.
Subsidies and Incentives	€500,000	Government grants for renewable adoption.

Appendix D: Stakeholder Interviews

Interview Excerpts:

1. **Local Government Representative, Évora:**
   "Energy communities are a game-changer for regional development, creating jobs and fostering sustainability."
2. **Greenvolt Executive:**
   "Our focus is on integrating advanced technologies to maximize efficiency while empowering communities through renewable energy."
3. **Community Member:**
   "Access to affordable and clean energy has not only reduced our bills but also inspired us to take a more active role in energy decisions."

Appendix E: Policy Documents

Key Regulations and Policies Referenced:

4. **Decree-Law No. 162/2019:** Framework for collective self-consumption in Portugal.
5. **RED II (Directive 2018/2001):** EU-level directive promoting renewable energy adoption.

6. **IEM (Directive 2019/944):** Directive supporting citizen energy communities (CECs).

Appendix F: Supporting Data

Table F1: Carbon Emissions Reduction Achieved by Greenvolt's Projects

Year	CO_2 Reduction (Tons)	Project
2022	20	Lisbon Solar Community
2023	25	Évora Wind and Solar Hub
2024	30	Braga Energy Community

Table F2: Performance Metrics of Battery Storage Systems

Parameter	Value	Notes
Energy Storage Capacity	100 MWh	Supports peak load times.
Efficiency Rate	1	Reflects energy retention over time.

This section includes supplementary visuals, technical details, financial data, and qualitative insights to provide a comprehensive understanding of the study's findings and practical applications.

Technical Annex: Establishing a Utility-Scale Energy Community in Sines

Case Synopsis

The Municipality of Sines is strategically addressing its rapidly increasing energy demands driven by substantial industrial expansion. Historically significant as an energy hub, recent developments such as large-scale data centers, hydrogen production facilities, battery manufacturing plants, and logistics terminals are reshaping the local economic landscape. The proposed Utility-Scale Energy Community (USEC) will integrate renewable energy sources, advanced smart-grid technologies, and localized energy trading mechanisms. This strategic initiative aims to deliver sustainable, resilient, and cost-effective energy solutions, involving local businesses, industrial consumers, residents, and renewable energy producers. By fostering economic circularity and reinvesting energy revenues into the community, the USEC will contribute significantly to regional economic stability, infrastructure enhancement, and employment opportunities.

Classroom Implementation Guide

This technical annex is specifically developed for MBA, Executive MBA, Executive Masters and advanced undergraduate courses addressing sustainability, energy management, digital innovation, and public policy. It enables a thorough, practical analysis of innovative and sustainable business models, governance frameworks, and technology-driven ecosystems within decentralized energy communities. Students will explore real-world challenges, collaboratively evaluate strategic solutions, identify effective stakeholder management practices, and critically discuss sustainable development and innovation strategies in complex industrial and community settings.

Learning Objectives

- Critically assess network effects and their role in enhancing community benefits.
- Analyze collaborative governance for effective stakeholder engagement and resource allocation.
- Understand innovation ecosystems to support sustainable economic growth through policy and technology.
- Formulate strategic responses to operational, regulatory, and financial challenges in decentralized energy communities.

Recommended Teaching Approach

Pre-Class Preparation:

- Assign mandatory reading of the case and supplementary materials on renewable technologies, regulatory frameworks, and market trends.
- Provide a glossary of essential terms (e.g., microgrids, blockchain, energy storage).

Classroom Dynamics:

Introduction (10 minutes):

Overview of Utility-Scale Energy Communities (USECs) and their significance in global sustainability.

Opening discussion question: "Why are USECs innovative in energy transition efforts?"

Case Analysis (30 minutes):

Group discussions focusing on:

- Business models (revenue generation, costs, partnerships).
- Operational and technical challenges.
- Regulatory and policy constraints.

Presentation of group analyses.

Insights and Reflections (20 minutes):

Comparison of USECs to traditional energy systems.

Identification of insights relevant across various sectors.

Future Trends and Opportunities (20 minutes):

Explore emerging trends impacting USECs.

Discuss strategies to enhance the effectiveness and scalability of USECs.

Post-Class Assignment:

Students prepare a strategic memo outlining how a business can strategically invest or engage in a USEC for sustainability objectives.

Discussion Questions

How do USECs generate and capture value?

What operational and regulatory challenges do USECs encounter?

How do USECs benefit local businesses, governments, and communities?

What strategic lessons from the USEC case can be transferred to other industries or contexts?

Theoretical Framework

This annex incorporates three frameworks: Network Effects Theory, Collaborative Governance Theory, and Innovation Ecosystem Theory.

- **Network Effects Theory**: Emphasizes broad participation to maximize communal benefits.
- **Collaborative Governance Theory**: Highlights inclusive decision-making and resource management.
- **Innovation Ecosystem Theory**: Focuses on stakeholder interconnectedness, policy support, and technological investments.

These frameworks collectively guide stakeholders in leveraging collaborative approaches, strategic investment, and innovation, essential for the successful implementation and sustainability of USECs.

Analysis and Application of Theories

Network Effects Theory (Amir & Lazzati, 2011; Draghi, 2024; Gupta & Godwin, 2022; Chai & Amaral, 2022; Koo & Madhavji, 2022; Daou et al., 2020)

Network Effects Theory, articulated by Amir and Lazzati (2011), emphasizes how the value of goods and services significantly increases with the number of adopters, creating a self-reinforcing cycle that enhances market attractiveness and stimulates further growth. For the Municipality of Sines, strategically leveraging these network effects involves encouraging broad-based participation among residents, local businesses, industrial stakeholders, and external entities within the Utility-Scale Energy Community (USEC). Reaching critical mass through active and diverse stakeholder engagement fosters economies of scale, reducing individual costs and enhancing the community's attractiveness to new participants and external investors.

Michelin's Digital Service Platform exemplifies practical strategies to achieve rapid stakeholder adoption through initial economic incentives and proactive communication, resulting in sustainable network expansion (Gupta & Godwin, 2022). Grab further demonstrates that transparent and frequent stakeholder communication, alongside incentivization, enhances early enthusiasm, leading to accelerated adoption rates (Chai & Amaral, 2022). Binance's strategic approach emphasizes early diversification of partnerships, effectively minimizing adoption barriers and swiftly extending the ecosystem's reach (Koo & Madhavji, 2022).

Integrating circular economy principles recommended by Draghi (2024) strengthens the network effects by fostering resource efficiency and aligning incentives among stakeholders, thereby intensifying the virtuous cycle of participation. Additionally, the Ecocanvas framework proposed by Daou et al. (2020) provides structured tools for operationalizing circular economy concepts, enhancing stakeholder alignment, sustainability, and overall ecosystem resilience within the USEC.

Collaborative Governance Theory (Rapp, 2020; Koo & Madhavji, 2022; Gupta & Godwin, 2022; Chai & Amaral, 2022; Daou et al., 2020)

Collaborative Governance Theory, proposed by Rapp (2020), underscores the necessity of inclusive governance structures, transparency, and multidimensional trust (dispositional, rational, procedural, and affinitive) among stakeholders. Implementing this theory within the Municipality of Sines involves establishing a dedicated Collaborative Governance Council that integrates diverse stakeholders, including local government, businesses, residents, academic institutions, energy providers, and community organizations, ensuring inclusive representation and participation.

Procedural transparency and consistent communication significantly bolster rational and procedural trust. Binance's strategic management of regulatory frameworks exemplifies how clear, transparent communication effectively reduces uncertainty and enhances stakeholder trust (Koo & Madhavji, 2022). Michelin demonstrates how structured incentives and clear procedural guidelines encourage sustained stakeholder engagement, promoting affinitive trust and cooperation (Gupta & Godwin, 2022). Furthermore, Grab's use of participatory forums reinforces community trust and aligns governance decisions with stakeholder values and priorities (Chai & Amaral, 2022).

The Ecocanvas methodology complements these governance practices by providing a systematic framework that integrates stakeholders' economic, environmental, and social priorities, ensuring broad stakeholder engagement and procedural fairness. This structured approach facilitates continuous stakeholder interaction, promoting sustained trust and collaborative decision-making, crucial for the long-term success and stability of the USEC.

Innovation Ecosystem Theory (Adner & Kapoor, 2010; Ikenami, Garnica & Ringer, 2016; Gupta & Godwin, 2022; Chai & Amaral, 2022; Koo & Madhavji, 2022; Daou et al., 2020)

Innovation Ecosystem Theory, outlined by Adner and Kapoor (2010), highlights the critical role of managing technological interdependencies and mobilizing complementary resources and stakeholders effectively. Ikenami et al. (2016) further stress the significance of active stakeholder interactions and partnerships for sustained innovation ecosystem success. Applying this theory, the Municipality of Sines should proactively engage diverse actors, such as technology providers, energy specialists, SMEs, research institutions, and regulators, addressing interdependencies and potential innovation bottlenecks.

The strategic ecosystem model demonstrated by Grab illustrates how early investments, targeted incentives, and proactive partnership development significantly accelerate innovation adoption and scalability (Chai & Amaral, 2022). Michelin's approach, emphasizing targeted resource allocation for technological infrastructure and stakeholder capacity-building, effectively mitigates initial technological and adoption challenges, fostering rapid stakeholder engagement and ecosystem growth (Gupta & Godwin, 2022). Binance's successful navigation of regulatory challenges through strategic alliances further highlights proactive partnership management's importance (Koo & Madhavji, 2022).

Integrating the Ecocanvas framework proposed by Daou et al. (2020) significantly enhances this theoretical application by systematically guiding stakeholders towards circular economy-driven innovation. This practical framework aligns stakeholder objectives, maximizes resource efficiency, and supports long-term ecosystem scalability and resilience, ensuring comprehensive socioeconomic and environmental sustainability of the USEC initiative.

Integration of Theoretical Perspectives for Strategic Governance in Sines

Integrating Network Effects Theory, Collaborative Governance Theory, and Innovation Ecosystem Theory provides a robust, multidimensional strategic framework for the Municipality of Sines. Network Effects Theory emphasizes the necessity of achieving critical mass and sustaining stakeholder adoption through structured incentives and effective communication; Collaborative Governance Theory ensures inclusive stakeholder participation, procedural transparency, and multidimensional trust-building; Innovation Ecosystem Theory highlights proactive partnership management, resource allocation, and strategic resolution of technological interdependencies and bottlenecks.

By simultaneously applying these integrated theoretical frameworks, the Municipality of Sines can strategically establish and sustain the Utility-Scale Energy Community (USEC), effectively addressing stakeholder expectations, technological challenges, governance complexities, and market uncertainties. Such a holistic approach ensures equitable stakeholder representation, enhances resource efficiency, fosters innovation, maximizes community-wide benefits, and reinforces the long-term resilience and sustainability of the entire ecosystem.

Selected Discussion Questions

Question 1: How can the Municipality of Sines effectively stimulate widespread stakeholder participation to maximize the overall benefits of the USEC?

To maximize stakeholder participation and overall benefits of the Utility-Scale Energy Community (USEC), the Municipality of Sines should strategically harness network effects, recognizing that greater participation exponentially enhances communal and economic value (Amir & Lazzati, 2011). Early adoption can be encouraged through targeted economic incentives such as preferential tariffs, subsidies, and fiscal benefits, emulating Michelin's structured incentive model, which successfully overcame initial stakeholder resistance and accelerated widespread participation (Gupta & Godwin, 2022).

A crucial factor is incorporating circular economy principles, which emphasize resource efficiency, waste minimization, and long-term sustainability, as refered by Ellen MacArthur Foundation (2013) that "the circular economy is a regenerative economic system by design, which aims to decouple economic growth from the consumption of finite resources by keeping products, materials and resources in use for as long as possible". Mario Draghi's report highlights that these practices significantly increase the resilience and competitiveness of local economies by aligning stakeholder incentives and promoting collective innovation (Draghi, 2024). Applying the Ecocanvas methodology further supports stakeholder engagement, clearly visualizing circular value propositions and aligning environmental, operational, and economic goals, thus promoting robust and inclusive governance (Daou et al., 2020).

Technological interoperability also significantly influences stakeholder participation. Standardizing technologies such as interoperable smart grids, integrated renewable energy systems, and advanced energy storage solutions reduces technical uncertainties, simplifying stakeholder integration. Michelin's successful digital transformation demonstrates how standardized technological solutions effectively accelerate adoption and enhance ecosystem attractiveness (Gupta & Godwin, 2022).

Moreover, transparent and consistent communication strategies are essential in maintaining stakeholder trust and market enthusiasm. Adopting Grab's effective communication practices—highlighting transparency, openly addressing setbacks, and consistently celebrating successes—can reinforce stakeholder commitment and mitigate the risks associated with declining participation rates (Chai & Amaral, 2022).

In summary, the Municipality of Sines can effectively stimulate widespread participation by strategically deploying economic incentives, embedding circular economy frameworks, ensuring technological interoperability, and maintaining clear communication. This comprehensive approach amplifies network effects, securing long-term sustainability, and delivering significant environmental, social, and economic benefits to the local community.

Question 2: What approach should the Municipality of Sines adopt to ensure effective and sustained collaborative governance within the USEC?

To ensure effective and sustained collaborative governance within the Utility-Scale Energy Community (USEC), the Municipality of Sines should establish a dedicated Collaborative Governance Council encompassing diverse stakeholders, including representatives from local businesses, energy providers, residents, academia, community organizations, and government entities. This inclusive approach, emphasizing transparency, inclusivity, and consensus-building, aligns with Rapp's (2020) principles of effective collaborative governance.

Michelin's successful governance experience underscores the importance of structured stakeholder representation, clear governance frameworks, and procedural transparency to secure stakeholder commitment and facilitate ongoing collaboration (Gupta & Godwin, 2022). Transparent, consistent decision-making processes similar to Binance's proactive communication practices—characterized by openness, clarity about internal processes, and frequent stakeholder updates—can significantly mitigate stakeholder uncertainty and build rational trust (Koo & Madhavji, 2022).

Strategically aligned incentives are crucial for fostering stakeholder buy-in and affinitive trust. Clearly articulated incentives, tailored to stakeholder-specific interests, have proven effective in Michelin's governance structure by enhancing stakeholder engagement and overall participation (Gupta & Godwin, 2022). These incentives should explicitly align with circular economy principles to emphasize resource efficiency and long-term sustainable benefits, as advocated by Draghi (2024).

Proactive community engagement through participatory forums and local workshops, as effectively utilized by Grab (Chai & Amaral, 2022), ensures that governance decisions resonate with local priorities and values. Such inclusive engagement practices help build trust, encourage ownership, and maintain long-term stakeholder commitment.

Addressing trust asymmetry is also essential for sustaining collaboration over time. The governance structure should institutionalize mechanisms to actively engage stakeholders who feel marginalized or exhibit lower trust levels through regular consultations, targeted outreach programs, and dedicated mediation roles (Rapp, 2020).

In summary, the Municipality of Sines should implement a governance approach characterized by inclusive stakeholder representation, transparent and consistent decision-making, strategic incentive alignment focused on circular economy principles, proactive community engagement, and trust asymmetry management. This comprehensive strategy will enhance collaborative effectiveness, support long-term sustainability, and maximize social, economic, and environmental benefits for the local community.

Question 3: How can Sines strategically leverage European and national funding to ensure the USEC's financial viability and support local renewable energy initiatives?

The Municipality of Sines can effectively secure the financial viability of the Utility-Scale Energy Community (USEC) by strategically leveraging European and national funding sources, particularly from the European Green Deal and Horizon Europe. These programs provide critical financial support to address early-stage ecosystem challenges, fostering innovation adoption and sustainability, as highlighted by Adner and Kapoor's Innovation Ecosystem theory (2010).

Priority should be placed on critical infrastructure investments, including modernized smart grids, advanced energy storage solutions, and integrated renewable energy systems. Michelin's digital transformation case demonstrates that proactive infrastructure investment significantly mitigates initial stakeholder resistance and enhances market adoption (Gupta & Godwin, 2022). By strategically allocating European and national funds, Sines can upgrade essential energy infrastructure, thereby enhancing operational efficiency and long-term ecosystem resilience.

Developing strong public-private partnerships is another strategic approach. Binance's experience underscores how proactive partnership-building enhances regulatory responsiveness and market adaptability (Koo & Madhavji, 2022). By establishing strategic alliances with diverse public and private entities, Sines can navigate regulatory uncertainty effectively, capitalize swiftly on emerging opportunities, and optimize funding utilization.

Additionally, directing funding towards comprehensive stakeholder training and capacity-building initiatives is essential. Michelin's targeted educational programs illustrate how investment in stakeholder capability significantly boosts adoption and ecosystem effectiveness (Gupta & Godwin, 2022). Similar strategic investments will equip local businesses, residents, and organizations with essential skills, fostering ecosystem acceptance and sustainability.

Significant upfront economic incentives, such as subsidies and preferential tariffs, are critical for rapid stakeholder adoption. Grab's strategic use of early-stage incentives demonstrates how substantial initial financial support accelerates ecosystem participation and quickly achieves critical mass (Chai & Amaral, 2022). Deploying funds to incentivize early participation will expedite market penetration and stabilize the financial model of the USEC.

Incorporating circular economy principles, advocated by Draghi (2024), amplifies the benefits of strategic funding by emphasizing resource efficiency, aligned incentives, and collective innovation. Applying circular economy frameworks ensures long-term economic resilience, supports local renewable energy initiatives, and maximizes environmental benefits.

In conclusion, by strategically leveraging European and national funding for critical infrastructure, stakeholder capacity-building, public-private partnerships, economic incentives, and circular economy integration, the Municipality of Sines can ensure robust financial viability, local acceptance, and enduring sustainability of the USEC initiative.

Question 4: How can local stakeholders—residents and businesses—actively engage in co-creation and innovation processes to support the USEC's sustainability goals?

Active participation and innovative contributions from local stakeholders—residents and businesses—are crucial for achieving the sustainability goals of the Utility-Scale Energy Community (USEC) in Sines. According to Adner and Kapoor's Innovation Ecosystem framework (2010), these stakeholders significantly influence the ecosystem's overall value by addressing key adoption and practical implementation challenges.

Residents are central actors, whose acceptance and adoption of complementary technologies such as smart meters, energy-efficient appliances, and home energy management systems directly impact the success of the USEC. Michelin's strategy illustrates that clear, tailored communication and structured incentives effectively enhance stakeholder adoption (Gupta & Godwin, 2022). Similarly, the Municipality of Sines should implement targeted incentive strategies and clear communications to maximize residents' engagement and acceptance.

Local businesses play an essential role as catalysts for innovation within the ecosystem, developing and deploying critical technologies such as energy storage, demand-response solutions, and renewable energy infrastructure. Grab's experience demonstrates that leveraging local partnerships and complementary innovations significantly enhances ecosystem functionality and adoption (Chai & Amaral, 2022). The municipality should thus actively incentivize and support local businesses in innovation, enhancing the overall ecosystem value and market attractiveness.

Transparent and consistent stakeholder communication is critical for sustained engagement and trust. Binance's successful governance communication model—characterized by openness and transparency—highlights how ongoing dialogue strengthens stakeholder trust, particularly in evolving market environments (Koo & Madhavji, 2022). Implementing regular stakeholder updates and dialogue forums can significantly bolster community engagement and trust.

Additionally, the integration of circular economy principles, as recommended by Draghi (2024), can amplify stakeholder involvement by promoting resource efficiency, stimulating inter-sectoral collaboration, and enhancing local innovation. Adopting these principles within governance and incentive structures will ensure stakeholders are actively involved in circular innovation, contributing to long-term economic resilience and environmental sustainability.

In conclusion, by strategically utilizing clear incentives, transparent communications, supportive governance structures, and integrating circular economy principles, the Municipality of Sines can effectively enable residents and businesses to actively co-create and innovate, overcoming downstream adoption challenges, maximizing innovation potential, and delivering substantial social, economic, and environmental benefits.

Financial Structure and Potential Results

The financial viability of the Utility-Scale Energy Community (USEC) in Sines, informed by Amir and Lazzati's Network Effects Theory (2011), strengthens significantly as community participation expands. As participation reaches a critical mass (approximately 60%–70% of local residents and businesses within five years), the Municipality anticipates substantial cost savings and revenue generation. With increased user participation, direct energy production and sales could generate annual revenues of around €5–10 million by year five, progressively increasing as adoption rises due to economies of scale.

A structured fee system for ancillary grid services—including energy storage, grid balancing, and demand response programs—further enhances the community's financial resilience. It is anticipated that these ancillary services can generate additional annual revenues ranging from €1–3 million by year five. As the network grows, reduced per-unit energy costs will significantly incentivize new stakeholder participation, further reinforcing the financial sustainability and attractiveness of the USEC through a self-reinforcing feedback loop.

Stakeholder participation fees, envisioned as modest annual contributions (€100–300 per household or small business, €500–2000 for medium-sized enterprises, and scaled accordingly for large industry partners), will collectively offset operational costs, estimated at €2–4 million annually. As Amir and Lazzati's concept of fulfilled-expectations equilibria suggests, rising participation will continuously validate and enhance the perceived value of these contributions, thus ensuring sustained stakeholder buy-in and continued community expansion.

Strategically leveraging Innovation Ecosystem Theory (Adner & Kapoor, 2010; Ikenami, Garnica & Ringer, 2016), the Municipality of Sines can actively utilize substantial financial support available through European and national funding mechanisms. Programs such as the European Green Deal and Horizon Europe could realistically contribute €20–30 million of initial funding over the first five years, covering crucial infrastructure investments including smart grids (€8–10 million), battery energy storage systems (€5–8 million), and blockchain-based energy trading platforms (€2–4 million). These initial funding injections significantly offset entry barriers and foster rapid technological deployment, accelerating community-wide adoption and innovation.

Public-Private Partnerships (PPPs), structured as recommended by Adner and Kapoor (2010), represent a crucial pillar of the financial strategy, allowing effective distribution and management of investment risks. Initial projections suggest PPPs could attract private-sector investments totaling an additional €15–25 million in the first five years. Sharing financial risk between the public sector and private investors ensures attractive return profiles, with targeted internal rates of return (IRR) of 8–12%, sufficient to attract and sustain long-term private-sector interest. These PPP structures enhance financial stability and resilience by diversifying risk and unlocking larger-scale, innovative projects previously unfeasible for single actors.

Aligned with Collaborative Governance Theory (Rapp, 2020), the Municipality will emphasize a transparent, equitable financial model to maximize procedural trust and stakeholder confidence. Clear guidelines and open reporting of revenues, costs, and investments, facilitated through transparent governance and digital platforms, will ensure equitable access to affordable energy for all stakeholders—particularly benefiting small businesses, low-income residents, and community organizations. Such transparency fosters sustained participation, creating stable operational conditions and guaranteeing long-term stakeholder cooperation and commitment.

In the medium to long term (five to ten years), the combined application of these theories and strategic financial structuring is expected to significantly reduce municipal energy costs and operational expenditures by approximately 20–30%, resulting in annual savings of around €1–2 million. Stable and diversified revenue streams from energy sales, stakeholder fees, ancillary services, and PPP investments are estimated to contribute total annual revenues between €10–15 million after full operational maturity. These financial results enable reinvestment into community infrastructure, local development projects, educational initiatives, and further economic diversification, strengthening the overall municipal budget and economic resilience.

Moreover, the Municipality of Sines anticipates indirect economic benefits from the increased attractiveness of the USEC. By establishing Sines as a leading hub for renewable and decentralized energy solutions, the municipality expects to attract additional external private investments totaling €5–10 million annually after operational maturity, further stimulating local economic growth, employment creation, and enhancing overall municipal prosperity and competitiveness.

In conclusion, the structured and integrated application of Network Effects, Innovation Ecosystem, and Collaborative Governance theories will secure robust and sustainable financial outcomes for the Municipality of Sines' USEC initiative. Concrete financial projections and strategically managed funding mechanisms guarantee substantial cost savings, consistent revenue streams, and strong local economic growth. Over the longer term, these favorable outcomes solidify Sines' position as a pioneering, resilient, and economically prosperous community committed to sustainable energy innovation.

Required Additional Information

Additional information required to thoroughly apply the theories includes explicit financial projections and detailed scenario analyses under varying levels of stakeholder participation. Further clarity on regulatory constraints, specific EU funding eligibility criteria, and detailed application processes is essential for accurately evaluating governance effectiveness, financial feasibility, and sustainability of the USEC. Additionally, precise identification of stakeholder roles and responsibilities, local renewable resource potential assessments, and stakeholder readiness evaluations are necessary to ensure the community effectively captures network effects, collaborative governance mechanisms, and innovation ecosystem dynamics.

Conclusion

The successful implementation of a Utility-Scale Energy Community in Sines hinges on strategic municipal leadership employing Network Effects, Collaborative Governance, and Innovation Ecosystem theories. By actively facilitating stakeholder participation and collaboration, leveraging extensive European funding opportunities, and fostering an environment conducive to technological innovation, the municipality can significantly amplify economic, environmental, and social benefits. The structured engagement of all stakeholders, supported by transparent governance and targeted financial strategies, positions Sines as an exemplary model of a decentralized, resilient, and innovative energy ecosystem. This approach will ensure long-term sustainability, economic competitiveness, and affordability, benefiting both local communities and industrial stakeholders.

Glossary of Technical Terms (teaching handout)

Energy Systems

USEC (Utility-Scale Energy Community) - Large, local energy system combining renewable generation, storage, and consumption.
Example: Sines explores a USEC to support its growing industrial energy demand.

Distributed Energy Resources (DERs) - Small-scale, local energy sources like solar panels or batteries.

Microgrid - Local energy network that can function independently from the main grid.
Example: Proposed for balancing energy supply in Sines' industrial areas.

Smart Grid - Digitally enhanced grid that optimizes energy flow and integrates renewables.
Example: Inspired by Évora's smart grid model, considered for Sines' integration.

Energy Storage System (ESS) - Technology that stores energy for later use, like batteries.
Example: Needed in Sines to stabilize intermittent solar and wind input.

Demand Response (DR) - Adjusting energy use during peak times in exchange for incentives.

Renewables & Generation

Solar PV - Panels that convert sunlight into electricity.

Offshore Wind - Wind turbines located at sea to capture strong wind resources.
Example: Sines is preparing for Portugal's first offshore wind auction.

Green Hydrogen - Hydrogen produced using renewable electricity and water.
Example: Sines hosts a hydrogen production hub as part of its energy strategy.

HVO (Hydrotreated Vegetable Oil) - Renewable diesel fuel made from bio-based sources.

Energy Yield - Total energy output from a renewable installation over time.

Digital Innovation

Blockchain Energy Trading - Peer-to-peer energy exchanges using blockchain.

Digital Service Platform (DSP) - Software to manage and automate energy services.

IoT (Internet of Things) - Smart devices connected to manage and monitor energy use.

Telematics - Vehicle tracking systems for efficient energy and logistics management.

Energy-as-a-Service (EaaS) - Energy provided as a subscription service instead of ownership.

Business Models & Financing

PPA (Power Purchase Agreement) - Long-term energy supply contract at fixed prices.

LCOE - Average cost of generating electricity over a project's lifetime.

CapEx / OpEx - Initial vs. ongoing project costs.

Ancillary Services - Services that support grid stability (e.g., balancing, storage).

PPP (Public-Private Partnership) - Cooperation between governments and companies.
Example: Suggested model for Sines to develop its USEC without overburdening public finances.

Green Bonds - Loans for funding environmentally friendly projects.

Energy Tokens - Digital units representing energy, used in decentralized markets.

Policy & Regulation

RED II - EU directive promoting renewable energy development.

IEM (Internal Electricity Market) - EU framework for integrated energy markets.

Energy Communities (EU model) - Groups managing energy locally under EU law.
Example: Sines' USEC aligns with EU definitions of energy communities.

Net Metering - Crediting consumers for excess energy they export to the grid.

Grid Parity - When renewables are as cheap as conventional energy.

Permitting - Legal approval needed to build energy infrastructure.
Example: A key challenge in implementing large-scale solar and wind projects in Sines.

Governance & Strategy

Collaborative Governance - Shared decision-making across sectors.

Network Effects - More users make a system more valuable.

Ecocanvas - Tool for designing circular economy business models.

Affinitive Trust - Trust built through shared values and long-term goals.

Transparency - Clear communication and open processes for stakeholders.

Participatory Forums - Events for community involvement in energy planning.
Example: Used in Sines to involve community and industrial stakeholders in energy planning.

Social & Economic Impact

Energy Poverty - Lack of access to affordable energy.

Social License to Operate (SLO) - Community approval for a project.
Example: Important for gaining support from Sines residents amid industrial expansion.

Local Resilience - Economic stability through local resource circulation.
Example: A goal of the USEC in Sines to ensure stable energy supply and pricing.

Circular Economy - Reducing waste by keeping materials and energy in use.