First
Quarter
2024

Issn 1944-3188

IAEE ENERGY FORUM

CONTENTS

Editor: IAEE Headquarters

Published By:
IAEE
International Association for
ENERGY ECONOMICS

PRESIDENT'S MESSAGE

20 years ago, I participated in my first international conference. I was a first year PhD student, printed out (just in case on transparencies for overhead projector) a presentation on the development of international natural gas prices and went to the ETH in Zurich. It turned out to be a European conference of the IAEE and I have participated in several international and regional conferences ever since. I have now the pleasure and honor to succeed to Jean-Michel Glachant as the President of the International Association for Energy Economics. Thank you, JM, for energetic support of the Association last year which was marked by organizational transition. Today we are in year 1 of a new era: it will be the first full year under the management of Talley, it will be the first year during which SAGE will publish our prestigious Energy Journal and it will also be the first year that we have an Editor from Europe of the Energy Journal.

For me the goal during this year will be to re-install the outstanding scholarship of the Energy Journal, lift up EEEP to competitive level and make our conferences a place of scientific excellence with contributions from industry, policy and academia. All three contribute in their own to this and nourish each other but need to be in dialogue with each other. So, let us aim to find a good balance and maintain the friendly and level-playing field atmosphere at our meetings.

Together with Council, which has recently welcomed new Council members, Leila Dagher, Matteo Di Castelnuovo, Eric Hittinger, and Pedro Linares, and with the support of the President-Elect Edmar Almeida, and continuing Council Members Jean-Michel Glachant, Peter Hartley, Andrew Slaughter, Swetha Ravi Kumar, Christophe Bonnery, Lin Zhang, Adonis Yatchew, Maureen Paul, Aaron Praktiknjo, Roula Inglesi-Lotz, Nils-Henrik von der Fehr, Han Yan, and Charles Mason, I intend to carry out this presidential mandate in full collaboration with the Council and all of you, Members in a fully transparent manner. Just like previous, current and future presidents and council members I take this position on a pro-bono basis.

Last year, IAEE's council has approved a tiered approach to membership dues based on World Bank national income categories. Council hopes to expand IAEE's outreach in emerging and developing countries while keeping up with cost inflation since our last rate increase in 2019. More information and details can be found at: https://iaee.org/documents/2024/2024_membershipinfo.pdf

I would like to invite you to accompany us on this journey again this year by renewing your membership if you have not done so yet. I encourage all of you to invite new individual members to join and help us to attract new institutional members. It is the contribution of individuals and the support of institutions that enables us to manifest our international platform for exchange that our Association is. We are the association that backs the conversion of (global) energy systems to net-zero emissions with solid research and inform the energy policy debate.

IAEE will hold this year its 27th International Conference in Istanbul, Turkey, from June 25th to 28th. The Local Organising Committee and the Programme Committee are working hard to deliver a high-level programme. This will be a good occasion to meet, reconnect, and update each other. Over 527 papers were submitted. The program is under active development with many exciting speakers on board. I hope it will be an occasion to meet again in person and to experiment with some hybrid sessions. We will also have the opportunity to indulge in Turkish Music and encounter a Mevlevi Sema ceremony, an UNESCO Intangible Cultural Heritage of Humanity. I am almost certain that there will also be Baklava! Registrations are open and the conference will be preceded by a PhD-day, tailored for academic researchers.

Visit the website for updates and take advantage of the discount available for flights with Turkish Air. Visit the conference website at https://www.iaee2024.org.tr/

Other opportunities to meet this year this year will include the 9th ELAEE Meeting in Rio de Janeiro, Brazil, and the 41th USAEE/IAEE North American Conference in Baton Rouge, LA.

Are you interested in becoming the next Executive Director of IAEE? Or do you know somebody in your network who might be interested? We thank Frank Mortl, who decided to seize another opportunity, for his guidance in the past year. A search committee is leading the search for a new Executive Director, the announcement can be found here.

To close for today let me stress this: Please do not hesitate to send me your comments or report bumps on the road: I will personally respond to each one.

Careers, Energy Education and Scholarships Online Databases

IAEE is pleased to highlight our online careers database, with special focus on graduate positions. Please visit http://www.iaee.org/en/students/student_careers.asp for a listing of employment opportunities.

Employers are invited to use this database, at no cost, to advertise their graduate, senior graduate or seasoned professional positions to the IAEE membership and visitors to the IAEE website seeking employment assistance.

The IAEE is also pleased to highlight the Energy Economics Education database available at http://www.iaee.org/en/students/eee.aspx Members from academia are kindly invited to list, at no cost, graduate, postgraduate and research programs as well as their university and research centers in this online database. For students and interested individuals looking to enhance their knowledge within the field of energy and economics, this is a valuable database to reference.

Further, IAEE has also launched a Scholarship Database, open at no cost to different grants and scholarship providers in Energy Economics and related fields. This is available at http://www.iaee.org/en/students/ListScholarships.aspx.

We look forward to your participation in these new initiatives.

Editor's Notes

The topic of Energy Communities has proved to be a popular one. Energy Commnunities provide actions organized collectively by citizens. They have the potential to contribute to increasing public acceptance of infrastructure energy projects and make it easier to attract private investments. At the same time, they have the potential to provide direct benefits to citizens by increasing energy efficiency, lowering their electricity bills and creating local job opportunities.

In the context of an energy transition energy communities can help provide flexibility to the electricity system through demand response and storage. They can be a means to re-structure energy systems by harnessing energy and allowing citizens to participate actively in the process of the transition. We are interested in how energy communities can help contribute to a more decarbonised and flexible energy system, since they can act as one entity and access all suitable energy markets, on a level-playing field with other market actors.

We conclude with several articles on other topics that may be of interest. Finally, we are fortunate to have a summary of the EVER Monaco 2023 conference.

Amanda Harker Steele, Luke Clahane, Gavin Pickenpaugh, and **Jason Boerst** state that the benefits and costs of deploying technologies to meet decarbonization targets are not likely to be evenly distributed, and energy communities will face both risks and opportunities in response. This paper identifies metrics available to support energy justice impacts assessments in these communities based on a review of the literature.

Blanche Lormeteau writes that Energy communities are one of the legal tools to spread

the prosumer figure, called “active customer”. The contribution aims to focus on their governance by the “effectively controlled by members or shareholders” analysis and show how this element helps or not the prosumer figure concretisation, in European and French energy law.

Helen Fischer, Amela Ajanovic, and **Reinhard Haas** aim to shed light on the valuable insights gained from the Austrian experience. Their article encompasses the challenges and opportunities of renewable energy communities in Austria.

Vincent Musco and **Carolyn Berry** discuss that as policy makers increasingly recognize the value of community-driven energy investments, we highlight three examples of U.S. states where community-driven projects are an active part of the transitioning energy sector. Each demonstrates the importance of legislatures, regulators, utilities, third-party developers, non-profits, and individual community members in driving energy communities and community driven projects. These examples show that energy community programs use different business models, involve different levels of utility involvement, seek electricity products in addition to energy, and incorporate other policy goals. They draw out aspects of the programs that appear to be working well.

Laura Wangen and **Cédric Clastres** explain cost allocation is a crucial element in Energy Communities due to shared distributed energy resources between members. This review examines current and emerging methods before identifying challenges and future trends to ensure fair and stable sharing mechanisms among members while improving the overall feasibility of Energy Communities.

Sara Zaidan and **Mutasem El Fadel** introduce a framework linking the concept of “energy communities” to the Net Zero Emissions (NZE) agenda for envisioning the Paris Agreement. They present the potential benefits of energy communities and examples of selected case studies showcasing global developments in community-driven projects and initiatives. The challenges are discussed, followed by people-centred policy recommendations to accelerate the transition towards democratized NZE energy systems

Debora Cilio, Valerio Angelucci, and **Matteo Zulianello** contend that transition to a renewable energy-based system requires commitment and accountability both at individual and collective levels. In this context Renewable Energy Communities, as drivers of technological and social innovation, are recognized as an interesting tool. However, their complexity necessitates a holistic interpretative approach to fully realize their potential.

Georg Heinemann, Ana María Ramírez Tovar, Pasha Alidadi, and **Christian von Hirschhausen** propose sustainable variables for Colombian energy communities, inspired by European models. Key factors include social cohesion and financial support. Lessons from Europe inform above all local engagement and regulatory strategies for sustainability.

Sabine Löbbe, Fereidoon Sioshansi, and **David Robinson** assert that energy communities should be customer-centered, market- driven and welfare-enhancing1. Individual consumers with proper incentives are becoming prosumers and prosumagers. The next obvious step will be to aggregate thousands or millions of such participants into physical or virtual energy communities. Private companies will help to scale and develop easy-to-handle solutions. The role of aggregation to optimize community resources and to integrate with markets are among the main topics covered in Energy Communities, a review of which by Chirara Candelise was recently published in Energiea.

Christine Brandstätt, Jens Weibezahn, and **Nicolò Rossetto** maintain that energy communities are expected to deliver a variety of benefits, such as increased uptake of renewable energy, flexibility for overall system or grid optimization, and improved system resilience. Mechanisms to incentivize energy communities and align them with the overall system needs often include direct support schemes, agreements for grid use and connection, decentralized access to markets for flexibility and residual generation, and other administrative requirements. Initially, the focus both in policy-making and research has rightfully been on the enabling factors within the regulatory framework. As energy communities slowly but steadily gain traction across Europe, this focus is expected to shift more toward the coordinating power of the framework. Their article discusses qualitatively which (combinations of) mechanisms are more suitable, depending on the actors involved, the technologies adopted, and the policy objectives to further.

Moving away from Energy Communities, **Maylis Peyret** and **Frédéric Gonand** provide a concise overview of economic analysis in metallic raw material production. It examines the key concerns of economists over the past century, their relevance in light of available data, and recent developments over the last two decades. The subject's relevance for economic policy is significant, particularly in understanding a market with volatile demand, sluggish supply, and instable prices, to which capital-intensive business models add further complexity. Understanding primary metal production patterns is crucial for assessing current metal demand sustainability amid the low-carbon transition and digital economy.

Jackie Ashley and **David Morton** ask what is the value added that utility regulators provide? In order to articulate the key deliverables of utility regulators, they reach back in time to the seminal work undertaken by James Bonbright (1988). These deliverables could be used as a basis to measure a utility regulator's value added, and therefore provide further insight into a utility regulator's performance.

Diego Cebreros and **Christophe Bonnery** provide a write-up of the roundtables hosted by IAEE at EVER Monaco 2023. All the presentations revolved around three main topics: energy sobriety and electromobility, adaptation of territory networks, and local renewable energy production. Innovative technologies and emerging trends were showcased, and key lessons from private and public sectors were highlighted. Links are available to the programme and photos from the event.

Marc Vatter reviews research saying that exports of LNG from the U.S. are, on the whole, as dirty as coal, in terms of methane leaks and emissions of CO2 during liquefaction. He shows these concerns to be based on misinterpretation of data, unrealistic assumptions, and omissions of key metrics, and, therefore, invalid.

IAEE MISSION STATEMENT

IAEE's mission is to enhance and disseminate knowledge that furthers understanding of energy economics and informs best policies and practices in the utilization of energy sources.

We facilitate

- **Worldwide information flow and exchange of ideas on energy issues**
- **High quality research**
- **Development and education of students and energy professionals**

We accomplish this through

- **Leading edge publications and electronic media**
- **International and regional conferences**
- **Networking among energy-concerned professionals**

NEWSLETTER DISCLAIMER

IAEE is a 501(c)(6) corporation and neither takes any position on any political issue nor endorses any candidates, parties, or public policy proposals. IAEE officers, staff, and members may not represent that any policy position is supported by the IAEE nor claim to represent the IAEE in advocating any political objective. However, issues involving energy policy inherently involve questions of energy economics. Economic analysis of energy topics provides critical input to energy policy decisions. IAEE encourages its members to consider and explore the policy implications of their work as a means of maximizing the value of their work. IAEE is therefore pleased to offer its members a neutral and wholly non-partisan forum in its conferences and web-sites for its members to analyze such policy implications and to engage in dialogue about them, including advocacy by members of certain policies or positions, provided that such members do so with full respect of IAEE's need to maintain its own strict political neutrality. Any policy endorsed or advocated in any IAEE conference, document, publication, or web-site posting should therefore be understood to be the position of its individual author or authors, and not that of the IAEE nor its members as a group. Authors are requested to include in an speech or writing advocating a policy position a statement that it represents the author's own views and not necessarily those of the IAEE or any other members. Any member who willfully violates IAEE's political neutrality may be censured or removed from membership.

David L. Williams, Sr. 1928 - 2024

The International Association for Energy Economists has the sad duty of informing its members of the death of David L. Williams, Sr., on February 17, 2024. "Dave Sr" served as the Association's Executive Director from 1991 through 2005 and then stepped back but continued to be deeply involved with and supportive of the IAEE after his son, David Williams, Jr., succeeded him as Executive Director until Dave Jr.'s own retirement in 2022.

Recruited by senior IAEE members who had known him in his role as a former leader and Executive Director of the National Association of Business Economists, Dave Sr. took over the IAEE as an 11-year-old association teetering on the brink of bankruptcy. With quiet, astute management, he supported a sequence of volunteer Presidents and officers to develop a truly international non-profit enterprise. On his watch, the IAEE grew to claim a global membership of about 4,000 members in 128 countries, to publish two scholarly peer-reviewed journals and a magazine, to operate a foundation as well as a membership organization, to develop a network of national and regional affiliates, to host major multi-day international and regional conferences in cities around the globe, and, not least, to build a healthy endowment in operating funds and investments. Under his management, the IAEE made major gains toward its mission: growing the knowledge of energy economics globally by convening academic experts, students, business practitioners, and government policymakers, providing them a platform for ground-breaking analysis and new ideas focused on the economics of energy, a critical component of all modern economies and of interdependent global marketplace.

Longtime members may know this history; all members benefit from it. But only those who were lucky enough to cycle through leadership posts or Council positions were in a position to appreciate the courtesy, quiet efficiency, and care with which Dave Sr. provided the IAEE with its administrative services, tag-teaming with Dave Jr. Issues would come up over time – a long-planned conference cancelled over international political tensions, an IAEE President jailed over bogus political allegations, another forced to resign due to ill health – but the IAEE back-office function would quietly continue, finding effective responses and protecting the association membership from feeling the bumps in the road. As the IAEE's General Counsel, I was gratified at how few were the legal issues that ever arose, a credit to his detail-oriented and risk-averse management style.

And even former Presidents and officers may not have known that Dave Sr's cool and competent leadership and frugal financial management had been developed in a prior 34-year career as a business economist and executive in the machine-tool industry. They may not have known that he was an active community leader continuously for three decades at the Laurel Lakes Community where he and his wife Jinny lived. They may have known that he loved classic motorboats, but not that he rebuilt and restored them himself, or that he was a leader in the national organization that promotes boating safety. They almost certainly did not know that he was a multi-sport athlete in college, the Ohio college champion in the quarter-mile race in 1950. He was not one to tout his own achievements, past or present. However, all of us should recognize that bringing the IAEE into its preeminent position as the international gathering of those who care about and practice energy economics was at least as much his achievement as it was that of anyone else, and one that will continue to provide benefits and value to our world in the critical decades ahead.

John W. Jimison, IAEE General Counsel (1989 to present)

Energy Justice – Measuring Impacts in Energy Communities: A Synthesis of the Literature

BY AMANDA HARKER STEELE, LUKE CLAHANE, GAVIN PICKENPAUGH, AND JASON BOERST

Amanda Harker Steele, Luke Clahane, Gavin Pickenpaugh, and **Jason Boerst** are with the National Energy Technology Laboratory. Corresponding author Amanda Harker Steele can be reached at: Amanda.HarkerSteele@netl.doe.gov

Abstract

The benefits and costs of deploying technologies to meet decarbonization targets are not likely to be evenly distributed, and energy communities will face both risks and opportunities in response. This paper identifies metrics available to support energy justice impacts assessments in these communities based on a review of the literature.

1. ENERGY JUSTICE IN ENERGY COMMUNITIES

The assurance of energy justice has become a priority consideration for practitioners, scholars, and policy makers, alike (Baker, et al., 2023; Carley & Konisky, 2020). Referring to equitable social and economic participation in the energy system by all persons and the remediation of existing social, economic, and health burdens, energy justice is an essential component to successfully restructuring existing systems of energy production and consumption to meet current decarbonization goals (Initiative for Energy Justice, 2023; Berkely Lab, 2023; U.S. Department of Energy, 2023; McCauley, Heffron, Stephan, & Jenkins, 2013). Those likely to be most impacted by the restructuring are energy communities, whose interests have historically not been at the forefront of such decisions.

Passed in August of 2022, the Inflation Reduction Act (IRA) uses three different indicators to identify energy communities. These include 1) census tracts (and those directly adjoining) where a coal mine closed after 1999, or a coal-fired power plant retired after 2009, 2) metropolitan or non-metropolitan statistical areas where at any time after 2009 at least 0.17 percent of the direct employment or at least 25 percent of the local tax revenue was from the extraction, processing, transport, or storage of fossil fuels, and whose unemployment rate was at or above the prior year's national average rate, and 3) brownfield sites as defined by the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 (Interagency Working Group on Coal & Power Plant Communities & Economic Revitalization, 2024; Rami & Pesek, 2024). [1]

The U.S. Department of Energy (DOE) has developed a tool to spatially locate areas classifiable as energy communities based on the proceeding criteria (U.S. Department of Energy, 2023). Questions remain to be answered about if and how the energy justice impacts of clean energy projects sited within these energy communities and supported by the IRA or other similar policies can be measured. In particular, these questions pertain to projects wherein technologies designed to aid in decarbonization efforts are being designed, developed, or deployed. The purpose of this paper is to develop a shared and comprehensive understanding of what metrics are available and appropriate for evaluating the energy justice impacts of such projects by synthesizing the results of a scientific literature review conducted on energy justice impacts measurements.

Similar to Baker et al. (2023) we use the term metrics to refer to measures, tools, and frameworks. These include both qualitative and quantitative measures of individual well-being, mapping tools, and evaluation frameworks. We review the literature for each as a means to provide an overview of the ways in which progress toward decarbonization goals through implementation of energy technologies can be evaluated from the perspective of their influence on justice. As most energy justice metrics are built around assessing energy injustices (and similarly inequities), such as the percentage of the population that is energy poor or energy insecure, these types of metrics are listed where appropriate throughout the paper (Preziuso, Tarekegne, & Pennell, 2021).

2. MEASURES OF INDIVIDUAL WELL-BEING

Individual well-being is a broad construct encompassing multiple dimensions often assessed using qualitative and quantitative analysis methods. Qualitatively evaluating the well-being of an energy community requires gaining awareness of justice concerns from the perspective of those directly impacted (i.e., members of the community) and is achieved through the organization, synthesization, and interpretation of responses from focus groups, interviews, and other similar activities (Carley, Evans, & Konisky, 2018; Hammarberg, Kirkman, & de Lacey, 2016). Several studies have taken this approach to evaluate the energy justice impacts of the low-carbon transition – see Fuller and McCauley (2016), Carley, Evans and Konisky (2018), Sovacool, Martiskainwn, Hook, & Baker (2019), McCauley et al. (2019) and Axon and Morrissey (2020) for recent examples.

These approaches often involve micro-scale, human-centered investigations of the opinions, attitudes, values, beliefs, and preferences of community members. Data from such evaluations, however, are not amenable to counting or measuring, and can be time consuming, expensive, and difficult to both collect and replicate (Hammarberg, Kirkman, & de Lacey, 2016; Baker, et al., 2023). As such, traditional approaches to measurement do not apply. Instead, responses from individuals are presented to showcase analytical points

(Hammarberg, Kirkman, & de Lacey, 2016). In the case of energy justice impacts assessments, such approaches can be used to pinpoint whether and what types of injustices are present within communities, as well as the community's preferred approach for remediation.

Unlike qualitative evaluations, quantitative approaches to assessing energy justice impacts rely on numerical (i.e., quantifiable) metrics and utilize spatial, statistical, and regression analysis techniques. Quantitative energy justice assessments help identify who is experiencing energy injustices, the degree to which they are experiencing them, and what their underlying causes are or might be (Carley, Evans, & Konisky, 2018). Oftentimes, this requires combining different data points ranging from the sociodemographic characteristics (e.g., age, race, gender, education) of community members to economic and other well-being indicators.[2] Table 1 provides a list of indicators used to support quantitative energy justice impacts assessments identified from the literature review.

3. MAPPING TOOLS

Multiple mapping tools are available to identify energy communities and illustrate, as well as evaluate questions, policies, and practices with respect to their influence on energy justice (DOE Office of Energy Justice and Equity, 2024). These include the Energy Justice Dashboard (BETA), the Energy Justice Mapping Tools for Schools and Disadvantaged Communities, and the Low-Income Energy Affordability Tool. The Energy Justice Dashboard is a pilot data visualization tool displaying DOE-specific investments in communities experiencing disproportionately high and adverse economic, human health, climate-related, environmental, and other cumulative impacts. The Energy Justice Dashboard relies on data from different DOE offices, including the U.S. Environmental Protection Agency (EPA), which supplies the dashboard with data on communities experiencing air pollution or public health risks based on reports from their EJScreen tool (Office of Economic Impact and Diversity, 2023).[3]

The Energy Justice Mapping Tools for Schools and Disadvantaged Communities are visualization tools for exploring and producing reports for specific school facilities and communities classifiable as disadvantaged, respectively. The Energy Justice Mapping Tool for schools can be used to determine whether the school is located in a disadvantaged community, rural area, designated as a community shelter, or what percentage of the school's students qualify for free or reduced lunch. Similar to the Energy Justice Mapping Tool for Schools, the Energy Justice Mapping Tool for Disadvantaged Communities can be used to explore and produce reports on census tracts categorizable as disadvantaged communities, or DACs, pursuant to Executive Order (EO) 14008.[4]

The Low-Income Energy Affordability Data (LEAD) tool was created to help stakeholders understand housing and energy characteristics for low- and moderate-income households in the United Stated. As such, the tool maps household energy burdens to other socio-economic variables such as their income, age of the dwelling in which they reside, primary fuel used to heat their home, type of housing (e.g., single family home vs. apartment) and whether the household rents or owns (Office of State and Community Energy Programs, 2023). Each of the aforementioned tools can be used to geographically locate energy communities and analyze underlying data, such as what percentage of the schools within the community are Title 1.[5] Such tools are valuable for practitioners seeking to understand energy justice within these communities.

4. FRAMEWORKS

Large-scale, deep decarbonization models are frequently used to assess the emissions reduction potential and monetary impacts of deploying competing technology pathways to decarbonization (Spurlock, Elmallah, & Reames, 2022; NASEM, 2021). Noting the need to be able to assess these technology pathways from the perspective of their impacts to justice and equity, Spurlock et al. (2022) developed the Equitable Deep Decarbonization Framework. Cemented by the four tenants of energy justice – restorative justice, recognition justice, procedural justice, and distributional justice – the framework operationalizes the identification of just technology pathways to decarbonization through a series of steps.

Restorative justice, which calls for the repairment of prior harms to communities and the environment, informs each of the steps and serves as an *ex-ante* rather than *ex-post* evaluation criterion (Spurlock, Elmallah, & Reames, 2022).[6] Guiding the reader through each of the framework's steps, Spurlock et al. (2022) calls for the identification of different metrics to characterize outcomes of deploying one technology pathway over another. Suggested metrics are both quantitative and qualitative, focused on accountability, transparency, and inclusivity of energy communities in the decision-making process to address unequal and inequitable distribution of resources, risks, and responsibilities across both physical and spatial dimensions (Sullivan, 2006; Spurlock, Elmallah, & Reames, 2022).

Other frameworks developed to support energy justice impacts assessments include the Justice Underpinning Science and Technology Research (JUST-R) metrics framework (Arkhurst, et al., 2023), the Energy Justice Decision Making Framework (Sovacool, Heffron, McCauley, & Goldthau, 2016), and the Energy Justice Scorecard (Baker, DeVar, & Prakash, 2019). The JUST- R framework was developed to enable early-stage energy researchers to assess and address justice considerations associated with their research (Arkhurst, et al., 2023; Dutta, et al., 2023). It consists of thirty metrics from the energy justice literature and an additional twenty metrics proposed to fill gaps in the literature around applying energy justice to early-stage research (Arkhurst, et al., 2023; Dutta, et al., 2023).

The Energy Justice Decision Making Framework operationalizes eight different principles of energy justice – availability, affordability, due process, transparency and accountability, sustainability, intra and intergener-

Table 1. Indicators Used to Support Quantitative Energy Justice Impacts Assessments

Category	Indicator	Sources
Demographic	Race/Ethnicity	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Age	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016); (Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Gender	(Damgaard, McCauley, & Long, 2017); (Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Education	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016); (Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	% of Population Marginalized by Caste/ Ethnicity	(Damgaard, McCauley, & Long, 2017)
	Social Status	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Social Outlook	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	% of Population with No Household Facilities	(Damgaard, McCauley, & Long, 2017)
	Housing Type	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021); (Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
Geographic	Immigration Status	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Region	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Geographical Area Type	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016); (Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Distance From Energy Source	(Damgaard, McCauley, & Long, 2017)
	Elevation	(Damgaard, McCauley, & Long, 2017)
	Loss of Amenity to Local Communities Due to Energy Source	(Heffron, McCauley, & Sovacool, 2015)
Economic	Rent Burden	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Personal Income	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Economic Outlook	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Economic Energy Insecurity	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Family Income Level	(Hernandez, Jiang, Carrion, Phillips, & Aratani, 2016)
	Gini Coefficient of Equivalized Disposable Income	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Gini Coefficient of Wealth Distribution	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Gross Domestic Product Purchasing Power Standards (GDP PPS) Per Capita	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Median Income	(Pellegrini-Masini, Egner, Klockner, & Lofstrom, 2021)
	Cost of Energy	(Heffron, McCauley, & Sovacool, 2015)
	Income	(Napton & Day, 1992)
	Energy to Disposable Income Ratio	(Heffron, McCauley, & Sovacool, 2015)
	CO2 Tax	(Heffron, McCauley, & Sovacool, 2015)
	Cost/Benefit to Public Health Services from Energy Source	(Heffron, McCauley, & Sovacool, 2015)
	Cost of Energy Related Accidents	(Heffron, McCauley, & Sovacool, 2015)
	Environmental Pollutants from Energy Sources	(Heffron, McCauley, & Sovacool, 2015)
Energy Infrastructure	Subsidies for Energy Source Extraction	(Heffron, McCauley, & Sovacool, 2015)
	Fluctuation and Price Instability in Energy Supplies	(Heffron, McCauley, & Sovacool, 2015)
	Employment Created from Energy Infrastructure Development	(Heffron, McCauley, & Sovacool, 2015)
	Costs and Benefits of New Energy Infrastructure	(Heffron, McCauley, & Sovacool, 2015)
	Cost of Fluctuation and Instability in Energy Supplies	(Heffron, McCauley, & Sovacool, 2015)
	Cost and Benefit of Importing/Exporting Energy Supplies	(Heffron, McCauley, & Sovacool, 2015)
	% of Population with Access to Specific Energy Type	(Damgaard, McCauley, & Long, 2017)

Note: Indicators in this table include both quantitative and qualitative variables pertaining to energy justice within energy and other communities. Quantitative variable can be either continuous (i.e., can take any values within an interval) or discrete (i.e., can only take specific numerical values). Qualitative variables or categorical variables describe a feature of a community, or its members being studied (e.g., average income).

ational equity, and responsibility – that can be applied to real world problems of interest. Lastly, the Energy Justice Scorecard is a tool for evaluating an existing or proposed energy policy according to whether it 1) has participation in the policy making process by marginalized communities, 2) remedies prior or present harms faced by communities, 3) centers decision-making on the needs of marginalized communities, 4) offers social, economic, or health benefits, and 5) makes energy more accessible and affordable to these communities. Practitioners can use the scorecard to evaluate policies against a "perfectly" energy just policy.

5. CONCLUSIONS

Meeting current decarbonization goals will require demonstrating and deploying clean energy technologies. Of interest and particular importance are the energy justice impacts of such demonstrations and deployments for energy communities. This paper provides a synthesis of the quantitative and qualitative measurers, mapping tools, and frameworks, collectively referred to as metrics, available to support energy justice impacts assessments based on a review of the literature. While the results of the review suggest multiple metrics exist, ensuring a just energy transition, will require identifying how these metrics can be used together to collectively support analysis efforts related to energy justice impacts assessments. Specifically, the energy justice impacts related to designing, developing, and deploying energy technologies. Given their mission to drive innovation and deliver technology solutions to support affordable, abundant, and reliable energy, researchers at the DOE's National Energy Technology Laboratory are undertaking research to develop *EEJustTech* – a holistic procedure for conducting energy justice impacts assessments that will leverage the metrics described above.

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Footnotes

[1] While some energy communities are also disadvantaged communities, it is important to note that not all energy communities are also disadvantaged communities. The Department of Energy identifies disadvantaged communities as a group of individuals living in geographic proximity (such as census tract), or a geographically dispersed set of individuals who have something in common (e.g., their nationality) who are overburdened or underserved according to 36 indicators covering the topic areas of climate change, legacy pollution, energy, transportation, health, water and wastewater, housing, and workforce development (Office of Energy Justice and Equity, 2023).

[2] An example would be the number of persons in an energy community who are energy poor. Being able to quantify the rate of energy poverty requires gathering data on the income and fuel expenditures of households.

[3] EJScreen is an EPA's environmental justice mapping and screening tool that provides EPA with a nationally consistent dataset and approach for combining environmental and demographic socioeconomic indicators. EJScreen users choose a geographic area; the tool then provides demographic socioeconomic and environmental information for that area. All of the EJScreen indicators are publicly available data. EJScreen simply provides a way to display this information and includes a method for combining environmental and demographic indicators into EJ indexes (EPA, 2023).

[4] Disadvantaged communities are similar but different to energy communities. The DOE's working definition of disadvantage is based on the cumulative burden of a census tract. There are thirty-six (36) burden indicators that reflect fossil dependence, energy burden, environmental and climate hazards, and socio-economic vulnerabilities.

[5] Title I schools are schools that receive federal funding to support the hire of additional teachers and support staff, purchase computers or software, support after and summer school programs, and purchase additional materials. Eligibility is based on the number of students who qualify for free or reduced lunch (National Center for Education Statistics, 2024).

[6] Restorative justice as an *ex-post* criterion suggests compensating those harmed by a proposed policy.

The spread of the “prosumer” in European and French law: the structuring of energy communities

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Abstract

Energy communities are one of the legal tools to spread the prosumer figure, called “active customer”. The contribution aims to focus on their governance by the “effectively controlled by members or shareholders” analysis and show how this element helps or not the prosumer figure concretisation, in European and French energy law

Keywords: renewable energy; prosumer; energy communities

The European Union, which has a strategy of leadership in international climate policies [1], has, more quickly than the international order [2 ; 3 ; 3 ; 4 ; 5], adopted a common energy policy[1] combining the single market with environmental and climate issues. The crisis in the energy market has reinforced the need to ensure the energy security of the Member States[2], in particular through the use of renewable energies.

The growing use of renewable energy (RE) sources and greater competitiveness with traditional production methods [6], the desire of citizens to take back control of the way they consume and produce energy [7] have all helped to consolidate new local social dynamics [8], resulting in a proliferation of projects that produce or consume energy differently. The result is, notably, the emergence of energy communities (EC) in all shapes and sizes [9].

As early as 2008, Walker and Devine-Wright [10] identified the two pillars of these communities: governance processes that are intended to be open and participatory, and a concern to localise their economic, political and symbolic benefits [11]. Hoffman et al [12] define EC as “a decentralised method of energy production based on a variety of distributed energy technologies where production decisions are made as close as possible to the point of consumption”. These communities go beyond participatory financial investment. Consumers are no longer spectators of their energy consumption, but become players in it.

Energy law is being mobilised to support these EC [13]. This use of law is an international movement that is embodied in the spread of the figure of the *prosumer* (1) and carries over into European EC law (2), which French law transposes in a specific way (3).

1. The international spread of the prosumer concept

The International Energy Agency (IEA) has formalised the notion of the prosumer. It echoes the work of futurologist Toffler [14], who believes that the future will be made up of “prosumers”, i.e. citizens who become active producers of goods and services rather than passive consumers. Prosumerism characterises the breaking down of the distinction between producer and consumer [15], which emerged during the Industrial Revolution. In 2014, the IEA adapted the term to the energy sector: “The term prosumer is used to refer to energy consumers who also produce their own power from a range of different onsite generators” [16]. More broadly, and even if the definition is debated [17], according to Brown, Hall and Davis [18], a prosumer is an “actor who both produces and consumes renewable energy and actively modulates their demand”.

The IEA’s proposal has been accepted in developed countries [19]. For the European Union, in its 2015 communication, *A Framework Strategy for a Resilient Energy Union with a Forward-Looking Climate Change Policy*[3]: “our vision is of an Energy Union with citizens at its core, where citizens take ownership of the energy transition, (...), participate actively in the market”. The term “prosumer” is not used, but the broad outlines of the concept are present and will be given concrete form in the own-initiative opinion of the European Economic and Social Committee in 2016 [20]: “Prosumer energy can be regarded as an essential element of the transition to distributed generation”[4] . Prosumers are defined as “Prosumers are individuals, groups of individuals, households or farms able to operate in an organised way, e.g. through associations, foundations or cooperatives, that are both producers and consumers of energy produced in small installations located in back yards or on residential or commercial buildings (...). Prosumers can also be small businesses, including social enterprises and local authorities.”[5] .

These institutional positions have been incorporated into the directives, in particular the 2019 directive on electricity market, under the term “active customer” as “a final customer, or a group of jointly acting final customers, who consumes or stores electricity generated within its premises located within confined boundaries or, where permitted by a Member State, within other premises, or who sells self-generated electricity or participates in flexibility or energy efficiency schemes, provided that those activities do not constitute its primary commercial or professional activity”[6]. They may therefore, individually or collectively, consume, store, produce, sell or participate in flexibility or energy efficiency schemes.

The concept is legally defined, but it needs to be made operational, in particular so that it covers the implications in terms of “governance”, since prosumers must “operate in an organised way”[20] .

2. The operationalisation of the prosumer in the European legal order: EC

The "prosumer" can take many forms [21; 22], from individual self-consumption[6] to collective self-consumption [23; 24] or membership of an EC in which the notion of "making a group" is an innovative breakthrough in the energy system [25].

At European level, the EC makes it possible to operationalise the notion of the *prosumer* or active customer through two types of EC [26; 9]: the renewable energy community (REC)[7] , and the citizen energy community (CEC)[8]. As groupings of activities and players, they will give their members the opportunity to become active in the energy system. Based on "*open and voluntary participation", they are both "effectively controlled by members or shareholders*"[9]. Their aim is "*to provide environmental, economic or social community benefits for its shareholders or members or for the local areas where it operates, rather than financial profits*"[10] .

There are two main differences between them. Firstly, in terms of the activities carried out: the REC can produce, consume, store and sell RE, share within itself the RE produced by the production units it owns and access the relevant energy markets[11] ; the CEC, active only in the field of electricity (renewable or not) can carry out the same activities as the REC, but can also be an aggregator, energy supplier and/or energy services provider[12]. Secondly, their geographical scope is not the same. This criterion is decisive for the qualification of "*effective*" control of the community. Only the REC will be linked to its territory. It will be controlled "*by shareholders or members that are located in the proximity of the renewable energy projects that are owned and developed by that legal entity;*"[13]. It is exactly at the interface between these two criteria that the challenge of structuring community governance [27] arises, and therefore the operationalisation of the notion of "active customer". The French case is particularly exemplary.

3. The French legal framework for EC: an example of the complex implementation of the concept of effective control

The EC French law is now codified in articles L. 291-1 to L. 294-1 and R291-1 to R293-1 of the Energy Code. The effectif control mobilized to criteria, the autonomus and the geographical proximity

About effective control, there is a presumption when more than 40% of the voting rights of the community are held, directly or indirectly, by one of the categories of persons eligible to exercise such control and no other category of person holds a higher proportion of voting rights than that held by the first category[14]. These eligible persons meet certain criteria, distinguishing "open" participation from effective control[15]. For example, if there are no more than twenty people in the community, they may participate but may not exercise effective control over it[16].

The EC must comprise at least twenty natural persons or two of the categories of persons eligible to exercise effective control over the community, "*which must include those who benefit, whether free of charge or in return for payment, from the environmental, economic or social advantages that the community provides*"[17] .

A REC will be made up solely of natural persons, small and medium-sized (SMEs) autonomous enterprises[18], local authorities and groups of local authorities, local semi-public companies, social entrepreneurship funds[19], or associations[20]. The same categories of member as for the CER may be members or shareholders of the CEC, and effectively control it, without reference to geographical proximity[21].

EC should take the form of an "*autonomous*" legal entity or legal person, bringing together the various participants, whether consumers, producers or investors[22]. Autonomy, like effective control, is particularly linked to the search for the "*active customer*". It expresses a certain vigilance with regard to the more traditional players in the energy sector. The preamble to the RED II Directive states that "*To avoid abuse and to ensure broad participation, renewable energy communities should be capable of remaining autonomous from individual members and other traditional market actors that participate in the community as members or shareholders, or who cooperate through other means such as investment*"[23]. Under French law, autonomy is required for both communities[24] . The European text defines an autonomous company negatively as one that is neither "Linked enterprises" nor "*Partner enterprises*"[25] .

Articles R. 291-1 and R. 292-1 of the French Energy Code lay down special prohibitions for member companies of an energy pool and their employees. Thus, those "*holding more than 10% of the voting rights and 10% of the equity and quasi-equity [of a community], or of an undertaking controlling or being controlled directly or indirectly by such an undertaking, in particular, may not hold, directly or indirectly, (...) more than 10% of the voting rights and 10% of the equity and quasi-equity of that community*" on an individual basis. Collectively, these amounts may not exceed 33% or the amount held collectively by "*other natural persons [and] local authorities or groups thereof*". More generally, a company and its employees may not together hold more than 40% of the equity, quasi-equity and voting rights.

This vigilance also applies to companies in the energy sector. Partly in line with European law, French law stipulates that when a private company participates in a community, it may not do so as part of its main commercial or professional activity[26]. In European law, only the REC is directly concerned by this prohibition, which seems to be limited to cases where the company's participation is on behalf of "final customers"[27]. The CEC is not concerned, but the directive emphasises that decision-making powers are "limited to those members or shareholders that are not engaged in large-scale commercial activity and for which the energy sector does not constitute a primary area of economic activity" [28] .

The criterion of geographical proximity is the second element of effective control. It applies only to RECs and differs according to the legal nature of the members of the REC[29]. Only those of its members located "*in the geographical proximity*" of the RE projects it has developed or subscribed to will be able to control the community.

People must live in the area (french department) where the community's RE projects are located, or in an adjacent area. The REC's member associations must have at least twenty natural person members residing in the same area. This raises a number of questions. For example, will a REC that is effectively controlled by twenty natural persons living near the project have to replace the member leaving the community to move outside the geographical area in order to continue to exist?

For SMEs, the head office or one of the secondary establishments must also be located in the departement where the project is to be set up or in a neighbouring departement.

For local authorities, effective control is deemed to be exercised when each of the RE projects to which the community has subscribed or which it has developed are located in their territory or in a neighbouring territory, except for the Region, which can only act within its territory.

However, this condition of geographical proximity does not apply to all members of the REC, but only to those belonging to the category holding more than 40% of the voting rights in the community.

CEC is not subject to these conditions of geographical proximity[30], only its purpose, to provide environmental, economic or social benefits to its members, or "*to the local territories where it carries out its activities*"[31], creates a link with the territory. This may be explained by the CEC activities, which does not concern renewable energies, which are more likely to be local, but only electricity, whether or not of renewable origin.

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The notion of the prosumer makes it possible to analyse the spread of a paradigm shift in the energy system, which must now rely on consumers to ensure the deployment of RE. This move towards an active consumer is still in its infancy [21]. In France, the legal framework is beginning to be fleshed out by the concept of "effective control", but the other part of the prosumer concept has yet to be defined. To ensure full control, prosumers and communities must have rights equivalent to those of other players in the system [28]. In this sense, communities are subject to fair, proportionate and transparent procedures, and cost-reflective network charges, "ensuring that they contribute, in an adequate, fair and balanced way, to the overall cost sharing of the system in line"[32] and "should be allowed to operate on the market on a level playing field without distorting competition, and the rights and obligations applicable to the other electricity undertakings on the market should be applied (...) in a non-discriminatory and proportionate manner"[33] . The groundwork has therefore been laid; everything remains to be developed.

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Footnotes

[1] Art. 194(2) TFEU

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[3] COM/2015/080 final

[4] § 5.13

[5] §5.5

[6] Art. 2 8), dir. 2019/944 of 5 June 2019 on common rules for the internal market for electricity, OJ L 158, 14.6.2019

[7] Art. 2 16) ; art. 22, dir. 2018/2001 of 11 December 2018 on the promotion of the use of energy from renewable sources, OJ L 328, 21.12.2018

[8] Art. 2 11); art. 16, dir. 2019/944

[9] Art. 2 16) a), dir. 2018/2001; art. 2 11) a) dir. 2019/944.

[10] Art. 2 16) c), dir. 2018/2001; art. 2 11) b) dir. 2019/944.

[11] Art. 16, dir. 2018/2001; art. 2 11) b) dir. 2019/944.

[12] Art. 22 dir. 2019/944.

[13] Art. 2 16) a), dir. 2018/2001

[14] Art. L. 291-3, para. 3; L. 292-4, para. 3, Energy Code.

[15] Art. L. 291-1, 1°; L. 292-1, 1°, C. énergie.

[16] Art. L. 291-3, paras. 2 and 3; L. 292-4, paras. 2 and 3, Energy Code

[17] Art. L. 291-3, para. 2 and L. 292-4, para. 2, Energy Code

[18] Defined in art. 2, Annex Commission Recommendation concerning the definition of micro, small and medium-sized enterprises, C(2003) 1422), OJ L 124, 20 May 2003, art. 2 8), dir. 2018/2001.

[19] Art. L. 214-153-1, Monetary and Financial Code

[20] Art. L. 291-1, 2°, Energy Code

[21] However, the text refers to small autonomous companies within the meaning of art. 2 11), dir. 2019/944.

[22] Art. L. 291-3; L. 292-4, Energy Code

[23] §71, dir. 2018/2001

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[25] Art. 3(1), Commission Recommendation C(2003) 1422).

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[27] Art. 22, 1°, dir. 2018/2001.

[28] §44), dir. 2019/944.

[29] Art. R. 291-8, Energy Code.

[30] §46, dir. 2019/944

[31] Art. L. 292-1, 3°, Energy Code.

[32] Art. 22, 4° d) dir. 2018/2001

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Some lessons learned from Renewable Energy Communities in Austria

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Introduction

Citizen's involvement in energy supply has a long history in Austria since the beginning of the 20th century (Brazda, 2023). Back then, electricity cooperatives were founded in rural areas focusing on power supply and consumption. Some of them take advantage of Austria's geographical location and use renewable energy, such as hydropower, to supply rural communities with power. Until today, some founded energy cooperatives are running as grid operators and power suppliers. History shows that Austrian citizens have been a driving force behind using renewable energies as alternative generation forms. It can be said that energy cooperatives are the forerunners of energy communities (ECs) in Austria (Brazda, 2023). Both share fundamental principles such as decentralization, local and citizen engagement *(Boddenberg & Klemisch, 2018).* Renewable energy communities (RECs) aim to generate and consume renewable energy locally, increasing self-consumption and reducing the energy supply from the grid (Preßmair, Mayr, & Benke, 2024). All citizens, aside from living in a city or not owning a renewable energy source (RES) is given the chance and are engaged to actively participate in the energy transition and local energy concerns. At the same time, RECs locally may increase the use of RES and provide balance to urban regions with higher consumption patterns (Neubarth, 2020). The core objective of this article is to document the development of RECs in Austria and to discuss their future prospects.

Regulatory Framework

The Clean Energy for All Europeans Package (CEP) of the European Commission was introduced in 2019 and offers a legislative framework for ECs to strengthen their role in the energy system (European Commission, Directorate-General for Energy, 2019). The CEP determines a distinction between Citizen Energy Communities (CEC) and RECs. The main differences are that CECs can be engaged in different areas of energy supply and use, while RECs are focused on renewable energy and have stricter participation criteria and restrictions on fields of activity. Both aim to create an ecological and joint benefit. The European countries are obliged to transpose the supranational directives into national directives within two years. Since then, European countries have implemented the directives differently into national law. Austria is a pioneer in Europe since, in 2021, the international guidelines were almost entirely transposed into national law. Since then, registered ECs have risen to 675 RECs and 28 CECs (Status of June 2023) (see figure 1) (Energie-Control Austria, 2023).

In Austria, the Renewables Expansion Act (BMK, 2021) established a legal basis for ECs and determines a distinction between the following ECs: joint generation plant, REC, CEC. Since the creation of a legal framework for RECs, they are legally allowed to collectively generate energy (electricity, gas, or heat) from renewable sources across property boundaries and collectively consume, store, and sell it (BMK, 2021). In Austria, financial relief is provided for RECs, including the elimination of the renewable energy subsidy and electricity levy for the purchase of energy from RECs (RIS, 2010) (Cejka & Kitzmüller, 2021). Additionally, the grid tariff is reduced, and the reduction amount depends on whether it's a local or a regional REC.

Lessons learned from RECs in Austria

There are various motivations for founding or participating in an EC. The motivation to establish an EC is mainly based on ecological or economic reasons. However, RECs in Austria are allowed to be entrepreneurial, but their main purpose must not be financial gain. Most of the RECs surveyed stated they founded the REC for environmental reasons aiming to promote regional self-sufficiency and independence from energy supply companies. Some municipalities set specific goals for their town to spread renewable energy sources and save CO_2 emissions. However, economic reasons also play an essential role in founding and participating in an EC as, among others, financial incentives are created through low electricity procurement costs or increased feed-in tariffs generating an economic benefit. Besides that, RECs enable long-term stable prices and to some extent independence from the electricity market and supply companies.

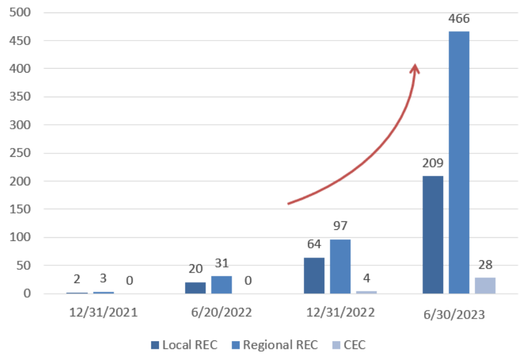

Fig. 1: Development of RECs in Austria

In the founding process a distinction is made between a local and regional REC, depending on the connected grid level. In Austria, regional RECs, which are connected to medium voltage levels 4 and 5 with voltages up to 37 kV, are established most frequently. Local RECs are connected to low-voltage level (6 and 7) with voltages up to 1 kV applies to local RECs. The founder of a REC can choose between the legal forms of association, cooperative, partnership, or corporation (BMK, 2021) (RIS, 2010). The non-profit nature of the REC should be a priority in the selection process. The results show that RECs mainly choose associations as their organizational form. There are also some cooperatives and a few limited liability companies. Experience to date shows that RECs are mainly set up by municipalities, followed by private individuals, companies, and small to medium-sized enterprises (SMEs). The participation structure is primarily made up of private persons, followed by companies, municipalities, and farms. The results show that the founding process varies greatly depending on the REC and can last from less than six months to two years. Generally, the start-up period lasts between 6 and 12 months.

Establishing RECs also involves several challenges in the founding process. The main difficulties in the founding process concern regulatory challenges, stakeholder engagement and economic interest, smart meter installation, operation, and energy pricing. Potential founders of RECs see this process as very complex and challenging as there are numerous portals to register and apply. In the first steps, REC's struggle to decide what legal form to choose and what tariff structure to determine. Additionally, the communication with gird operators is described as laborious, and participants may lack in understanding of the concept of RECs and the steps to participate in one. Both difficulties demand persistence and patience in the founding phase.

Further, it is necessary for each member to have a smart meter in order to operate the RECs. The results show that most RECs have a smart meter, or at least some members have one. Only a few RECs do not yet have a smart meter, what is perceived as a challenge as it makes the start-up process even longer until the smart meter installation is finished. The main reasons for the non-establishment of RECs are high efforts in founding and administration and a lack of acceptance and understanding among citizens.

Besides the founding process and its challenges, the evaluation gives insights into the structure and characteristics of RECs in Austria, showing that the primary type of electricity generation is PV systems (see figure 2). Furthermore, many ECs combine PV systems and hydropower plants for electricity generation. In contrast, the following generation types account for smaller shares: Wind, PV and biogas, PV and geothermal. The generation capacities vary depending on the RECs and range from a few kW to more than one MW. The different structures of the RECs are also reflected in the number of members and generation units. There are energy communities with three members or up to 100 members and generation units of one to 50 units per REC. Looking into the flexibility option of RECs, the characteristics of the RECs to date show that most of the RECs have not yet integrated storage and that some RECs are planning to integrate storage in the future or are already in planning an integration. So far, only a few RECs have coupled the electricity and heating systems. However, this may play an essential role for some RECs in the future or is already being examined. Today, e-mobility only plays a subordinate role for RECs, but some RECs are considering integrating e-mobility in the future or are already planning to do so. Large consumers such as heat pumps, electric heating systems, and small businesses can be found in almost all RECs, thus showing the potential for future adapted consumption behavior.

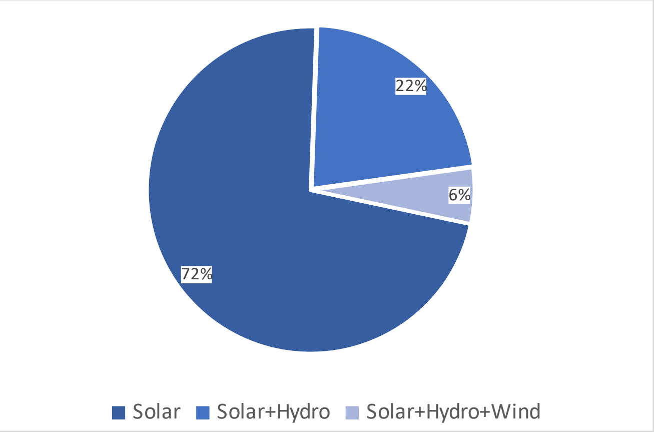

Fig. 2: Energy source of RECs in Austria

As RECs determine the tariff structure within their community, it is out of interest what the general tariff design looks like. The evaluation shows that most RECs in Austria have the same feed-in and consumption price for consumers and prosumers. This usually is between 18 and 20 ct/kWh. When setting the price, incentives should be created for both consumers and prosumers. For this reason, the RECs set the price between the feed-in tariff (set by OEMAG, the clearing office for green electricity in Austria) and the average consumer electricity prices. Some RECs in Austria create tariff models that make it possible to provide community energy more cheaply for financially weaker households or to keep the tariff at the same level in the long term. Thereby, RECs create social benefits and reduce energy poverty, which affects 3% of the population in Austria.

RECs also decide on a static or dynamic allocation method. The surplus electricity is fed into the grid depending on the selected allocation key. With static allocation, a fixed amount of generated energy is agreed upon for each participant, allocated every quarter of an hour (Cejka & Kitzmüller, 2021). The defined amount of generated energy is allocated to the consumer for consumption, and the amount of unconsumed energy is fed into the grid. For this reason, this allocation method has a lower amount of self-consumption, as the allocated energy is not adapted to the consumption behavior (Energiegemeinschaften, n.d.) (Bundesministerium für Wissenschaft, Forschung und Wirtschaft, 2017). In Austria, most RECs use a dynamic allocation key, in which the participants are allocated an individual energy share adapted to the respective consumption of all participants in the EC (Bundesministerium für Wissenschaft, Forschung und Wirtschaft, 2017). If a participant requires less community energy than they are entitled to, the surplus energy is allocated to another member who has a higher demand. The efficient use of energy provides more targeted support for the idea of energy communities to maximize self-consumption (Bundesministerium für Wissenschaft, Forschung und Wirtschaft, 2017). In addition, however, a more complex contract or settlement is required (Bundesministerium für Wissenschaft, Forschung und Wirtschaft, 2017). Each REC must determine the shares of the locally produced energy quantity to the participants based on the allocation key and inform the distribution system operator of the selected allocation key In this way, the grid operator can adjust the members' meter readings and divide each participant's electricity flow into the allocated generation share for the local electricity bill within the EC and the residual electricity demand purchased from the individual supplier (de Villena et al., 2020). Due to the high administrative expenses, the majority of RECs use a service provider for services such as billing. Analyzing several RECs' electricity generation and consumption data shows that successful RECs are characterized by the highest possible indicator of kWh saved per participant. The higher the kWh saved per participant, the higher the emissions and costs saved per participant. An EC's generation and consumption structure are directly reflected in indicators such as the degree of self-sufficiency and self-consumption. The quantitative indicators are changed by influencing factors such as a dynamic growth and loss of members or the installation of new generation systems. Additionally, the energy crisis, starting in 2022, impacted the dynamics of RECs. The high electricity prices meant that more and more citizens were interested in participating in RECs due to lower electricity prices within the RECs. On the other hand, a reduced interest on the part of prosumers was observed. This was partly due to the very high feed-in tariffs of the energy supply companies, which far exceed the feed-in tariffs of RECs. In addition, the RECs stated that they had invested more in new PV systems during this period and were able to attract new members.

Future Perspectives and Conclusion

Most participants see RECs as a successful model as economic and ecological goals can be achieved and as an essential instrument for increasing the participation of citizens in the energy transition and decarbonizing the energy system. However, there are still some improvements that would further improve both the foundation and the ongoing operation. There are two leading suggestions for improvement from the RECs' point-of-view. Firstly, the founding effort should be reduced. Secondly, communication with the network operator should be simplified and accelerated.

Many RECs have been operating well for over a year, and are planning future activities. These plans include PV expansions within the REC and the admission of new members with PV systems. Other plans of RECs are mostly in line with the optimization of self-consumption via storage systems and electricity and heat coupling. The evaluation shows that most RECs, especially those with PV-only electricity generation, cannot exploit their full potential and have a low self-consumption rate. Increasing the number of participants can improve the values of the community indicators. It also reduces the surplus energy, which supports the idea of local use of the generated energy. The evaluation of previous experience has shown that small-scale flexibilities such as heat pumps, electric heating systems, electric cars, and storage systems are already present in most RECs. It can be assumed that, due to the further electrification of energy services, the number of electrical consumers such as those mentioned above will continue to increase, thus increasing the flexibility potential (Neubarth, 2020).

Flexibilities such as load shifting can be used to increase self-consumption further and actually reduce consumption from the grid. Until now, there has been no load shifting, and the energy flows in the grid stay the same, as the surplus energy of the prosumer is subsequently allocated to the consumption of the REC participants (Preßmair, Mayr, & Benke, 2024). By integrating e-mobility into the RECs, the surplus electricity of the prosumers could be used to charge the members' electric vehicles. The integration of a storage system enables self-consumption to be increased further by storing surplus electricity and consuming it at times of low electricity generation from RES. The storage unit could be purchased collectively within a REC, and the investment costs could be implemented in the tariff structure. A further possibility has opened in Austria from January 2024, in which multiple participation in EC is permitted by law (RIS, 2010). This makes it possible to make surplus electricity available to another EC instead of feeding it into the public grid. A participation factor determines the share of generation or consumption in the respective EC. Multiple participation will initially only be possible at five ECs simultaneously.

An open point of discussion (Preßmair, Mayr, & Benke, 2024) (Fina, 2021) is the reduced grid tariffs for RECs and whether these are justified, as so far RECs do not yet provide grid and system services However the reduced grid tariffs create a financial incentive for establishing ECs. The Austrian supervisory and regulatory authority e-control will carry out and publish a cost-benefit analysis in the first quarter of 2024, as stipulated in §79(3) the Renewable Energy Expansion Act, which should ensure that the RECs and CECs participate appropriately in the system costs (grid costs and balancing energy costs) (BMK, 2021). The results could lead to a possible change in the cost structure (Energiegemeinschaften, 2024, FAQs). Other challenges are that RECs have an impact on energy suppliers. The energy supplier only serves as a residual electricity supplier to cover the residual load of the members, especially in the morning and evening when exchange electricity prices tend to be high. In the sunny hours of the day, when the electricity exchange prices tend to be lower, most RECs can cover their consumption and sell the surplus electricity to the energy supplier. For the energy supplier, this results in a loss of revenue for customers with a fixed price tariff per kWh. One possibility is the introduction of dynamic tariffs for consumers and prosumers of RECs. According to Preßmair, this could lead to higher balancing energy costs for the energy supplier due to the changed load behavior and the more difficult scheduling (Preßmair, Mayr, & Benke, 2024). This shows that a new dynamic pricing and tariff system will be needed, taking into account the power component of feeding electricity into the grid as well as drawning from the grid.

In conclusion, the REC concept has been successfully implemented and launched in Austria. However, there are still some hurdles that need to be overcome in order to establish a fully functioning and coordinated operation. RECs offer many opportunities, including the involvement of citizens in the energy transition, the spread of RES, and the use of small-scale flexibilities. The next few years will reveal the extent to which the full potential of RECs can be exploited in Austria.

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Communities Advancing the U.S. Energy Transition

BY VINCENT MUSCO AND CAROLYN BERRY

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Abstract

As policy makers increasingly recognize the value of community-driven energy investments, we highlight three examples of U.S. states where community-driven projects are an active part of the transitioning energy sector. Each demonstrates the importance of legislatures, regulators, utilities, third-party developers, non-profits, and individual community members in driving energy communities and community driven projects. These examples show that energy community programs use different business models, involve different levels of utility involvement, seek electricity products in addition to energy, and incorporate other policy goals. We draw out aspects of the programs that appear to be working well.

Increasingly, policymakers are recognizing a role for community-driven energy investments in decarbonizing the electricity sector. The European Union, for example, introduced the concept of energy communities in 2019 through legislation that overhauled its energy policy framework.[3] In the U.S., state legislatures and regulators have passed laws and rules that allow for and encourage participation by community-driven energy investments and projects, often included in efforts to allow for development of distributed energy resources.[4] Nevertheless, community-driven energy remains in its infancy. Of the approximately 1,300 GW of generation capacity in the U.S.,[5] just 5.27 GW (0.4 percent) is community solar generation,[6] which is by far the most prevalent form of community-driven energy investments to date.

Community-driven investments have historically faced substantial hurdles. Community-driven projects, averaging about 2 MW in size,[7] lack economies of scale resulting in a levelized cost of energy that is much higher than utility-scale solar projects.[8] Additionally, community-driven projects have been limited by legal restrictions, regulatory constraints, and interconnection challenges that prevent their development.

In the U.S., many states have taken steps to reduce or remove these hurdles and have designed programs that attract investment in community-driven projects. The programs create legal and regulatory structures that either pull together energy consumers to collectively finance in a project offered by a utility or third-party developer or allow those individual energy consumers to collectivize and invest as they see fit. At least 24 states have enacted community solar-enabling legislation,[9] and as we demonstrate below, the programs available in the U.S. can vary widely in their approaches to incorporating energy communities and community-driven projects.

No program allowing community participation is perfect. Each involves tradeoffs, competing policy goals, opportunity costs, and questions of rate design, cost allocation, and fairness. Not surprisingly, while some programs share similarities, no two are the same. Even the definition of "energy communities" can differ across jurisdictions. The definition in the U.S. Inflation Reduction Act (IRA) includes (1) brownfield sites, (2) census tracts, (3) "metropolitan statistical areas" and (4) "*non*-metropolitan statistical areas" that meet certain criteria,[10] whereas others, like Illinois, define community-owned projects as "owned collectively by members of the community to which an electric generating facility provides benefits" where "members of that community participate in decisions regarding the governance, operation, maintenance, and upgrades of and to that facility."[11]

Below, we provide examples in three U.S. states where community-driven projects are an active part of the transitioning energy sector. Each demonstrates the importance of legislatures, regulators, utilities, third-party developers, non-profits, and individual community members in driving energy communities and community driven projects. The programs elicit participation by providing economic, environmental, educational, and even psychological benefits to energy community participation. These examples show that energy community programs use different business models, involve different levels of utility involvement, seek electricity products in addition to energy, and incorporate other policy goals. We draw out aspects of the programs that appear to be working well.

Illinois

Illinois offers a variety of opportunities to subscribe to community renewable projects. In 2017, the Illinois state legislature passed Public Act 099-0906 (the "Future Energy Jobs Act", or "FEJA").[12] FEJA created three key programs for community participation.

"Illinois Shines" is a program created to facilitate investment in new solar photovoltaic projects, including distributed systems (rooftop solar) and community projects. A stated purpose of the program is to attract capital that, absent the program, would not be invested in solar projects. The Illinois Shines program accepts applications from qualifying vendors to obtain a 15 to 20-year contract under which they would receive renewable energy credit (REC) payments associated with the output from new solar arrays serving homes and businesses including those unable to site solar panels on their properties. Vendors, in turn, sign up individual subscribers, who receive bill credits for solar output on their electric bill. Community projects are required to have at least 50% of the project capacity subscribed by residential and small commercial customers with subscriptions no larger than 25 kW. REC payments are administratively determined using industry data and are designed to decrease as participation in the program ramped up (or increase if participation ebbs).[13]

To date, 116 community solar projects have been built and energized under the program, with another 1,099 projects under development.[14] In 2020, new legislation – the Climate and Equitable Jobs Act ("CEJA") – expanded the Illinois Shines program and adjusted the community project aspect. To better allocate limited program funds, an evaluation scoring metric was developed that prioritized projects placed on contaminated (or brownfield) lands or on existing structures, and that have other locational and environmental project attributes. The program changes introduced a new category – "community-driven" community projects – which, among other criteria, require projects to be at least 50 percent owned by community residents or non-profit organizations which directly serve the community where the project is located, and to provide community benefits, including bill savings, revenues from project ownership, tax credits, job creation, as well as indirect benefits (environmental, educational, cultural). Community-driven projects are required to comprise at least 5 percent of all projects procured under the program. To date, 110 community-driven projects are under development.[15]

The "Solar for All" program is similar to Illinois Shines but is designed to attract subscribers that lack sufficient means to participate in that program. It targets eligible homeowners and renters, non-profits, and public facilities serving eligible communities. To accomplish this, the REC prices for the Solar for All program are set higher than those in Illinois Shines.[16] Like the Illinois Shines program, vendors can receive upfront payment for all RECs upon energization of the project, which facilitates the financing of the project.[17]

The third FEJA program consisted of a series of competitive procurements in which jurisdictional utilities were required to solicit proposals from developers for non-solar community renewable and low-income community solar projects. Held in December 2019, the procurements had strict eligibility requirements. For example, community solar projects were required to partner with one community-based organization (for up to 40% of the project capacity) and demonstrate economic benefits to the community, such as local employment and revenue benefits. Unlike the Illinois Shines and Solar for All programs, qualified developers competed for 15-year contracts based on their bid prices, rather than on qualitative considerations. Two projects were selected in the low-income community solar category.[18] No bids were submitted in the "non-solar" community renewables procurement,[19] indicating that solar photovoltaics, at least for now, are the resource of choice for community projects.

The Illinois programs show the importance of legislation and regulation in fostering development of energy communities. FEJA and subsequent law revisions created mandates and funding sources for the programs. This allowed private capital to develop projects and seek interested community members to become subscribers and/or owners.

Some of the Illinois programs key aspects include:

- The programs result in *incremental* solar projects, i.e., invested capital that otherwise would not otherwise be allocated to solar projects.
- The programs seek to optimize land use by prioritizing investment in brownfield and environmentally hazardous areas or use of existing infrastructure.
- The programs use dedicated and specified funding set out in state law to pay for delivered RECs, which lowers investor risk associated with the programs.
- Illinois is using competitive procurements as tool to lower project costs.
- All programs use well-vetted contracts to govern the transactions. These contracts help protect counterparties from underperformance and other risks.
- State regulators, agencies, and legislators have shown flexibility in changing program designs to respond to the supply and demand observed for the programs. For example, when the Illinois Shines program was adjusted by law to expand funding and create additional categories of projects that better target specific state policy goals, such as subscriber-owned projects and projects that demonstrate greater levels of community benefits when it became clear that those kinds of projects were not being built.

Minnesota

Minnesota offers an example of a state with a lengthy history of community-driven projects that has adapted through time and spawned a unique business model that allows community members to participate in and own new projects. Minnesota's program, also known as Solar Community Gardens, was enacted through state legislation in 2013.[20] It defined a community solar garden as a solar facility, of up to one megawatt, that sells energy to subscribers who purchase a given portion of its output. It required all energy generated by the facility be purchased by the public utility at a "value of solar" rate. The "value of solar" rate incorporated savings from avoided costs such as the construction of new generation or transmission and line losses among other items.[21] The program initially adopted had no limits on the number of projects that could be built. The program was opened to residential and commercial subscribers, schools, government entities, and other organizations.

Electric cooperatives and some utilities in Minnesota own and operate community solar projects as a way to provide access to solar energy to their customers. Subscribers typically sign a 20 or 25-year contract to essentially lease individual solar panels in a project array giving them the rights to the energy produced. The "lease" payment can be made up front for the entire contract duration or monthly under a "pay-as-you-go" plan. The ownership of RECs associated with the solar energy production is negotiated with the developer. Payment is made through the public utility in the form of an energy credit on customer utility bills at the value of solar rate.[22]

Like those in Illinois, the Minnesota Solar Community Gardens program design has evolved. Over time, it became clear that more projects were being developed for companies and government entities than for residential customers, particularly low and moderate income (LMI) customers. This occurred as a consequence of the lower cost of serving fewer customers with bigger projects, and the higher level of customer expertise and creditworthiness for these projects. New legislation passed in 2023 increased the project size to a maximum of 5 MW and put in place a requirement that 55 percent of a project's capacity be given to LMI households, public interest groups (such as municipal or Tribal subscribers, non-profit organizations, schools, houses of worship, and libraries) and affordable housing residents. Limits on annual growth rates were established through 2032 which total to over 800 MW in the first eight years. The value of solar rate was also replaced with tiered rates based on customer class and defined subscriber types, capped at the customer's average retail rate.[23,24]

Minnesota's example provides three additional key aspects worth highlighting.

Because there is no requirement for projects to be built by the utility or a "qualified vendor" (as in Illinois), it is possible for grassroots development of energy community projects. One grassroots success story in Minnesota is Cooperative Energy Futures ("CEF"). Founded by a group of college students based on a vision of creating wealth locally through energy efficiency and clean energy, the cooperative[25] was an early adopter of the community solar model as a way to provide to all its customers access to clean energy. CEF secures project funding and constructs and operates the solar facilities which are owned by the cooperative members across the State.[26] It has eight community solar gardens in place and has plans to add seven more. As part of its strategy, CEF seeks to provide education, engagement, and neighborhood coordination, as well as innovative business models that allow community members to own projects and benefit from energy market participation.[27]

- The program's success in the service territory of the largest jurisdictional utility in Minnesota – Xcel Energy – has been hindered by interconnection delays. In 2021, the Minnesota Public Utilities Commission fined Xcel related to roughly 120 complaints regarding interconnection timelines.[28]
- The program has been particularly successful with electric cooperatives.[29] This may be because electric cooperatives already include a degree of organization that makes forming an "energy community" less burdensome.

Hawaii

Hawaii offers an example of a state at the cutting edge of distributed and community resources to provide not just energy, but key grid services. Given its geography – about 2,400 miles from the U.S. mainland – no U.S. state faces more difficult challenges in transforming its energy sector than Hawaii. Aside from supply chain challenges and costs, Hawaii's electric utilities have no power markets or neighboring control areas to fall back on for reliability or economic electricity purchases. The islands themselves are not interconnected and thus must self-supply all electricity. Not surprisingly, Hawaii has the highest average retail electricity rates in the U.S. (39.72 cents/kWh – 78 percent higher than second-place California)[30] and, due to its legacy thermal generating units, has some of the highest emissions-per-MWh of any state in the country.[31]

Against this backdrop, Hawaii has adopted the most aggressive renewable portfolio standard in the U.S., pledging 100% renewable energy by 2045. In pursuing this goal, Hawaii has engaged a multitude of programs and initiatives, many innovative, to increase renewable penetration and to do so reliably. One example is Hawaiian Electric's procurement of a recently-energized 185 MW/565 MWh battery project on Oahu developed by Plus Power (the "Kapolei Energy Storage" facility) to replace a 180 MW coal-fired power plant.[32] The history of these programs – which includes a community-based renewable energy program[33] – is extensive and noteworthy.

One innovative approach taken by the Hawaii Public Utilities Commission ("the Commission") and Hawaiian Electric[34] that is a form of an energy community development was to pursue competitive procurement of grid services from aggregations of customer-sited distributed energy resources. Interested developers were invited to submit bids that aggregated individual customer loads, with each individual contracting with the developers. Winning developers would then sign 5- to 10-year contracts to provide grid services to the utility. This type of energy community is dispersed but highly interconnected.

While the aggregator model itself is not necessarily new, Hawaii's use of it to provide grid services, including a "fast" frequency response,[35] is new. Traditional generation portfolios rely upon mechanical inertia from large rotating generators to provide frequency response; as these generators are replaced by inverter-based generation with no such mechanical inertia, grid operators and planners have needed new approaches to procuring frequency response to keep the grid reliable. By use of grid-forming inverters, renewable resources and battery storage systems can contribute frequency response. Hawaiian Electric's procurement allowed developers to aggregate their desired mix of customer loads, energy storage devices, and renewable generation to meet the utility's strict definition of the grid services being procured.

The Hawaii legislature, the regulator, the utility, the developer community, and utility customers all played a role in the formation of energy communities in Hawaii. The legislature's enactment of the 100% by 2045 RPS requirement, plus the allowance for net metering, created a mandate and removed hurdles to the development of community energy projects. The Commission has promulgated regulations requiring a "portfolio" approach to addressing the state's electricity needs (that includes innovative approaches, such as aggregated grid services), and along with the utility, has employed competitive procurement to manage the cost and risk of new resources.

Hawaii, like Illinois, is using competitive procurement and supplier contracts that protect customers. Additionally, Hawaii uses innovative approaches to solve modern grid needs, allowing new technologies, business models, and contracting methods to compete to fulfill the utility's needs. Hawaii is able to tap into the public groundswell to participate in energy communities by offering multiple options, including traditional community-based renewable energy projects or, as is the case here, in customer aggregations.

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35 Fast frequency response is product that requires resources to responds within 200 milliseconds or less.

Cost Allocation in Energy Communities

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Abstract

Cost allocation is a crucial element in Energy Communities due to shared distributed energy resources between members. This review examines current and emerging methods before identifying challenges and future trends to ensure fair and stable sharing mechanisms among members while improving the overall feasibility of Energy Communities.

1. Introduction

Energy Communities play a pivotal role in the clean energy transition by promoting the local generation of renewable energy sources. Characterised by shared and often jointly-owned energy assets, Energy Communities actively engage in energy-sharing activities, which include the distribution of their locally generated power among community members and external markets.[1] Recent literature has focused on the development of various strategies and rules for allocating the generated electricity within the community, leading to different bill reductions for its members.[2] Thus, a direct implication of these energy-sharing practices between community members is the allocation of emerging costs and benefits. Although the allocation of costs between members needs to be clarified in every Energy Community, there are no clear legal regulations and only little research on this subject. Therefore, the economic question of how costs can be shared among community members reveals unsolved allocation issues, arousing interest in both academic and practical fields.[3]

2. Cost Allocation and its Importance for Energy Communities

Cost allocation methods determine how costs associated with the generation, distribution and consumption of energy within the community are assigned to community members. This is a fundamental aspect of the viability of Energy Communities, as it affects their short and long-term success. The costs of electricity supply as well as the costs of shared infrastructure, such as storage facilities and grid maintenance, should be shared among the involved participants in a way that reflects their contributions. In other words, the costs should be paid by those who cause them, i.e., those who consume energy and their energy-related services in the community system.[4]

As self-sufficiency is not economically viable due to the high costs of distributed energy resources, particularly storage systems, the community must import additional electricity from the grid at retail prices. The payments of the community to remunerate either the grid for the energy imports or the prosumers (users who both generate and consume electricity in the energy system) for energy exchanges are essential for the long-term feasibility of an Energy Community. The question that arises is how each member must contribute to these payments. Since there is only one electricity bill for the entire community, which calculates the difference between the costs for imported energy and the costs of exported energy via the smart meter, the bill is shared between the members of the community according to the established methods.

However, if the Energy Community produces energy surplus, members can be remunerated for their energy exports to the grid through feed-in tariffs or agreed-upon wholesale prices. In some cases, the compensation for the sale of the energy production can be negotiated or even be completely eliminated.[1] The resulting profits should be distributed among the members by offering them either a reduced energy price or a reduced membership fee. This should be large enough to finance the capital costs of the community, especially if it does not have access to capital markets. Over time, the membership fee could even become negative, allowing the community to redistribute its profits to members in the form of dividends.[5] However, if there are no differentiated prices for the distinct contributions of the members, this will quickly lead to unfair results.[6] Hence, there is also a related but different task for the Energy Community, namely the distribution of the generated benefits among the members, which will not be elaborated further in this context.

The members of the Energy Community are active actors in an energy system who ideally participate in the planning, development and management of the community energy system, either directly or via a community manager who coordinates the community's trades. If this intermediary entity does not allocate costs to the members, there is ideally a community committee that develops a customised cost allocation model. To define a cost allocation method, the costs of energy exchanges within the community and with the grid must be considered and formulated. Subsequently, the community members must decide on a cost allocation method before the annualised costs can be distributed among the different participants.[4]

The chosen cost allocation method is therefore a central component in the design of the tariff structure and provides information on cost incurrence within the community. In order to design efficient tariffs, which should include non-discriminating, transparent and cost-reflective prices, suitable cost allocation methods need to be defined.[7] Firstly, the tariffs must reconcile the supply price of the energy producer with the demand price of the end-consumers. Secondly, it is imperative to take into account fundamental objectives and principles, in particular with regard to the cost recovery of the community's investments. In addition, these tariffs must ensure that the community's activities create economic value, so that the costs of generating and selling energy is lower than the costs of supplying energy from the grid or opting for individual self-consumption.[8]

Before proceeding with the allocation design, the amount of costs and benefits to be allocated should be determined. The variable expenses associated with electricity imports and exports are shared between the community members based on their net loads at each time step. These net loads are measured in the beginning of the following day using smart meters installed at the end-consumers locations.[9] During this process, it is important to provide information transparency to the members by explaining the pricing and allocation methods to them in a simplified and comprehensive manner, ideally involving them in the decision-making process.[6]

3. Cost Allocation Methods

To implement a cost-sharing model into practice, it is essential to establish rules for the cost allocation. These rules determine how costs are shared among the community members. Recent scientific contributions have analysed diverse cost-sharing mechanisms that have been discussed in the framework of local energy markets and distribution models. Within cost allocation models, many studies deal with the assessment of fairness principles, especially in scenarios with a community manager. To this end, various contributions use game theoretical methods to model fair cost allocations within Energy Communities. These models often include a cooperative setting and are based on solution concepts from coalitional game theory. Their fundamental concept focuses on the distribution of payoffs from the community coalition rather than on the factors that define how agents achieve those payoffs.[6]

The most frequently analysed cost allocation methods are described below:

- **The Equal-Split scheme** allocates the costs equally among all users, so that the total costs of the community are divided by the number of participating members.[10]
- **The Bill-Sharing scheme** shares costs of the community electricity bill between the members according to their individual total energy imports and exports, with each member paying the same unit price for their purchased energy and receiving a payment at a different unit price for their supplied energy.[11]
- **The Mid-Market-Rate scheme** sets exchange prices between members based on the average of electricity purchase and sale prices and adjusts them over time if the total energy generation does not match the total demand of the community. This encourages the adoption of flexible demand and energy assets that adapt to local generation patterns, leading to costs reductions compared to the conventional scenario.[10]
- **The Shapley Value** calculates the average marginal contribution of each member by considering all possible combinations of cooperation between the members in the community.[12]

Cost allocation methods vary according to their time horizons (daily, monthly or yearly) and their implemented distribution schemes, which may adopt more simple or complex computing systems. The Equal-Split scheme, for instance, is easy to compute but does not adequately guarentee fairness and stability within a community, as it does not consider individual contributions to the total costs of the community. On the contrary, the Shapley Value, which is known for its ability to include fairness in the results, is difficult to compute, especially for large Energy Communities.

To evaluate these cost-sharing mechanisms, the energy savings achieved by each community member must be compared with the benefits they would have yield individually outside of the Energy Community. The cost allocation method is evaluated as non-preferable if the sum of prosumers who are better off in the community is smaller than the sum of prosumers who are worse off. In that case, costs are reallocated such that all of them are at least equally off, as they would be without the community.[8] Additionally, the cost allocation is considered budget-balanced if each user contributes in a way that the total payment by all users corresponds to the costs incurred by the community.

The assessment of these methods remains very difficult and finding the right scheme for local energy trades inside Energy Communities is a complex task, accompanied by several challenges, especially in cases where multiple stakeholders are involved. Consequently, a thorough analysis of cost allocation methods is required and should be carefully evaluated on the basis of the principles for a sustainable energy distribution.

4. Challenges of Cost Allocation

Implementing cost allocation methods in local energy markets encounters significant obstacles that are distinct from those faced in larger energy systems.[4] Unlike traditional energy models, Energy Communities require tailored allocation strategies to take into account the dynamics and the structure of the participants.[6] To this point, there is no general framework available on cost allocation methods between Energy Community members. Among the emerging cost-sharing models, there exists no uniform acceptable consensus on how to allocate costs and benefits within Energy Communities. Additionally, there exists no one-fits-all cost allocation method, since the different schemes focus on different aspects of the energy demand profile.

The success of an Energy Community depends largely on its business model and its flexibility to adapt to evolving circumstances.[11] The Energy Community's environment is strongly influenced by diverse factors, including local regulations, governance structures and stakeholder preferences. Given the broad spectrum of contexts, objectives and energy needs — especially considering their inclusion of diverse members from the residential, commercial, or industrial sector — the composition of an Energy Community will significantly influence the allocation of costs between members. It is therefore crucial to present a variety of allocation schemes to effectively manage cost-sharing practices within Energy Communities.

Moreover, it is important to respect the rules of energy allocation to design cost and benefit distribution models, as the energy surplus allocation determines the benefits that each consumer derives from participating in the community in the long-term.[13] This includes the challenge of incentivising members to not leave the community by adapting prices and the existing cost allocation model for long-term plans. In addition, the amount of energy cost savings that an Energy Community can achieve depends on several factors. These include retail energy costs, applicable charges, taxes and levies, along with national regulations and economic incentives for energy-sharing pratices. Finally, the different types of practices, along with installed energy capacities play a crucial role in determining transaction and operational costs, which are pivotal for the community's profitability.[1]

Therefore, it is important to introduce a cost allocation method that is compatible with the economic objectives aimed at optimising trade within a collective economy.[14]

- First, the allocation needs to be **cost-efficient** in terms of the overall energy bills and benefits for members in contrast to trading exclusively with the grid. In this manner, an effective allocation method should be dynamic to incentivise consumers to shift their consumption to off-peak hours and reduce overall peak demand.[6]
- Another ultimate goal that affects the success of the cost allocation is its **social acceptability**. Cost allocation practices are socially accepted if it is perceived as fair in its final design, ensuring that members who are not involved in the costs do not unfairly harvest the resulting benefits. In addition, its process should be conducted in a fair, transparent and consistent manner, enabling broad citizen participation while empowering vulnerable groups.[15] Furthermore, fair and just prices should be maintained to discourage and prevent free-rider behaviours inside the community. Since fairness is a crucial element for prosumers to engage in aggregation schemes, its level is a highly discussed topic in terms of cost allocation methods.[16]
- Lastly, a **sustainable scale** constitutes a vital condition for well-functioning trades and highly impacts the social acceptance and thus the success of the implemented allocation method. Cost allocation methods are highly dependent on the size of the community, which should be adjusted to its members and capacities so that there is no energy over- or underproduction. Otherwise, this can lead to unstable communities, which is an important issue in scenarios where agents can act as self-sufficient prosumers.[17] If allocation rules do not integrate the individual's contribution to the value of the community, members might opt out, leaving the remaining agents with increased charges due to a redistribution among fewer users (also known under the snowball effect).[18] To mitigate such risks, it is imperative to assess the characteristics of the participants in advance.

However, there is an important trade-off between these three economic goals. Allocation methods that guarantee both fair outcomes (such as the Shapley value) and are robust to strategic behaviours are computationally complex and thus not easy to scale for larger communities. It is therefore crucial to evaluate the fairness and stability of a cost-efficient allocation design before implementing it in Energy Communities.

To find a balance between fairness and computational complexity, innovative schemes have been developed. For example, with the virtual net-billing method, each member's electricity bill is determined by their individual electricity imports from the grid and is reduced by costs savings achieved through virtually self-consuming a portion of the shared electricity. With this rule-based scheme, computation time savings are significantly improved, especially for large communities.[19] Also, a voting system, which considers the reputation of agents in the system, can optimise the computational complexity by ensuring fairness principles.[20] Another method consists in allocating costs based on the marginal contribution of each prosumer and with respect to the larger group.[6] This provides both a fair distribution and computation traceability, since it has an improved scalability as the number of members inside the Energy Community increases. Due to the complexity of the members' coalitions, the national context and the aim of Energy Communities, it is preferable to design different allocation methods that should be consistent with the goals, values and local context of the Energy Community.

5. Conclusion and Perspectives

Cost allocation is an important aspect of the management of an Energy Community, especially considering the shared resources and infrastructures that are involved. However, the choice of allocation rules remains challenging, as the adaptability of allocation schemes largely depends on the characteristics and circumstances of the community. Implementing effective cost allocation schemes not only contributes to the long-term sustainability of Energy Communities, but also fosters broad societal acceptance, thereby facilitating a smooth transition to sustainable energy practices.

Hence, efficient cost-sharing procedures should be designed in a way that they maintain stability within the community and fair conditions for the members. In addition, the cost allocation must be tailored to the participants' characteristics as well as to the size of the community, while being framed by simplified legal requirements. Moreover, strategic considerations and technological advancements are crucial aspects that should be carefully considered. Emerging future trends include dynamic pricing models, blockchain technologies facilitating transparent and decentralised accounting processes as well as advanced algorithms to take into account peak in energy demands as well as member's resource contributions.

Overall, more clarity is needed on the allocation and distribution of costs and benefits among members. This includes a deeper understanding of how the performance of cost-sharing methods can be most meaningfully assessed. Finally, cost allocation schemes should define incentives that foster efficient energy usage and incorporate different options for distributed energy systems to achieve the most sustainable outcomes for Energy Communities.

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Power to the People: A People-Centred Approach to Accelerate the Transition Towards Net Zero Emissions Energy Systems

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Abstract

This article introduces a framework linking the concept of "energy communities" to the Net Zero Emissions (NZE) agenda for envisioning the Paris Agreement. It presents the potential benefits of energy communities and examples of selected case studies showcasing global developments in community-driven projects and initiatives. The challenges are discussed, followed by people-centred policy recommendations to accelerate the transition towards democratized NZE energy systems.

In line with the directions of the Paris Agreement, the current global agenda is moving towards net zero emissions (NZE) energy systems given across different timelines but mostly centred around 2050, to limit global warming temperature levels to between 1.5°C to 2°C by 2100. The NZE agenda necessitates clean energy transitions, which involve shifting from traditional, fossil fuel-based energy systems to more sustainable and environmentally friendly alternatives. Since the enactment of the Paris Rulebook in 2016, much efforts ([1]–[5] targeted various types of energy-driven technologies that are deemed promising in attaining and accelerating the clean energy transition. Examples include (a) renewables such as solar photovoltaics, wind turbines (onshore and offshore), hydropower, biomass, and geothermal energy, (b) energy storage such as battery storage (lithium-ion, solid-state, flow batteries), pumped hydro storage, compressed air energy storage, thermal energy storage, (c) energy efficiency technologies such as high-efficiency HVAC (heating, ventilation, and air conditioning) systems, lighting and appliances, (d) advanced nuclear technologies, (e) advanced materials and manufacturing, (f) electrification such as electric vehicles, charging infrastructure and battery technologies, (g) smarts grids and grid management, and (h) carbon capture and utilization (CCU) and storage (CCS), and (i) hydrogen-based technologies considering green hydrogen production, hydrogen fuel cells and hydrogen storage and transportation. In fact, the existing spectrum of feasible technologies for attaining the long-desired goal of NZE energy systems is wide, with over 550 individual technology designs and components related to the energy system [6] reported by the International Energy Agency (IEA) towards envisioning a global trajectory to keep the ideal 1.5°C goal in reach [7]. These technologies have different readiness levels, which are identified within several phases of either concept, small to large prototype, demonstration, market uptake, or mature.

Nonetheless, the fundamental question remains: is technological change "enough" or "just enough"?

In attempting to answer this question, recent efforts ([8]–[10]) examined the role of societal behaviour and lifestyle change in pursuit of the NZE agenda. It is invariably argued that technological change alone is not sufficient without the consent and active support of people. From here emerges the concept of "energy communities" which hands the power to people towards achieving people-centred clean energy transitions. A people-centred approach means the active involvement of the general public in decision-making and the delivery of NZE energy systems [11]. While there is no standard definition of it, energy communities refer to collective entities or groups of individuals, businesses, or organizations that voluntarily accept to participate in energy generation, distribution, and consumption for the management of the energy system [12]. Irrespective of the actual "structural form", the role of people, or what we can refer to hereafter as local citizens, lies at the heart of energy communities that are founded on the principles of social cohesion and unity to promote sustainability for regional development. Members of these communities adopt measures that foster development mainly in the areas of renewable energy and energy efficiency to share common objectives of supply security, accessibility and affordability, as well as environment protection. The concept of energy communities is closely linked to the broader goals of the energy trilemma pillars in the context of the NZE agenda as demonstrated by Figure 1.

As demonstrated, policy interventions are the vehicle to implement technological changes that go hand-in-hand with complementary social changes that emphasise a people-centred approach. This is exemplified by concepts like energy communities, contributing towards attaining just and inclusive clean energy transitions. The proposed framework emphasizes sustainable policy planning and formulation integrating both technical and social solutions to accelerate the transition towards NZE energy systems. Zooming into the social dimension, the concept of energy communities is becoming increasingly prevalent worldwide for realizing the Paris Agreement goals. Energy community projects are entirely or partially owned, managed, and democratically controlled by local citizens. Members of these communities can have different levels of involvement in the project from production to storage to management of energy. Figure 2 depicts a fictional schematic conceptualizing "energy communities" as part of the NZE transition.

Certain countries have long adopted energy communities as an energy management model, while others have recently discovered their potential, and many have yet to do so. The history and culture of a country determine its driving policy levers and implementation

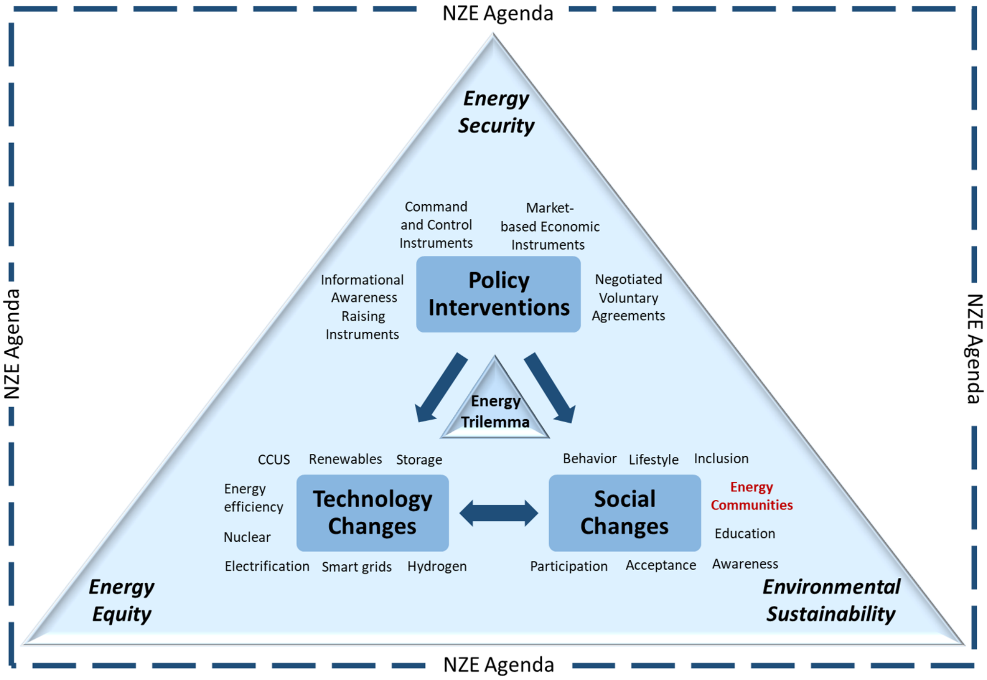

Figure 1: Proposed framework linking policy, technology, and social dimensions with the energy trilemma pillars within the context of the NZE agenda.

Figure 2: Schematic illustration envisioning the concept of “energy communities” within NZE energy systems.

Table 1: Selected case studies demonstrating the status of energy communities from a global perspective.

Region	Country	Projects/Initiatives
Europe	Italy	—The Italian National Recovery and Resilience Plan provided a fund of EUR 2.2 billion to aid energy communities and self-consumption initiatives.
	Spain	—Crevillent village, a local energy community using solar photovoltaic technology allowing residents to consume self-generated electricity from collectively owned photovoltaic panels.
	Greece	—Allocated a fund of EUR 42 million to support local energy communities operating via net metering and fulfill the electricity requirements of public facilities and households experiencing energy poverty.
	United Kingdom	—Introduced a GBP 10 million Community Energy Fund in 2023 to support the growth of energy communities considering a variety of projects including wind farms, rooftop solar systems, battery storage, heat networks, and electric vehicle charging stations for rural and urban areas.
	Germany	—The Renewable Energy Act was passed guaranteeing fixed feed-in tariffs for local citizens generating renewable power, which encouraged households to install rooftop photovoltaic panels and feed the produced electricity into the grid or consume it themselves.
	Denmark	—Karise Permatopia eco-village established a shared geothermal heating system powered by locally produced renewables, along with Avedøre which is an energy community that supports projects related to the production and storage of renewable energy.
	Scotland	—Barr River Hydropower Scheme has an installed capacity of 1.6MW and delivers 100% community-owned hydropower to 1000 homes.
North America	United States	—The Inflation Reduction Act provides 10% additional financial incentives for community-based clean energy projects.
Oceania	Australia	—Collective utilization of battery resources by 119 households led to savings exceeding AUD 81,000 within five years, reducing 85% of electricity consumption from the grid at peak times.
Asia	India	—Aga Khan Foundation developed a project to help 100 villages in remote areas escape energy poverty using a community-led model that increases the adoption of efficient, renewable energy products.
South America	Brazil	—RevoluSolar photovoltaic community project enabled renewable energy access for 30 families, where the profits from the projects were used for job training to reduce local unemployment rates and protect the citizens from rising energy prices.
Africa	Zambia	—Mwembeshi Solar Mini-Grid provides electricity to a rural community with over 600 households, schools and health clinics.

models. Nevertheless, differences disappear when we consider the common goal of clean energy transitions towards NZE community-driven energy systems. Table 1 presents a brief overview of global developments in the field of energy communities considering various case studies.

These global energy community projects have demonstrated clear benefits which include [13]:

—Adopting energy efficiency measures and renewable energy resources such as individual homes solar panels and larger-scale community wind farms or biomass plants

—Reducing energy bills, enhancing local resilience, alleviating energy poverty, and minimizing regional disparities and vulnerability through the supply of affordable energy

—Minimizing grid stress and costly infrastructure upgrades during peak demand periods

—Creating jobs, investment opportunities for local businesses, and generating income/profit which supports the local economy

—Improving energy security and independence by supporting access to local sustainable resources and improving the quality and reliability of power supply

—Developing stronger social bonds through people's active involvement including management of citizen-owned production units and the use of local resources. Citizens can become prosumers and participate in local energy system decisions, fostering a sense of ownership and obligation

—Improving local air quality and decreasing air pollution levels by substituting fossil fuel-based energy generation with sustainable energy production and consumption

—Deploying new technologies to restructure the energy system, offering a testing ground for emerging innovations such as smart grids, energy storage, and demand-response systems

—Decarbonizing the energy system to attain the NZE target for the overall mitigation of climate change

However, despite their benefits, community-led energy projects can face their share of persistent challenges in terms of their establishment and operation. These challenges commonly span the technical, economic, social, and institutional domains. In particular, there are regulations to navigate, funding to secure, and public support to gain. Further illustrative examples include [13]–[16]:

—*Technical:* grid connection, infrastructure (generation, transmission, and distribution networks), smart meter operation, information and communication technology (ICT) installations

—*Economic:* financing and funding issues (cost of new technological components and equipment), unequal distribution of costs and benefits, instability of energy market conditions

—*Social:* public acceptance (motivation and positive attitude), community participation, capacity building (reskilling and training), ownership, customers unwill-

Table 2: Policy instruments for clean energy transitions considering a people-centred approach.

	Policy Instrument	Type of Instrument
1.	Command and Control Instruments	—Codes (building codes, land and other resource management codes) —Standards (appliance, vehicle, building, technology, renewable portfolio) —Energy auditing and assessment programmes —Obligation/compulsory schemes —Regulations / directives / acts / ordinances / laws —Bans / prohibitions / limits / thresholds
2.	Market-based Economic Instruments	—Taxes / charges / penalty —Subsidies / grants / rebates / funds / loans —Feed-in tariffs / premiums —Tax deductions / relief / exemptions —Credits (energy saving loans) —Licenses —Tradable permits / quotas (emissions trading system or cap and trade) —Direct/public investments (infrastructure, procurements, research and development spending) —Environmental offset and banking —Competitive auctions / bidding —Net metering —Time of use pricing
3.	Informational Awareness Raising Instruments	—Labels (energy efficiency labels, performance labels) —Smart meters and billing information —Subsidized consultation / advisory services —Education/communication campaigns and promotions —Training and professional qualification / capacity building —Research, development and deployment programs —Demonstration project / pilot trials / prototypes —Environmental reporting, monitoring and verification —Access to information and justice rights —Opinion and feedback surveys —Third-party certification programs (green and white certificates)
4.	Negotiated Voluntary Agreements	—Agreed commitments / target setting —Consensus-based negotiations / networks —Recognition and innovation awards / prizes —Technical support / technology transfer / capital exchange —Internationalism / public-private partnerships / joint venture —Institutional creation / organizational structures —Strategic planning / action plans / initiatives

ingness to alter consumption habits, inclusivity and equity across diverse community members

—*Institutional:* regulatory and legal barriers, political obstacles, effective business models, supportive governance schemes, administrative and authorization processes bottlenecks, monitoring and controlling the newly structured energy system, environmental considerations of potential new projects

The highlighted challenges related to energy communities pave the route for identifying opportunities in achieving democratized, community-driven energy systems. Policy governance emerges as a pivotal force for driving change in this context, considering that energy communities are shaped by policies at several levels ranging from regional to national and local. Consequently, the role of the government and policymakers is vital in enabling regimes that establish and nurture energy communities. This necessitates identifying how to engage people in the clean energy transition towards NZE, understanding how people's lives will be disrupted, and integrating co-benefits into the policy-making process [11]. Table 2 outlines examples of the policy instruments that can be adopted to drive change towards just and inclusive clean energy transitions considering a people-centred approach.

Evidently, policy governance structures within energy communities can range from informal grassroots initiatives to formalized legislation. Future prospects can be guided by the broad arena of potential policy techniques to advance developments of energy communities [13]–[16]. For example, a specialized legal framework can be established to overcome the complexity of operating these communities. A legal entity can be formed to allow for open and voluntary participation among members and to increase the coordination between national and regional governments, following a democratic format for internal decision-making. Periodic meetings and public consultations can be conducted to address rising community concerns. Legislation on collective self-consumption can also provide energy communities with a strong legal foundation, while clear guidelines and streamlined administrative processes facilitate community-led activities. On a similar note, collaboration is required among academia and industry with energy communities through joint transdisciplinary projects and knowledge transfer. This may include conducting pilot trials and designing real system prototypes to demonstrate potential benefits and thus increase public acceptance at the community level. With relevant stakeholders, governments can facilitate for energy communities knowledge exchange platforms and networks such as campaigns, workshops, and online forums to promote sustainable cultural awareness and education. Other supportive policy levers that governments can introduce include net metering, feed-in tariffs, community-based renewable targets, updated grid codes, as well as tax incentives, grants, subsidies, low-interest loans, grants, or venture capital for community-led energy projects, among many others. Additional technical support mechanisms involve increasing grid capacities, providing easy-to-use tools to show energy generation and consumption profiles, and securing reliable information and communication technology (ICT) structures and load management logistics. To top that, joint purchase, remuneration and smart contracts for shared flexibility, along with Pay for Performance (P4P) contracting and Energy Performance Contracting (EPC), represent innovative mechanisms to further streamline the adoption of community energy projects. Other potential opportunities include leveraging artificial intelligence and machine learning techniques to effectively manage the energy system and optimize its operation, along with maintaining and controlling community assets.

To close, a people-centred approach is paramount for the successful implementation of climate policies required to achieve the Paris goals. Without putting people at the heart of future energy systems, the NZE ambition is most certainly out of reach.

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A Holistic Approach to Energy Communities: From Symbolic Value to the Definition of an Algorithm for Fair Incentive Allocation

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Abstract

The transition to a renewable energy-based system requires commitment and accountability both at individual and collective levels. In this context Renewable Energy Communities, as drivers of technological and social innovation, are recognized as an interesting tool. However, their complexity necessitates a holistic interpretative approach to fully realize their potential.

Introduction

The need to outline a path of energy production and consumption that promotes the transition from an energy system based on fossil energy sources (oil, coal, and natural gas) to a system based on a significant deployment of renewable energy sources while maintaining the stability, balance, and resilience of the grid, requires a collective responsibility and strong commitment to achieve global sustainability goals and mitigate climate change.

This implies a paradigm shift, not only technological, which views distributed generation also as recognition of the role of the end-user in defining the change itself.

Despite the development of various energy policies aimed at promoting the use of renewable energy sources and increasingly ambitious goals for reducing greenhouse gas emissions, particularly at the European level, the path towards a true ‘transition of era’ still appears to be winding.

In light of collective awareness regarding the impacts of energy production and consumption on the environment, there are still strong resistances (including, and especially, mental ones) towards redefining consumption patterns and adopting a psychological approach to the energy issue that is based on its multidimensional and multidisciplinary nature.

The concentration of electricity production through the construction of large power plants[1] in locations relatively distant from the area of use has, over time, defined not only a physical distancing from its - often perceived only as a potential risk source and therefore subject to local conflicts and protests - projecting the “energy good” into the dimension of the “taken for granted” [1] [2] and beyond the control of the end-user.

The gradual, and in many respects troubled, reconfiguration of renewable generation technologies aimed at enhancing the use of non-programmable renewable energy sources (NPREs) - such as solar and wind - in conjunction with traditional renewable energy sources (RESs) (such as hydro, geothermal, and biomass) has, on one hand, aimed to redefine the (electric) generation process towards reduced use of fossil fuels - with the goal of containing GHG emissions into the atmosphere and mitigating the effects of global warming, increasing energy self-sufficiency, reducing the risk of negative repercussions from geopolitical imbalances, and accelerating the decarbonization process of the economy. On the other hand, it has also imposed a weighty redefinition of the entire energy system - which is nevertheless called to respect criteria of balance, safety, and resilience of the grid - to facilitate the access of a new type of stakeholder, namely the energy prosumer.

The reconfiguration, limited to defining the process just on production and only at an individual level (in the case of residential photovoltaics), has only partially translated into a real collective approach to the “energy issue.”

Within this interpretative framework, Renewable Energy Communities (RECs) are inserted as sociotechnical configurations and potential paths of innovation.

Renewable Energy Communities: an interpretative framework

Although for over two decades, in a more or less structured manner, “Community Energies” have entered the practice of movements and enthusiasts and into scientific debate as a potential paradigm shift – as demonstrated by [3] [4] – it is only with the publication of the Clean Energy for All European Package, and in particular with directives 2018/2001 (RED II) and 2019/944 (IEM Directive), that the concept of “energy community” rightfully arrives in the European political debate and effectively closes the rhetorical interpretative flexibility on the possible definitions accompanying the establishment of a RECs.

In front of about ten possible definitions of energy communities found in the specialized literature [5] [6] [7] [8] [3] [4], the RED II [9] clarifies the concept of RECs by enclosing it within a specific technological interpretative framework - which is based on the instant self-consumption of energy produced by renewable energy sources - and identifying the spatial boundaries for potential participants’ actions (leaving the specification definitions to the member states).

Renewable energy production facilities, proximity, co-responsibility, the principle of open access, and prioritizing ‘social, economic, and environmental benefits, even before financial profits’ are the keywords outlined in the directive to guide the establishment of renewable energy communities. This process, often described as a promising pathway toward transitioning to distributed energy generation, optimizing consumption, and thus promoting a more rational use of energy, aims to create an electricity market that is more inclusive of citizen involvement. It also aims to foster marked forms of social inclusion, ensuring access to energy for the most vulnerable segments of the population. Consequently, it contributes not only to an ecological energy transition but also to one that addresses social justice concerns.

A defining process that, in practice, aims - in the extreme complexity derived from the multidimensional nature of the subject - to facilitate a real approach, both physical and psychological, to the production, consumption, and management of locally produced energy.

However, according to [10], research on energy communities has tended to focus primarily on technical aspects, examining energy savings and emission reductions achievable in the building sector through optimization of the dimensions and management of Renewable Energy Sources (RES). Energy communities, however, signify more than just a techno-economic commitment to creating and managing energy resources collectively; they represent a fundamental shift in perspective [11]. When individual energy producers and consumers aggregate into an energy community, they cease to be mere constraints or fixed energy loads to be met. Instead, they become dynamic elements of an energy system capable of actively contributing to achieving community goals through their own behavior. In this manner, energy communities empower energy producer-consumers and foster social collaboration to attain shared objectives, such as reducing energy costs and attaining energy self-sufficiency [12]. Additionally, they combat energy poverty and vulnerability while striving for higher levels of environmental well-being.

Figure 1 illustrates the interpretative keys that define the value aspects and horizons of meaning guiding the establishment of RECs.

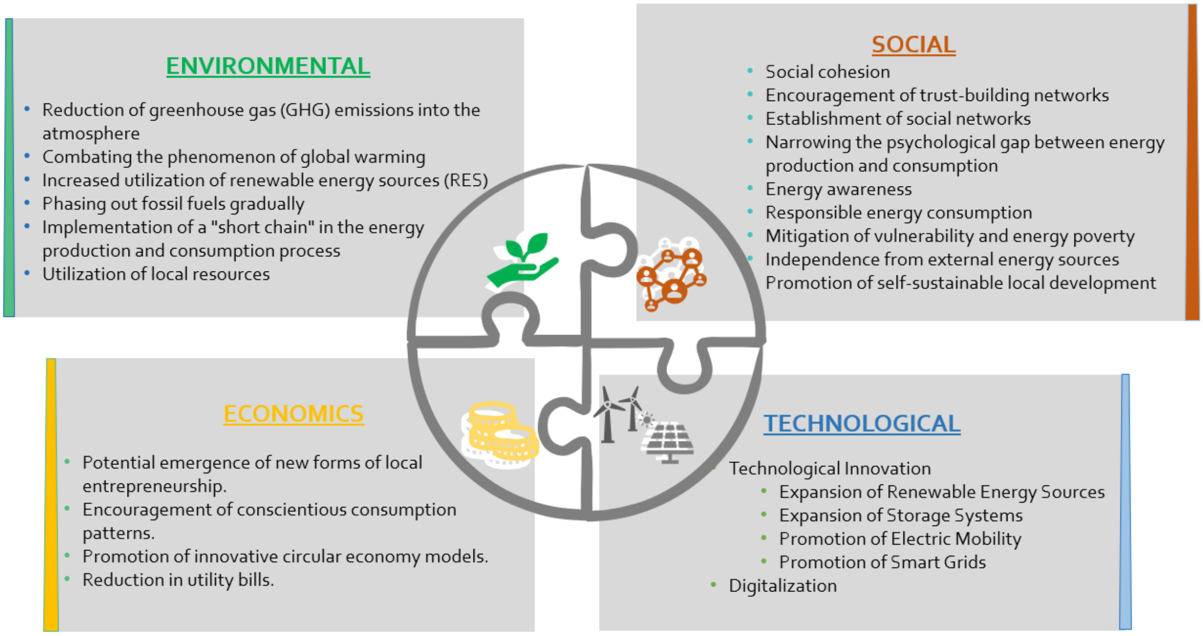
Renewable Energy Communities in Italy

In Italy, the early transitory implementation of the RED II directive - inserted in Article 42 bis of the Milleproroghe Decree [13] - has defined an intense process of promotion of Renewable Energy Communities, resulting in the birth of several “experiments” at the national level. Currently, according to data released by GSE [14], there are 115 overall configurations of self-consumption with “active service”, including 82 collective self-consumption groups (AUC) and 33 REC, for a total of 140 installations with an average power - per configuration - of about 20 kW and the involvement of 900 end-users.

The final transposition of the directive, initiated with the publication of Legislative Decree No. 199 on November 8, 2021, in the Official Gazette [13], and concluded on January 24, 2024, with the publication of the implementing decree of the MASE (CACER Decree) [15], has brought substantial changes to national regulations. These changes include expanding the scope of REC (from the perimeter of the secondary substation to the primary substation) and increasing the size of installations (from 200 kW to 1 MW). Consequently, this favors the broadening of participation to a significantly larger number of “users” in the potential configuration and the involvement of increasingly extensive territories.

Starting from these premises, we have investigated - through the construction of a regional database on

INTERPRETATIVE KEYS



ENVIRONMENTAL
- Reduction of greenhouse gas (GHG) emissions into the atmosphere
- Combating the phenomenon of global warming
- Increased utilization of renewable energy sources (RES)
- Phasing out fossil fuels gradually
- Implementation of a "short chain" in the energy production and consumption process
- Utilization of local resources

SOCIAL
- Social cohesion
- Encouragement of trust-building networks
- Establishment of social networks
- Narrowing the psychological gap between energy production and consumption
- Energy awareness
- Responsible energy consumption
- Mitigation of vulnerability and energy poverty
- Independence from external energy sources
- Promotion of self-sustainable local development

ECONOMICS
- Potential emergence of new forms of local entrepreneurship.
- Encouragement of conscientious consumption patterns.
- Promotion of innovative circular economy models.
- Reduction in utility bills.

TECHNOLOGICAL
- Technological Innovation
  - Expansion of Renewable Energy Sources
  - Expansion of Storage Systems
  - Promotion of Electric Mobility
  - Promotion of Smart Grids
- Digitalization

SOURCE: Prepared by RSE

post-experimentation energy community proposals, analysis of regional laws on the topic, and literature analysis - how the phenomenon is evolving both in terms of "vision" and "mission".

Specifically:

- What are the objectives of the renewable energy communities currently being defined, and how are they developing?
- What are the prevailing organizational models, and what is their impact on the governance models defining the process?
- What are the forms of engagement and openness to participation?
- How will organizational models redefine themselves considering an expansion of "participation boundaries"?

These are just a few of the research questions currently being explored, using a multilevel perspective, at the 'meso' level of the creation/birth process of Renewable Energy Communities (RECs). This approach acknowledges the necessity, on one hand, to identify territorial and local strategies that ensure the social acceptability of initiatives and stimulate interest and participation by mobilizing shared values and interests. On the other hand, it seeks to identify the conditions necessary to establish an institutional framework capable of promoting and supporting community-oriented energy production and consumption.

While on one hand, in accordance with the dictates of the RED II, it remains firm that the objectives of RECs must be defined in terms of "economic, environmental, and social benefits, rather than financial ones, for the members of the community and the territories hosting it," on the other hand, it is increasingly evident that:

- The extreme technological complexity underlying RECs - in their most advanced versions - requires increasing levels of specialization in managing the process.
- The increase in the size of installations not only opens up to the "diversification" of technologies underlying renewable energy production but also increases the scale of investments necessary for project realization.
- The need to integrate generation systems with energy storage systems and consumption management technologies.
- The widening of the electrical perimeter - from the secondary substation to the primary substation - shifts the boundary of possible participation from a few hundred connected users to several thousand connected to the primary.
- Defining increasingly effective mechanisms for fair distribution of REC incentives.

All of this implies several possible scenarios directly linked to the decision-makers' capacity to steer the process, those who physically promote the endeavor, the chosen legal structure, as well as the ability to assess the impacts (social, environmental, and economic) that projects and initiatives will have on territories in the short, medium, and especially long term.

Towards the development of an algorithm for fair distribution of incentives

The nature of RECs, as identified in the European [9] and Italian [13] [15] regulatory frameworks as a 'legal entity' with purposes extending beyond mere financial profit, coupled with potentially capital-intensive investments, necessitates the establishment of cohesive agent networks. These networks should be oriented towards objectives involving active participation and significant non-economic costs as well.

While energy storage systems (a technical solution) can effectively "balance" the intermittency of solar sources [16], it's important not to overlook the impact that the behavioral component and processes of enhancing awareness in energy consumption can have on the process. This can be achieved through strategies related to the concept of Energy Flexibility (EF), particularly focusing on short-term strategies like Load Reduction and Load Shifting. Both aim to reduce power demand during peak periods by engaging users in direct actions, such as temporarily reducing power and modifying the timing of energy usage [18] [19].

Among the various possible strategies, Load Shifting is considered particularly effective because it directly engages community members in adopting conscious behaviors regarding the timing of energy usage [20], thereby facilitating energy management and production.

In this theoretical framework, given the significant mobilization of public funds allocated to support the establishment of RECs in Italy, also as part of a twenty-year incentive regime, a methodology for distributing REC revenues (or collective self-consumption schemes) is being developed. Drawing inspiration from cooperative game theory, this methodology assumes that players (in this case, members of the configuration) derive a common benefit from collaborating to achieve a shared goal. The identified goal is to promote virtuous consumption behaviors aimed at increasing shared energy, while the benefit lies in the reduction of users' energy expenses, achieved through the revenue generated by participating in the configuration.

The algorithm emphasizes the reduction in energy expenses achievable by users of a REC/AUC through cooperation in adjusting their consumption to favor increased shared energy. Distribution is carried out by allocating incentives generated by energy sharing, the avoided costs recognized by the TIAD [21], and revenue obtained from selling energy to the grid at market prices based on:

- The entities investing in the configuration.
- The types of fiscal support utilized (e.g., tax deductions).
- Availability of additional revenue streams, such as leasing spaces for equipment installation to serve the configuration.
- Users' readiness to adopt flexibility measures to encourage increased shared energy.

The assumptions underlying the distribution process are:

- — Rewarding sharing.
- — Avoiding penalizing members who, while not sharing high volumes of energy, still bear the costs of participating in the REC.

In accordance with these two principles, the algorithm utilizes the sale of energy injected into the grid by the configuration's plants to cover their installation and maintenance costs. The allocation of the revenue share to cover these expenses depends on the nature of the entities investing and the economic value of the sale. The latter may be sufficient to generate profits (residual margins of the sale after deducting expenses).

The incentive and costs avoided by the TIAD are divided based on each user's level of energy sharing. The algorithm assesses the average monthly expenditure of all users during the plant's production period and allocates the incentive so that each user's expenditure is equal to or lower than the average value. Users with a monthly expenditure below the average value receive a small portion of the incentive as a contribution to participation. This portion is determined based on the user who shares the least energy in the month.

Acknowledgments

This work has been financed by the Research Fund for the Italian Electrical System under the Contract Agreement between RSE S.p.A. and the Ministry of Economic Development – General Directorate for the Electricity Market, Renewable Energy and Energy Efficiency, Nuclear Energy in compliance with the Decree of April 16th, 2018".

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Footnotes

[1] In hydroelectric power plants, first, and then in thermoelectric ones.

From Vision to Action: Building Sustainable Energy Communities in Colombia

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Abstract

This study proposes sustainable variables for Colombian energy communities, inspired by European models. Key factors include social cohesion and financial support. Lessons from Europe inform above all local engagement and regulatory strategies for sustainability.

1. Introduction

Energy communities (ECs) are gaining popularity as a response to the growing need for sustainable energy solutions amid global concerns such as energy security, climate change, and social inequalities within the energy sector (Lode et al. 2022). These communities enhance overall energy efficiency, promote the use of renewable energy sources, and empower end-users to actively participate in the energy market, contributing to government climate change mitigation goals (Bauwens et al. 2022). Policymakers, particularly in the European Union, recognize the potential of ECs to alleviate public resistance to renewable energy transitions, making them a focal point of attention. In the European Union, countries like Germany, Denmark, and Italy have a rich tradition of successful cooperative communities in the energy sector, emphasizing both top-down and bottom-up approaches. However, the concept of energy communities is gaining traction in Latin American countries, particularly in Colombia, as part of a socially just energy transition aimed at involving marginalized communities.

Colombian´s president Gustavo Petro is actively promoting the inclusion of energy communities in the national energy transition and development roadmaps, as evident in Law 2294 of 2023 with article 235 in which it is specifically created the figure of energy community,[1] followed by the decree 2236 of 2023 on the partial regulation of energy communities released by the Ministry of Mining and Energy.[2] The focus is on vulnerable population groups and the inclusion of minorities. The Colombian government acknowledges the importance of energy communities as a strategic element in its political agenda. By aiming to strengthen and empower local communities, improve energy access, address energy poverty, and contribute to the democratization and pacification of the country, energy communities represent a significant opportunity for positive change and development in Colombia.[3]

Despite their potential, establishing ECs face various challenges, including financial hurdles, complex organizational and administrative tasks, and the need for adept legal and operational approaches to ensure sustainability and efficiency. Specific factors unique to the Colombian context, such as a weak social fabric, high investment costs, grid connection complexities, lack of legal regulations, and the requirement for utility company status, pose additional hurdles (Energía y Equidad 2023).

These challenges need attention when trying to implement and scale EC in Colombia. Especially when it becomes evident that community energy research must consider social inclusivity alongside technical and financial aspects, especially concerning vulnerable populations (Belmar, Baptista, et Neves 2023).

The new Colombian government is ambitious in finding countermeasures, making it imperative for us to synthesize lessons from the European context and propose a holistic framework with sustainability parameters tailored to the Colombian case. For doing so, this paper adopts a New Institutional Economic perspective integrating debates on infrastructure provision effectiveness and implementation, while employing the Organizational Model Framework developed by the TU Berlin team to identify suitable sustainability variables (Beckers, Gizzi, et Jäkel 2012; Wealer et von Hirschhausen 2020; Heinemann 2023). It employs a three-step approach to construct the Organizational Model, initially based on the technical system, including assets, goods, value chain, and demand. Subsequently, tasks, roles, and relationships are identified to meet the requirements of the technical system, culminating in the establishment of actors and institutions necessary to complete the Organizational Model (cf. Figure 1). This framework prioritizes a bottom-up approach, empowering local communities in development processes, drawing inspiration from the insights of Hirschman (1958), Ostrom (1993) and Williamson (1994). Through a mixed-methodological approach, including an extensive literature review and empirical interviews tailored recommendations for Colombian policies were derived.

We find that a strong social component is critical to the success of energy communities, with community participation and cohesion being key factors. In addition, financing plays a critical role in enabling the success of these communities by supporting social efforts.

In the next section, we briefly introduce the Colombian context before discussing in detail the results of our literature review and interviews. The implications of these results for energy communities in Colombia are discussed then. From our analysis, we conclude that there are valuable lessons to be learned from Europe, particularly in terms of local community engagement, motivation, and the importance of a strong social fabric coupled with a tailored regulatory approach. Ultimately, sustainability in energy communities is multifaceted and requires a delicate balance between human well-being, social equity, and environmental considerations.

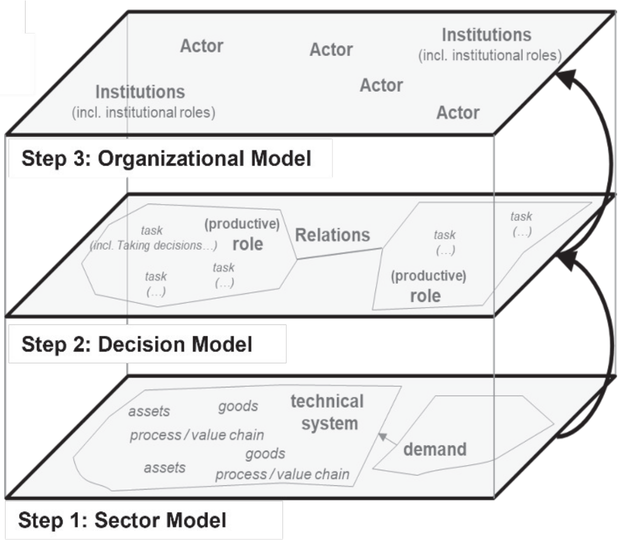


Figure 1: Research framework.

Source: Beckers et al. (2012).

2. Context Colombia and energy communities

Historically, energy communities have emerged in response to escalating energy costs, economic challenges, and a market dominated by multinational energy corporations (Hewitt et al. 2019). They are entities where citizens, along with other stakeholders, jointly invest, own, and participate in energy production. They can take various legal forms such as associations, cooperatives, or capital companies, often originating from pre-existing groups like municipalities or housing cooperatives (Eriksson Berggren et al. 2023). By granting more decision-making power to local communities, ECs foster inclusive and democratic energy environments (Hanke et Guyet 2023).

2.1 Energy Transition in Colombia

Colombia boasts significant renewable energy potential yet lags in energy sector innovation. Despite pledging ambitious emission reduction targets, challenges persist. Over 90% of the industrial sector relies on coal or fuel energy, necessitating innovation to optimize energy usage without compromising productivity. Enhanced collaboration between industry, research, and policy is crucial. The Ministry of Mines and Energy has devised strategies to expedite the transition to a low-carbon economy, addressing challenges such as over-reliance on hydropower and fossil fuels and inadequate infrastructure in remote regions. Decentralizing power generation through community-based technologies is a key strategy, albeit hindered by technological and entrepreneurial limitations (IEA 2023).

2.2 Status Quo of Energy Communities in Colombia

Only since recently, energy communities hold a prominent position in Colombia's political agenda, heralded as tools to empower local communities, broaden energy access, alleviate poverty, and bolster democracy. Aligned with the government's ambitious net-zero goals, ECs represent a crucial step towards sustainable energy infrastructure. President Gustavo Petro's administration is spearheading these efforts, integrating them into national policies and development plans, such as the National Energy Transition Roadmap [4] and the National Development Plan.[5] The Ministry of Mines and Energy's presents a decree on energy community regulation underscores inclusivity, especially for vulnerable populations and minorities. In this context, energy communities encompass groups of individuals or entities collectively owning, managing, and benefiting from non-conventional renewable energy projects, as outlined in Law 2294/2023, Article 235.[6] Colombia's energy policy regarding energy communities aims to advance renewable energy sources, decentralize energy production, and foster community participation in the energy sector. Before the officialization of the aforementioned law, the Energy and Mines Ministry issued decree 2236/2023 on December 22nd, mandating the establishment of a sustainable model for energy communities (Article 2.2.9.2.2).[7]

It is worth noting that specific details of Colombia's energy policy concerning energy communities are still evolving, awaiting technical regulations from regulatory bodies like CREG (Comisión de Regulación de Energía y Gas). This includes determining the maximum installed capacity for the energy planning unit (UPME) and outlining the supervision and control framework for the superintendent of public services.[8] Existing energy communities in Colombia primarily stem from top-down initiatives, often financed by development banks or government entities. To accelerate their proliferation, key challenges such as high investment costs, complex grid connections, legal barriers, and a lack of incentives or institutional support must be addressed. Bottom-up initiatives may play a vital role in combating energy poverty and fostering participation, necessitating knowledge transfer and supportive frameworks. Guidelines and evaluation tools are indispensable for facilitating feasibility studies and empowering community-led initiatives (Martínez et al. 2023).

3. Results from the literature review

3.1 Framework conditions for energy communities

Energy communities, established since the 20th century, focus on decentralization, ecological sustainability, and corporate independence, with a common emphasis on local governance and collective benefits (Klemisch 2014; Drewing 2020). These communities aim for collective management, ownership, and participation, supported by regulations for secure energy access (Rogers et al. 2008; Hargreaves et al. 2013; Yildiz et al. 2015). Essential attributes of cooperatives include "self-help, self-accountability, self-administration, democratic governance, and the convergence of ownership and utility among stakeholders" (Drewing 2020, 1). The European Commission as well as the German law provide exemplary frameworks for energy communities (*Erneuerbare Energie Gesetz, EEG* 2023, §3; European Commission et al. 2020; *Genossenschaftsgesetz, GenG* 2022). The formation of a cooperative involves board establishment, member recruitment, and project planning focused on environmental and financial sustainability (Klemisch 2014; Bauwens 2016; Ruggiero et al. 2019). Research indicates that the connection between social capital, civic behavior, environmental concerns, and interpersonal trust influences members' decision to join and support energy communities (Bauwens 2016). ECs sustainability and resilience to insolvency stem from their ability to maintain self-sustained economic viability. Economic empowerment and resilience against (external) financial and economic challenges are crucial, with energy communities operating on principles of identity, aiming for deprivatization and leveraging democratic governance for climate goals (Klemisch 2014; Drewing 2020). The social innovation potential of these communities enables energy consumers, regardless of financial standing, to integrate into decentralized energy systems. These features makes energy communities less susceptible to global economic crises compared to fossil fuel-based systems reliant on imported energy sources (Walker et Devine-Wright 2008; Koirala et al. 2018; Caramizaru et Uihlein 2020).

3.2 Insights from German energy communities

Energy communities have played a transformative role in Germany's journey towards renewable energy adoption, originating in the 1990s but gaining significant traction in the 2000s. This growth coincided with Germany's intensified focus on alternative energy sources, driven by mounting environmental concerns and a strategic shift away from fossil fuels. The implementation of the Renewable Energy Sources Act (EEG) in 2000 served as a catalyst for the proliferation of energy communities by introducing a feed-in tariff policy that provided financial incentives for renewable energy producers, thereby encouraging local communities, citizens, and businesses to participate in decentralized energy production (Klemisch 2014; Drewing 2020).

As of 2022, Germany boasts a diverse landscape of over a thousand energy communities, ranging from grassroots initiatives to more established entities. These communities have become instrumental in decentralizing energy production, fostering community engagement, and promoting the acceptance of renewable energy projects at the local level. Moreover, they have generated economic opportunities, created jobs, and contributed significantly to Germany's renewable energy targets, thereby aiding in the reduction of the country's carbon footprint and facilitating a transition towards a more sustainable energy ecosystem (Energieagentur Rheinland-Pfalz GmbH 2016; DGRV 2023). Despite their successes, energy communities encounter challenges such as financing issues, regulatory uncertainties, and the need for professional management. Overcoming these challenges is crucial to sustaining their growth and impact, as they continue to serve as key agents of change in Germany's energy transition, embodying the principles of Energiewende and advocating for a more sustainable and inclusive energy future (Pfister et al. 2015; DGRV 2023; Kajimura 2023).

3.3 Insights from other energy communities in Europe

The European Union (EU) spearheads the development of Energy Communities (ECs), boasting over 1,900 projects involving more than 1.2 million citizens, particularly prominent in Germany and Denmark. These initiatives, leveraging various technologies like solar panels and windmills, provide a rich context for understanding the potential and challenges of ECs (Yildiz et al. 2015; Caramizaru et Uihlein 2020; Tarpani et al. 2022). The Renewable Energy Directive Recast (RED II) reveals a concentration of ECs in Austria, Germany, and Denmark, while the EU's Clean Energy Package (CEP) serves as a legislative framework addressing hurdles within the energy transition, akin to challenges faced by prosumers in Spain, Poland, and mirroring issues encountered in Colombia (European University Institute. 2020).

Given the absence of uniform standards across the EU, national strategies, and the establishment of "one-stop shops" (OSS) are imperative to support EC creation and development. These OSS address crucial aspects like team management, local intricacies, financial backing, and risk mitigation, underscoring the significance of expert guidance, community involvement, sustainable financing, and effective risk management for EC success (European University Institute. 2020; REScoop.eu 2022).

In Austria and Ireland, specific strategies encompass legal and infrastructural planning, operational governance, and strategic integration of energy communities with market and grid operators, alongside initiatives by the Cork City Council emphasizing service development and business planning for OSS efficacy. These instances underscore the tailored approaches within the EU to foster ECs, stressing the need for holistic strategies to navigate local challenges and capitalize on opportunities.

To bolster the growth of energy communities in Europe, research advocates for adopting well-defined business plans, promoting direct community participation, and ensuring inclusivity of minorities as foundational steps (Energieagentur Rheinland-Pfalz GmbH 2016; Hanke et Guyet 2023). Key components encompass developing business models, economic plans, legal frameworks, and establishing founding groups (dena 2022; Innova eG 2007; Gruber, Bachhiesl, et Wogrin 2021; European University Institute. 2020). InnovaEG (2007) delineates a structured approach through phases: orientation, planning, creation, and stabilization, aiming to mitigate risks and clarify member responsibilities. Supporting tools like intelligent measuring systems and distributed ledger technology are recommended for efficient management (dena 2022).

Furthermore, the role of third-party aggregators is underscored for managing energy flow and facilitating local energy trading (Energieagentur Rheinland-Pfalz GmbH 2016; dena 2022; Kyriakopoulos 2022; Gruber, Bachhiesl, et Wogrin 2021). Peer-to-peer (P2P) trading is advocated as a strategy for optimizing local energy consumption within communities, although microgrids, present in only 16% of reviewed literature, may not be indispensable (Gruber, Bachhiesl, et Wogrin 2021).

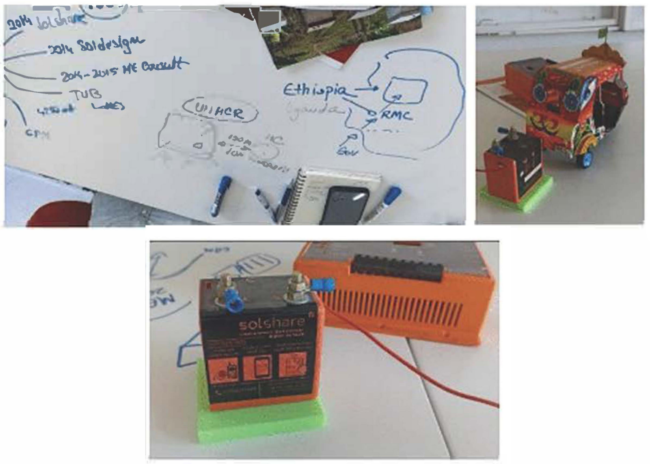
4. Results from interviews

Non-structured qualitative interviews were conducted with five institutions during the research: the Critical Infrastructure in Crisis - EADP, which held a workshop in which the goal of this research was carried out and some conclusions were extracted; Micro Energy System International - MEI; and the *Deutsche Energie-Agentur* - DENA. In addition, fieldwork in Lolland-Denmark was carried out, with visits to the Lolland Climate Center and *Ren Energi Lolland* -REEL.

4.1 Critical infrastructure in crisis (EADP)

The workshop on Critical Infrastructure in Crisis - EADP[9] concludes that complex challenges, including inadequate regulation, administrative limitations, and insufficient community participation, hinder addressing societal issues in energy communities. Competing needs and priority settings further complicate decision-making, leading to suboptimal outcomes. Moreover, limited access to supply chains and misinformation impedes resource delivery and accurate knowledge dissemination, affecting community cohesion. Paternalistic approaches exacerbate dependency and disempowerment, while Western-focused interventions may overlook Indigenous knowledge and cultural nuances. To address these challenges, a holistic and inclusive approach is necessary, integrating effective regulation, community engagement, and equitable resource access. Collaboration among stakeholders and culturally sensitive interventions can enhance community resilience and self-determination, fostering a sustainable societal landscape.

4.2 MicroEnergy International



The interview[10] highlights the importance of understanding diverse community needs, especially among ethnic and vulnerable populations, in addressing energy infrastructure challenges effectively. It emphasizes the need for tailored interventions and incentivizing community ownership to ensure the longevity of energy projects. Formal registration and active participation in investment systems are crucial for economic empowerment and project sustainability. While private sector involvement can offer resources and expertise, it must align with community needs and project sustainability. Contextual relevance and cultural inclusion are essential for seamless integration of energy projects into communities. Regulatory sandboxes for testing innovative schemes require adaptive frameworks and voluntary participation. Overall, the interview stresses the importance of a holistic, community-centered approach that promotes self-sustainability and aligns with each community's specific needs, contributing to the discourse on resilient and inclusive energy communities.

4.3 DENA

The interview[11] concludes by highlighting two crucial aspects of energy communities: energy digitalization and real-time market interaction, and the evolving regulatory framework for peer-to-peer (P2P) models. It emphasizes the role of technology in optimizing energy distribution and fostering efficient market interactions. Robust regulatory frameworks are deemed necessary to support the growth of P2P energy models, balancing flexibility for community-driven initiatives with necessary oversight. The discussion emphasizes the interconnected nature of technological advancements and regulatory frameworks, stressing the need for collaboration between stakeholders, policymakers, and communities to ensure the evolution of energy communities towards a more resilient, inclusive, and sustainable energy future.

4.4 Lolland, Denmark: Lolland Climate Center, REEL

Fieldwork in Lolland[12] focused on sustainable cooperative approaches, including visits to the Lolland Climate Center and REEL, providing insights into innovative strategies for community development. A key observation was the challenge of educating adults, particularly men, leading to a strategic shift towards focusing on children as agents of change due to their effectiveness in disseminating sustainability messages at home. The imperative for change extends beyond energy generation to consumption reduction, with Lolland emphasizing the importance of educating the community about hourly consumption and energy prices. Co-ownership of systems, including energy communities and cooperatives, emerges as crucial for successful energy transitions, offering diverse solutions to evolving challenges. Transparent communication about the benefits of cooperative models is essential for their widespread adoption. Clear communication fosters community engagement and shared responsibility, accelerating the adoption of sustainable practices.

5. Implications for Colombia

5.1 Summary of relevant criteria

From the literature review and the conducted interviews, a number of relevant criteria than can be a sustainable variable for our targeted framework for energy communities in Colombia can be derived:

Table 1: Summary of criteria found.

Relevant criteria than can be a sustainable variable	Grouping under a collective term
Combat misinformation and strengthen social fabric	*Strong social fabric for a cooperative approach*
Effective team management and advisory support are vital	
Understanding local complexities is crucial	
Risk management is essential, especially early on	
Educate communities about hourly consumption and energy prices	
Empower individuals to make informed energy choices	
Trust and community cohesion promote renewable energy acceptance	*Clear and defined motivation by the community*
Promote community participation and ownership	
Encourage care for energy infrastructure	
Democratic governance empowers citizens against privatization	
Prioritize needs effectively amidst competition	
Tailor projects to diverse community needs	
Avoid paternalistic interventions and respect cultural differences	
Adapt projects to local contexts and include community culture	
Emphasize voluntary participation and avoid overburdening communities	
Long-term security ensures resilience	
Engage the private sector while aligning with community interests	*Community initiative, skills, and opportunities*
Self-sustained financial activity drives diversification	
Financial support must align with community values	
Policy support incentivizes community initiatives	
Focus on educating children as transformative agents	
Ensure transparent benefits for cooperative models	
Minimize reliance on subsidies for sustainability	
Establish self-sustainable mechanisms to reduce external financial dependence	*Clear definition of a business plan*
Improve access to the supply chain	
Third-party aggregators support various functions	
Peer-to-peer trading optimizes energy flow	
Microgrids enhance community functionality	
Supporting tools include intelligent systems and smart contracts	
Facilitate formal registration and investment participation	*Formalization of the system*
Operational considerations follow a critical order	
Adaptive organizational structures are key	
Promote energy digitalization and real-time market interaction	
Recognize diversity in co-ownership structures	
Ensure adequate regulation and administrative capacities	
Explore regulatory sandboxes for testing schemes	
Develop regulatory frameworks for peer-to-peer energy models	

Source: own elaboration.

5.2 Design of the Sustainable Organizational Model

Based on Figure 1 and the mapping of the central elements of the research framework (Beckers, Gizzi, et Jäkel 2012, 3), an organizational model emerges that considers the five key sustainable variables at several points and clearly shows where interfaces and critical coordination issues arise (cf. Figure 2).

5.3 Discussion

Applying the Organizational Model framework to the results of our literature review and interviews reveals five key variables crucial for sustainability in energy communities: a strong social fabric, clear community motivation, community initiative and skills, a defined business model, and system formalization.

5.3.1 Strong social fabric for a cooperative approach

A robust social fabric is essential for fostering unity and shared purpose within a community. Active citizen participation, property involvement, voluntary yet reliable engagement, reconfiguration of social practices, and effective coordination between formal institutions and informal networks are key elements. Citizen participation reflects commitment and strengthens collective resolve, while property involvement signifies shared ownership and responsibility for communal resources. Voluntary but reliable participation builds trust, and reconfiguring social practices aligns norms with cooperative principles. Effective coordination ensures a synergistic balance between structure and grassroots connectivity, sustaining mutual trust, shared responsibility, and adaptive resilience.

5.3.2 Clear and defined motivation by the community

Community motivation stems from understanding its needs, wishes, and priorities, forming a shared vision. Examining tangible and intangible needs establishes a roadmap for action, ensuring efforts address pressing issues. Understanding community wishes inspires purpose, driving collaboration towards shared goals, whether it's infrastructure improvement or cultural preservation. Prioritization allocates resources efficiently, focusing on initiatives with the greatest impact. Clear motivation, derived from needs, wishes, and priorities, guides purposeful community initiatives, fostering growth and development.

5.3.3 Community initiative, skills, and opportunities

Communities must appropriate external support for projects, crucial for their success and related to securing financing. Community initiative, skills, and opportunities form a dynamic framework empowering local initiatives. Technical appropriation, understanding and applying relevant technologies, enhances self-sufficiency and resource utilization. Access to financing mechanisms, including grants and loans, is essential

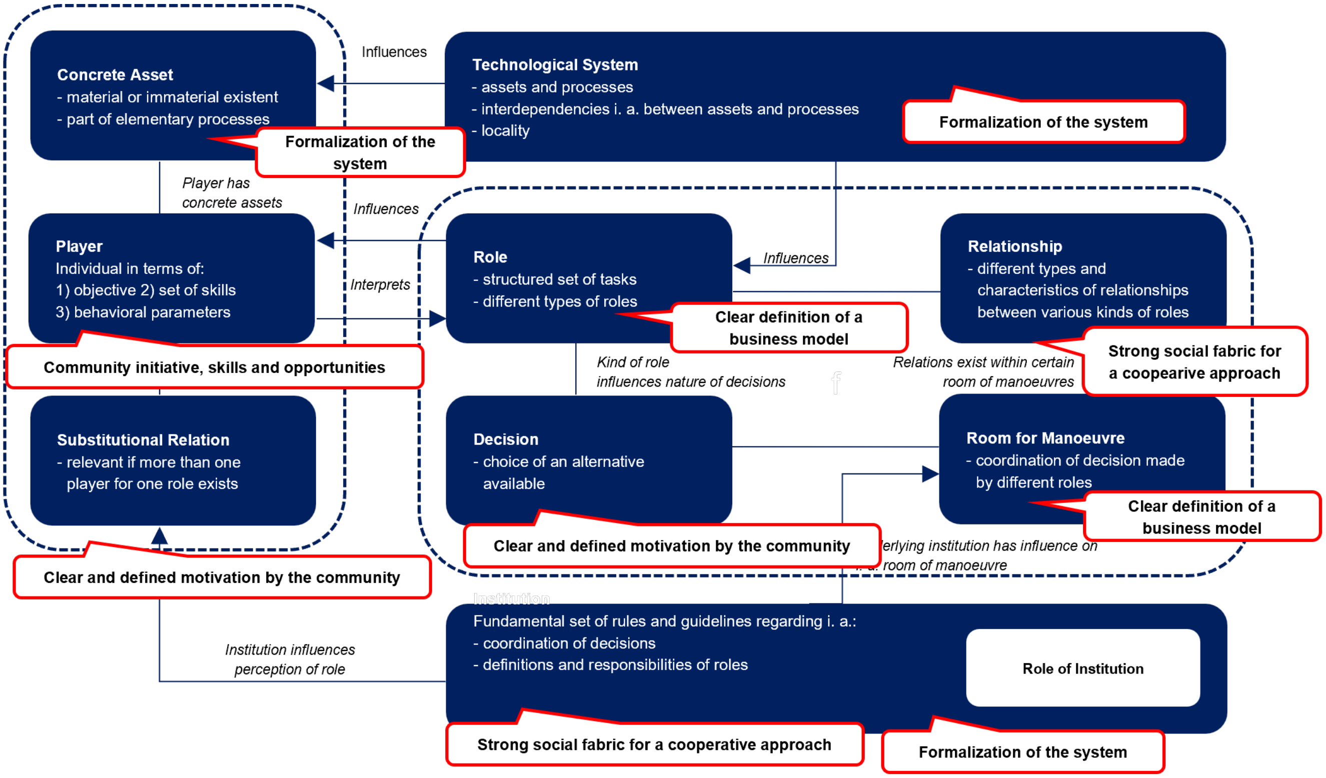


Figure 2: Organizational Model with five sustainable variables for energy communities in Colombia.

Source: own elaboration, based on Beckers et al. (2012, 3).

for funding and sustaining projects, fostering economic independence. Community knowledge is pivotal, enabling informed decisions and effective project implementation. Overall, community initiative, skills, and opportunities converge to drive positive change, economic growth, and member well-being.

5.3.4 Clear definition of a business model

Consolidating a business model and income will be important in understanding how the systems will be funded. It is vital in this model to avoid earnings for external dependency as constant subsidies, which indicate the non-finance closure of the electrical system. Involving the private sector will also be required for a successful business plan.

5.3.5 Formalization of the system

The formalization of the energy system is crucial for efficiency, accountability, and adaptability. Defined roles establish clear responsibilities, streamlining decision-making and promoting transparency. Citizen participation should mirror their responsibilities, enhancing engagement and fostering ownership. Resilience is essential to accommodate new technologies and changing conditions, ensuring the system can adapt and integrate innovations effectively. Ultimately, formalization aligns roles, responsibilities, and citizen participation, fostering resilience and serving as a foundation for sustainable energy practices.

5.3.6 Sustainable analysis of the variables

Sustainability, as defined by Ramírez-Tovar (2021), is a dynamic process balancing human well-being, social justice, and biosphere respect. This study evaluates sustainability in five components: environmental (ENV), social (SCL), financing (FNG), and technical (TEC). Each variable is scored 0-3 in each component (cf. Figure 3). The result emphasizes social and financing aspects as most crucial, prioritizing community engagement and ownership over financing. Environmental and technical aspects, while important, are secondary due to renewable energy's mature technology.

6. Conclusions

In conclusion, establishing a sustainable paradigm in Colombian energy communities requires a strong social component, with community participation, behavioral change, and social cohesiveness laying the groundwork for long-term success. Financing serves as an enabler for social efforts, contributing to overall resilience and success. The study provides insights from a literature review and interviews, capturing the diverse landscape of energy communities and highlighting key components for success. Challenges include regulatory dependencies and financial hurdles, but collaborative efforts can overcome these obstacles. Colombia can learn valuable lessons from Europe's experience, particularly in community engagement and regulatory frameworks, fostering energy cooperative growth. Prioritizing regulatory clarity and community engagement can create an enabling environment for sustainable energy practices.

Sustainability in energy communities is a multi-faceted process, balancing human well-being, social justice, and environmental limits, with social issues emerging as most critical. Prioritizing community participation and engagement, supported by adequate

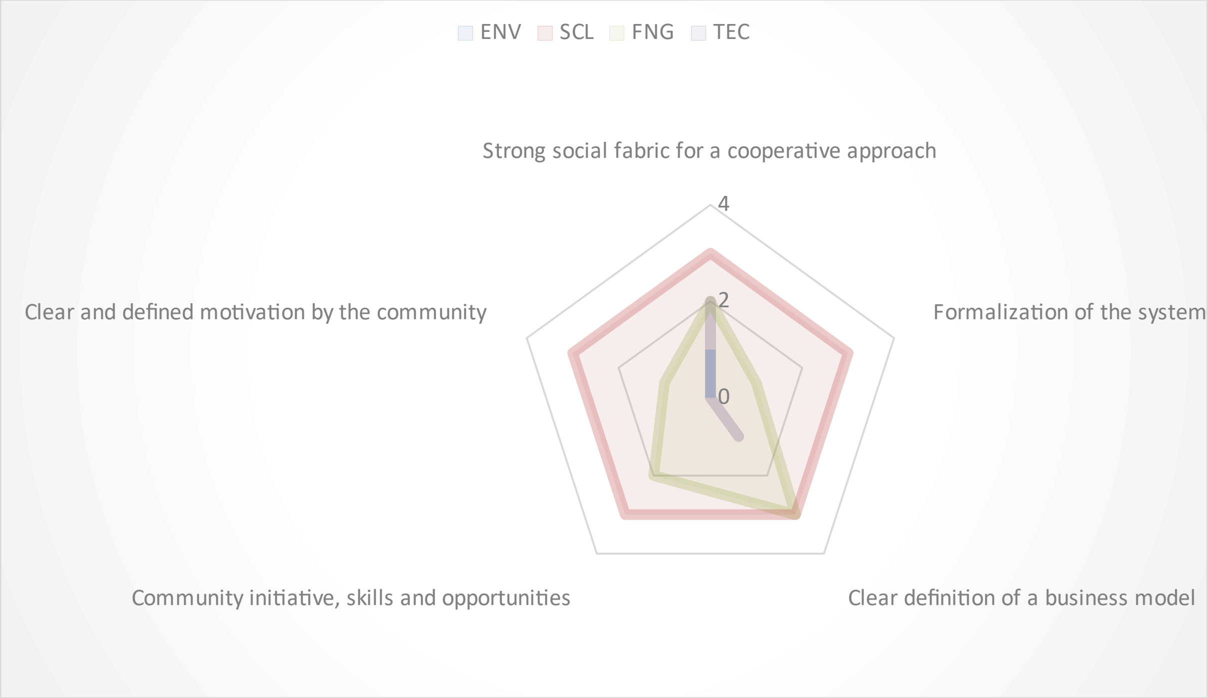


Figure 3: Rating sustainability of the five variables selected for a sustainable energy community model.
Source: own elaboration.

financing, lays the foundation for successful models, enabling long-term sustainability.

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Footnotes

[1] El Departamento Administrativo de la Función Pública de Colombia. 2023. "Ley 2294 de 2023." Accessed February 28, 2024.

[2] El Departamento Administrativo de la Función Pública de Colombia. 2023. „Decreto 2236 de 2023." Accessed February 28, 2024.

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[9] This synthesis is a result from the 06/2023-09/2023 Berlin workshop series „Critical Infrastructure in Crises: Local Perspectives on the Role of Energy in (Violent) Conflict" organized by the Energy Access and Development Program (EADP). We thank the organizers for discussion and suggestions; the usual disclaimer applies.

[10] This snapshot is a result from an interview with MicroEnergy International carried out on September 24, 2023, in Berlin, Germany. We thank Diego Garcia and Dr. Raluca Dumitrescu for their time, discussion, and suggestions; the usual disclaimer applies.

[11] This summary presents the results of an interview conducted with DENA on October 24, 2023, in Berlin, Germany. We would like to express our gratitude to Robert Westermann, Claire Gauthier, and Tim Sternkopf from DENA for their time, insightful discussion, and valuable suggestions. Please note that the usual disclaimer applies.

[12] These findings were derived from a field trip to Lolland, Denmark, conducted from October 16 to October 17, 2023. We extend our appreciation to Leo Christensen of Lolland Climate Center/REEL and Henry Hecker from RLI for sharing their time and insights. The standard disclaimer is applicable.

Successful Energy Communities Attract Innovation and Private Investors

BY SABINE LÖBBE, FEREIDOON SIOSHANSI, AND DAVID ROBINSON

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Abstract

Energy communities should be customer-centered, market-driven and welfare-enhancing[1]. *Individual consumers with proper incentives are becoming prosumers and prosumagers. The next obvious step will be to aggregate thousands or millions of such participants into physical or virtual energy communities. Private companies will help to scale and develop easy-to-handle solutions. The role of aggregation to optimize community resources and to integrate with markets are among the main topics covered in Energy Communities, a review of which by Chirara Candelise was recently published in Energiea.*

Worldwide, energy communities are emerging as part of the solution for a more sustainable, low-carbon, decentralized, resilient and semi-independent energy systems. Consumers question their traditional role as passive “load” while regulation and policy are beginning to reflect the new role of active citizens. In Germany, for example, customers have already installed around 3.3 million distributed generation systems, mostly rooftop solar systems. While the growth of distributed energy resources introduces complexity to the system, it also introduces new resources that can contribute to managing the same complexity. Energy communities are one means to address these challenges. They serve to integrate the consumer as an active part of the future energy system. This transfers responsibilities to the end consumer or to communities of consumers and those representing these stakeholders in the value chain.

While the basic technology to do what is needed already exists, putting the pieces together and making them work at scale remains a challenge. However, as the political and regulatory support for energy communities grows, technology advances, and customers become more aware of and interested in local, ecologically sound alternatives as well as self-generation and consumption, the case for developing energy communities becomes more compelling. In this context, the role of private actors is crucial.

Energy communities: a means to serve citizens and market development

The key finding of the book on energy communities[2] is that they

- Should be customer-centered to attract energy customers (i.e. citizens) to participate actively in the energy community;
- Should be market-driven and integrated into the existing or the evolving future market design of the surrounding system; and
- Should be welfare-enhancing, a key issue, with some debate on who benefits from the enhancements; – members of the energy community or the society at large.

The next obvious but challenging step will be to aggregate thousands or millions of such participants into physical or virtual energy communities. They may act both as a competitive alternative to, as well as a means of complementing, the central electricity system comprised of large generation stations, storage facilities and high voltage networks.

Multiple roles of private actors in energy communities

Energy communities share energy on a yearly, monthly, hourly or minute-by-minute basis as well as services like renewables generation, storage, optimization, supply, charging and trading. They invest in renewables, storage and other distributed resources (e.g. EV charging networks) In most cases, they share beliefs and values to engage the community members in the energy transition as well as in addressing social issues like equity, poverty relief, environmental gains and job creation.

In practice, energy communities rely on contributions from companies like start ups and incumbents, cooperatives, energy suppliers as well as providers of production assets, IT providers for data management, metering service providers; these are essential to making energy communities a success. In their chapter[3] Jake Barnes and Paula Hansen challenge the idea of single actors as the sole proprietors of energy community business models and articulate the role of actors and expertise in explaining what such business models achieve. The authors explore three business model archetypes of energy communities, with different governance models to integrate a defined set of cooperation partners and service providers.

In another chapter[4] Christian Chudoba and Tereza Borges examine advantages and challenges of energy communities using energy-as-a-service digital platforms to enable energy community models. They underline how platform-based approaches can help to manage energy communities and remove barriers to innovation.

Digital energy platforms are becoming a foundation for new consumer-centric business models that offer simple solutions to complex problems. We are all familiar with the rise of digital platforms, including fully integrated platforms like Google and Amazon, as well as sector-focused platforms like Airbnb and Uber. Airbnb's platform is an illustration of how a platform can create value by connecting buyers and sellers (in this case travelers with hosts around the world), disrupting the traditional tourism business. A key feature of platform models is their very low marginal costs of operation once the digital platform has been built.

The chapter by Chudoba and Borges explains how digital platforms, such as those provided by Lumenaza, enable consumers to join and participate effectively in energy communities, optimize the resources within the community and integrate into the wider system. First, these platforms enable energy communities to operationalize all the tasks of an energy service provider, including management of the processes for signing up new members, billing not only energy services but also insurance, bonus schemes, and the sharing of electricity, storage, EV charging and other community services. Second, energy communities become increasingly complex as they grow and adopt new distributed energy resources (e.g., solar panels, EV batteries, stationary batteries, heat pumps and other storage and demand-management tools), frequently behind individual consumer meters. Digital platforms optimize the use of these resources within the community, for instance by shifting demand (through remote control or incentives) to periods when community solar is operating and by storing electricity for use when the solar resources are not available. Digital platforms enable innovation, for instance the adoption of new algorithms to manage the smart charging of EVs when community renewables are available. Third, to minimize the wider costs of the electricity system and benefit all consumers, energy communities should be integrated into the wider system. Platform providers can automate that integration. Indeed, these platforms enable the community to act as an aggregator that sells energy and flexibility services in local and wider markets.

The theme of system integration and cost sharing is addressed further in the chapter by Del Pizzo et al, which discusses the integration of energy communities from the perspective of an Italian Distribution System Operator (DSO), E-Distribuzione. The authors, from Enel Foundation, argue that a DSO in Italy can provide several services and act as market facilitators to the community and to its members. It is important to recognize that under EU legislation, citizens have the right to be a member of an energy community (for instance to share jointly produced solar energy), while retaining the right to buy electricity and services from competing retailers and aggregators; and indeed, to sell their energy and services outside the community with the support of a retail or aggregator. Among other services, the DSO provides an advanced metering structure (Open Meter) that enables consumers to receive near real-time data with high granularity and facilitate the energy settlement of each member and of the whole energy community. It also enables energy competing retailers and aggregators to provide "tailor-made" commercial offers to consumers within the community, for instance rewarding a consumer's flexibility to support system balancing needs by shifting demand to adapt it to the daily production of renewable resources.

Conclusion

The growing availability of distributed energy resources constitutes a decarbonized citizen-centered alternative to, and complement for, the central electricity system. To date, energy communities are a relatively small part of the overall system. An obvious next step is to aggregate thousands or millions of citizens into physical or virtual energy communities to exploit economies of scale and scope based on digitalized, AI-based, innovative solutions. This will require private actors collaborating with citizens and developing solutions in a competitive environment. Allowing and supporting this competition within a well-defined regulatory framework for our future energy systems is one of the most challenging issues facing regulators around the world.

However, many energy communities have been designed with a view to isolating energy communities from the existing energy system. This is partly due to the view that the existing system and the companies that operate in it do not adequately reflect the growing concern for environmental and social objectives. There is a risk that this will lead to a balkanization of electricity systems, raising the costs of the energy transition. This view is expressed in the Chapter by Robinson and del Guayo who argue for a regulatory approach that aligns the interest of energy communities with those of the wider energy system.

Footnotes

[1] Löbbe, Sabine; Sioshansi, Fereidoon; Robinson, David (2022): Energy Communities: Customer-Centered, Market-Driven, Welfare-Enhancing?, Elsevier, Academic Press, ISBN: 978-0-323-91135-1

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Plant the Seeds, then Tend the Garden: How to Incentivize and Coordinate Energy Communities

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Abstract

Energy communities are expected to deliver a variety of benefits, such as increased uptake of renewable energy, flexibility for overall system or grid optimization, and improved system resilience. Mechanisms to incentivize energy communities and align them with the overall system needs often include direct support schemes, agreements for grid use and connection, decentralized access to markets for flexibility and residual generation, and other administrative requirements. Initially, the focus both in policymaking and research has rightfully been on the enabling factors within the regulatory framework. As energy communities slowly but steadily gain traction across Europe, this focus is expected to shift more toward the coordinating power of the framework. Our article discusses qualitatively which (combinations of) mechanisms are more suitable, depending on the actors involved, the technologies adopted, and the policy objectives to further.

1. Introduction

With the "Clean Energy for all Europeans" package (European Commission and Directorate-General for Energy 2019), the European Commission introduced energy communities to strengthen the active role of consumers in the energy system. Legally, energy communities are of two types. One of the activities they are expected to perform is energy sharing.[1] Following the taxonomy of Rossetto, Verde, and Bauwens (2022), in the context of this article, we want to shed light on Energy Sharing Communities (ESCs), that is, virtual communities with distributed generation and storage assets that can produce, use, store, and sell electricity or energy using the public grid and therefore not only limiting themselves to behind-the-meter applications. Their geographical scope can reach from local to regional.

Energy communities are often "internally oriented", that is, they exist for the benefit of their members, be it economic or social (Vogler and Kump 2023). However, since they also interact with the "external" world of the wider electricity and energy system and are oftentimes incentivized using economic instruments, in this article, we discuss how those incentives can be used to coordinate energy sharing communities to align them with the goals for the system at large.

2. Policy and Objectives

In its proposal for the improvement of the EU's electricity market design, the European Commission (2023) states several technical and social objectives for energy communities. Some of them are quantifiable and others rather qualitative. The social goals are an increased acceptance of renewable energy and the energy transition and the democratization of the transition through a better inclusion also of less affluent and vulnerable customers. In this article, we focus on the more technical goals: (1) Energy communities primarily support the uptake of **renewable energy production** by making use of, for example, private rooftop areas for solar PV; (2) in addition, they can provide the needed **flexibility to the overall system** for the inclusion of fluctuating renewables; and (3) they can contribute to **system resilience** through the uptake of a more decentralized system.[2] While (1) is the initial goal requiring incentives that enable the community in the first place, (2) and (3) are complementary goals that require incentives that coordinate the communities.

Energy communities can be categorized using different characteristics. Rossetto, Verde, and Bauwens (2022) develop a general taxonomy of energy communities. Schwidtal et al. (2023) provide a theoretical overview of the possible business models for the different actors in a community, while Kubil and Puranik (2023) have reviewed 90 real-life energy communities and their business models.

Building on those reviews, we can distinguish the following three characteristics. Firstly, the **communities' assets** can include non-dispatchable (solar PV, wind) or dispatchable (biogas, hydro) generation, storage units (batteries, heat storage), and dispatchable demand (heat pumps, electric vehicles). Secondly, the **type of actors** involved in the community, ranging from small individual actors to large commercial ones, can characterize it. Those can be asset owners like prosumers, pure generators, or flexible consumers. Still, they can also include purely passive consumers as well as facilitators of the community like aggregators, market/platform operators, or suppliers of other services. Lastly, and building on the composition of the energy sharing community, different internal **economic objectives** can arise, leading to several possible business models for the community:

— *Reducing the cost of energy supply within the community*
An energy community that establishes cheap local production and employs local flexibilities to maximize the local usage of the community production, will be viable mostly via revenues from internal sales and services.

- *Marketing excess generation outside the community* Energy communities that find lucrative options to market local production outside the community can subsidize their local supply via revenue from bilateral sales or trading on energy markets.
- *Marketing flexibility outside the community* Energy communities that find lucrative options to leverage their flexibility outside the community can subsidize their local supply via revenue for example from balancing and redispatch markets and from other flexibility mechanisms.

Other occasionally relevant characteristics include the size and geographic scope, which can differ between close proximity via a common (distribution) grid level up to a larger region – or even no specific scope can be applied.

3. Discussion of coordination mechanisms

Energy communities develop and operate within the larger energy system and its regulatory framework. Many aspects of this framework affect which types of energy communities can flourish and how they align with the system at large. Importantly, this is irrespective of whether these regulatory aspects are intentionally designed with energy communities in mind or simply historically continued. Based on currently existing frameworks in Europe (Energy Communities Repository 2024b) and the experience with mechanisms applied to renewable energy generators, energy efficiency and demand response, we assess in the following what mechanisms are suitable to align the overall policy targets with the objectives of different types of energy communities.

The selection of mechanisms for this assessment is by no means exhaustive; the analysis focusses on those mechanisms that can coordinate energy communities with the overall energy system in a tangible and potentially quantifiably manner. By and large this includes (1) direct support schemes, (2) agreements for grid use and connections, (3) market access rules, (4) agreements for the use of smart meters and the related data and services, and lastly (5) administrative requirements to qualify as an energy community and benefit from dedicated agreements and support schemes.

Table 1 sums up the main features of the mechanisms which are discussed in more detail.

Direct support schemes include mechanisms such as grants for initial investments, as well as special tenders and production premiums for energy generation in energy communities. Ireland and Denmark, for example, offer direct investment support for renewable energy communities; Lithuania awards a bonus to communities when participating in public tenders for RES support (Energy Communities Repository 2024a). These mechanisms typically address the asset owners within a community, particularly renewable energy generators but potentially also flexible assets such as batteries, electric vehicles, and heat pumps. Italy for example implemented a per kWh extra-remuneration for locally shared renewable generation (Energy Communities Repository 2024c). From the internal perspective of the community, these mechanisms serve mostly to reduce the cost of energy supply within the community. In so far as investments in excess generation or flexible assets are supported, they can also facilitate revenues from excess generation and from flexibility services outside the community. From a policy or overall system perspective, direct support schemes mostly foster the target of increasing the uptake of renewable energy generation, yet by raising the level of local and distributed generation they also contribute to improved system resilience. Insofar as flexible assets are included, support schemes can also lay the foundation for energy communities to provide flexibility to the overall system or to the grid if this is incentivized by other complementary mechanisms. The Energy Community Repository[3] highlights the relevance of dedicated support schemes for energy communities. They observe that the support levels found appropriate for the average profit-oriented investment may not be sufficient for collective actors with a varied set of objectives; and that communities do not perform well in tenders where they compete with purely profit-oriented and professional actors.

Agreements for grid use and connections encompass grants for grid connection cost or priority access to limited connection capacity, as well as proximity- and time-related reductions of tariffs for withdrawal and feed-in, and collective (rather than individual) billing and metering. Several European states, such as Ireland, Greece, and Spain reserve part of their scarce grid connection capacity specifically for community projects (Energy Communities Repository 2024c). Austria offers a proximity-based reduction of use tariffs. Mechanisms linked to connection and location address primarily the owners of assets, especially generators and consumption devices requiring additional capacity. Time-varied mechanisms, on the other hand, are relevant for all dispatchable and flexible assets, so long as the tariffs are not limited to feed-in or withdrawal. From current practices for example in the Netherlands and Germany, we can see how priority access may exhibit restrictions regarding location and use times as well.[4] Unlike connection agreements, time-varied tariffs also regard facilitators such as aggregators and asset managers. Collective billing and metering even involve the passive consumers within a community. Agreements for grid use and connections often support communities in their internal goal to reduce supply cost. From the system perspective, they lay the foundation for capacity buildup of renewable generators and flexible asset. If the mechanisms involve a time-varied feature they additionally serve to coordinate these assets with the system and provide flexibility. Proximity-related tariffs on the other hand benefit system resiliency by promoting distributed capacities.

Access rules for different types of markets also set the scene for the uptake and coordination of energy communities. The relevant mechanisms include suitable prequalification for collective sellers in wholesale and balancing markets, as well as the inclusion of collective actors in redispatch markets or mechanisms.

Table 1: Assessment of coordination mechanisms.

Types of Mechanisms		Link to Policy Target Asset	Link to Types of Communities		
			Asset	Objective	Actors
Direct Support Schemes	grants for initial RES investments	renewables, resilience	generation	reduce supply cost, revenue from excess production, revenue from flexibility	asset owners
	grants for initial investments in flexible assets	flexibility, resilience	storage, flexible demand	reduce supply cost, revenue from flexibility	asset owners
	special tenders for energy generation in energy communities	renewables, (resilience)	generation	reduce supply cost, revenue from excess production	asset owners
	production premiums for energy generation in energy communities	renewables, (resilience)	generation, storage	reduce supply cost, revenue from excess production	asset owners
Agreements for Grid Use and Connections	grants for grid connection cost	renewables, (resilience)	all	all	asset owners
	priority access to limited connection capacity	renewables, (resilience)	all	all	asset owners
	proximity-related tariff reduction	renewables, flexibility, resilience	all	reduce supply cost	asset owners
	time-variable tariffs for withdrawal and feed-in	renewables, flexibility, resilience	all	reduce supply cost	facilitators
	collective billing and metering	renewables, flexibility	all	reduce supply cost	all
Market Access Rules	suitable prequalification for collective sellers in wholesale markets	renewables, resilience	generation, storage	revenue from excess production	asset owners, facilitators
	suitable prequalification for collective sellers in balancing markets	renewables, flexibility, resilience	dispatchable generation, storage, flexible demand	revenue from flexibility	asset owners, facilitators
	inclusion of collective actors in redispatch markets and mechanisms	(renewables), flexibility, resilience	dispatchable generation, storage, flexible demand	revenue from flexibility	asset owners, facilitators
Agreements for Use of Smart Meters, Data, and Services	grants for / provision of smart meters	flexibility, resilience	flexible demand	revenue from flexibility	asset owners, facilitators
	access to smart meters data for the community and for third-party aggregators	flexibility, resilience	flexible demand	revenue from flexibility	asset owners, facilitators
	balancing and forecasting responsibilities outside the community	flexibility, resilience	all	reduce supply cost	asset owners, facilitators
Administrative Requirements to Qualify as an Energy Community	requirements regarding the share of renewable energy supplied	renewables	generation	reduce supply cost	all
	requirements regarding self-consumption	flexibility	dispatchable generation, storage, flex demand	reduce supply cost	all
	limitations regarding assets size	resilience	all	reduce supply cost	asset owners
	limitations regarding geographical proximity of assets	flexibility, resilience	all	reduce supply cost	all
	exclusion of certain technologies and energy vectors	depends	depends	reduce supply cost	asset owners

It is mostly the facilitators, in the form of both aggregators and market operators, that are addressed with these aspects of the regulatory framework. To a lesser degree they can also concern the asset owners themselves; in the case of wholesale markets owners of generation assets in general, and in the case of balancing and redispatch mostly owners of dispatchable generators, flexible demand assets, and storage. Internally, for the community, these mechanisms enable revenues from excess generation as well as from flexibility provision. From a policy perspective, market rules are vital to harvesting energy communities' flexibility for the overall energy system and for grid optimization. Especially with regards to balancing and redispatch they also benefit the short- and mid-term resilience of the energy system. As market participation provides additional revenues for distributed generation, it also indirectly supports the policy target of increasing renewable generation capacity. Collective access and suitable prequalification particularly benefit small actors who otherwise individually often are not allowed to participate or face too high transaction costs.

Agreements regarding smart meters and the related data and services are a further aspect of the relevant framework for aligning energy communities with the needs of the energy system. They include grants for or the provision of smart meters, access to smart meter data for the community and third parties, and the assignment of balancing and forecasting responsibilities outside the energy community, for example with suppliers and network operators. Belgium, in the Brussels region, for example, has established a limited supplier license shielding energy communities against some of the complexities of commercial, large scale energy supply (Energy Communities Repository 2024a). These mechanisms address the facilitators within the community, for example aggregators and service providers, as well as potentially the owners of flexible assets, such as electric vehicles, heat pumps, and batteries. Smart meters enable energy communities on the one hand to reduce supply cost internally but also potentially to generate revenues from providing flexibility outside the community. Shielding communities from the complexity of electricity supply, that is, from balancing and forecasting requirements, furthermore enables them to provide flexibility without incurring unproportionally high transaction costs. From a system perspective, access to smart meters and the related data is essential for many ways in which communities contribute to system flexibility and resilience as well as for grid optimization. Importantly, smart meters unlock these benefits mostly in combination with dedicated grid tariffs and access to the relevant markets.

Lastly, we observe a number of **administrative requirements to qualify as an energy community** and thereby benefit from dedicated agreements and support schemes. These include requirements regarding the share of renewables supplied or the self-consumption within the community and the respective matching period. It also encompasses limitations regarding the capacity or the geographical proximity of assets in the community, as well as the exclusion of certain technologies or energy vectors. Spain, Austria, and Portugal for example prescribe a maximum radius or limit the activities to a subsection of the distribution grid. Matching periods for communities currently range between 15 minutes for among others Portugal, Belgium, and Austria, and up to the entire year in the case of Greece (Energy Communities Repository 2024c). The qualification as an energy community by itself has relatively little implications. The benefit from complying with these administrative requirements lies in the eligibility for other dedicated mechanisms, such as special tenders for support of collective assets or dedicated grid tariffs. Thus, these mechanisms are mostly relevant in combination with or as a specification of the mechanisms already discussed above. These mechanisms often concern primarily the asset owners and serve to reduce supply cost by unlocking support or savings potential. Thus, at least indirectly they affect all actors in the community. From a system perspective, administrative requirements can serve to finetune the mechanisms above to balance between the targets of system flexibility provision and improved system resilience, and supporting the uptake of renewable energy.

4. Conclusions

Mechanisms to incentivize energy communities are expected to deliver in at least two dimensions: enabling energy communities in the first place and coordinating them with the overall energy system. Initially, the focus both in policymaking and research has rightfully been on the enabling factors within the regulatory framework. As energy communities slowly but steadily gain traction across Europe, this focus is expected to shift more toward the coordinating power of the framework. This article qualitatively discusses which (combinations of) mechanisms are suitable to coordinate communities and their different actors and technologies with the overall energy system and with the overarching policy targets.

We focus on direct support schemes, agreements for grid use and connections, market access rules, agreements for the use of smart meters and the related data and services, and lastly administrative requirements to qualify as an energy community and benefit from dedicated agreements and support schemes.

In many respects, energy communities seem to merit a dedicated regulatory framework. This is because collective generation and flexibility provision is not necessarily well-established and coordinated by the same rules and mechanisms as individual actions. Similarly, communities delivering on a varied set of objectives do not perform well in competition for tenders with purely profit-oriented actors. Furthermore, the specific characteristics of mechanisms are critical to the alignment of an energy community with the needs of the system. Mechanisms with time-varied and proximity-related features seem particularly promising to coordinate flexibility and improve system resilience. Lastly, from a system perspective, administrative requirements can serve to finetune the reviewed mechanisms to balance between the targets of system flexibility provision and improved system resilience, and supporting the uptake of renewable energy.

This article offers a brief and qualitative overview, for further research this topic certainly merits quantitative assessment of the effects to help improve future coordination efforts. Another issue for further dedicated research concerns the interaction of these coordinating mechanisms with rather soft and inherently qualitative goals set at European level, such as for example inclusion of vulnerable consumers and promoting the acceptance of the energy transition.

Acknowledgements

Christine Brandstätt and Jens Weibezahn acknowledge financial support from the Copenhagen School of Energy Infrastructure (CSEI). The activities of CSEI are funded jointly in cooperation between Copenhagen Business School and energy sector partners. Jens Weibezahn acknowledges funding from the European Union's Horizon 2020 research and innovation program under grant agreement No. 101025788.

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Footnotes

[1] Different manifestations of the concept exist in the literature, ranging from Peer-to-Peer trading (P2P) to Transactive Energy (TE) and Collective Self Consumption (CSC). The European legislation distinguishes between Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs).

[2] Goals (2) and (3) translate for example into a reduced need to build new transmission lines or a reduced dependence on imported primary energy respectively.

[3] https://energy-communities-repository.ec.europa.eu/.

[4] C.f. connection restrictions in different grid areas of the Netherlands and time-dependent and interruptible grid access for controllable assets in Germany.

Economics of Metals in the Long Run: A Short Overview of the Academic Literature

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This article provides a concise overview of economic analysis in metallic raw material production. It examines the key concerns of economists over the past century, their relevance in light of available data, and recent developments over the last two decades. The subject's relevance for economic policy is significant, particularly in understanding a market with volatile demand, sluggish supply, and instable prices, to which capital-intensive business models add further complexity. Understanding primary metal production patterns is crucial for assessing current metal demand sustainability amid the low-carbon transition and digital economy.

The article exclusively focuses on the economic analysis approach, excluding geopolitical and ESR considerations. It also focuses on the optimal extraction of scarce resources under maximized intertemporal utility, leaving the minority branch of research dealing with intergenerational equity unaddressed.

A long-term macroeconomic analysis framework is applied, considering short-term metal price variations to have, on average, subdued impacts on long-term trajectories according to available studies (*e.g.*, Ulloa 2015).

A chronological structure is followed, covering Hotelling's model and its theoretical importance (1), taking stock of its empirical limitations (2), highlighting the restricted utility of peak models (3), exploring recent Cumulative Availability Curve approach developments (4), and providing insights on market models focused on short-term demand fluctuations (5).

1. Hotelling's analysis: a rich theoretical framework...

Hotelling (1931) studies the optimal behavior of a raw materials producer. He likens a natural resource production site to an asset whose yield has to correspond to that of the financial markets. Compared with a financial asset, however, a raw material deposit is unique in that it pays neither interest nor dividends. Consequently, its return can only be linked to an increase in the price of raw material extracted. For Hotelling, this price depends on the supply behavior of the producer, who chooses between producing today at the current price, or producing tomorrow at a higher price. Hotelling thus analyzes the supply of raw materials within an intertemporal framework.

The dynamic framework of Hotelling's model leads to consider the notion of opportunity cost. In standard economic theory, a company in a competitive market produces output until the marginal cost of production is equal to the market price. In the case of the extractive industries, producing an additional unit today reduces the available reserves of non-renewable resources[1] for the future, and therefore the future production of raw materials.

As a result, if owners of non-renewable resources follow Hotelling's rule, *i.e.*, they extract and sell these resources over time to maximize their net present value with respect to the interest rate, then they will extract the resource faster when the price rises due to its scarcity or a deterioration in the quality of future reserves and leave less resource for the future.

Therefore, on the optimal production path, and if opportunity and extraction costs are constant, the producer will only extract ore if the market price increases at a rate at least equal to the interest rate. This is Hotelling's rule in its simplest version, known in the literature as the *r*-percent rule (where the private discount rate is assimilated to the long-term interest rate *r*).

The intuition is that the discounted profit of a unit of resource extracted from the soil must be the same in all periods, there is therefore no gain in shifting extraction from one period to another. For the present value of the price (net of the extraction cost) to be the same in all periods, the undiscounted value must grow precisely at a rate equal to the interest rate. In this framework, if ex-ante demand is stable from one year to the next, production declines monotonically over time[2].

Because of the existence of this opportunity cost, which the market price must cover, the price of the raw material will always be higher than the marginal cost of extraction. Hotelling concludes that there is no risk of overexploitation of mining resources: a price higher than the marginal cost of production implies lower demand than in a standard market, where equilibrium is reached for a price equal to the marginal cost of production alone.

In terms of production profile, Hotelling predicts an asymmetrical bell-shaped trajectory, with an acceleration of production to a rapidly reached maximum, followed by a decrease in production rate.

2. ... though its empirical validity is often questionable

In the wake of Solow's (1974) remarkable article on Hotelling, numerous contributions appeared in the years that followed (*e.g.*, Levhari and Liviatan (1977), Dasgupta and Heal (1979), Devarajan and Fisher (1981)). Some of them introduced extensions to the basic model, mainly along three themes: the dynamics of extraction costs (Herfindahl (1967), Heal (1976), Solow et Wan (1976), Weitzman (1976), Hartwick (1978), Slade (1982)), uncertainty (Stiglitz (1975), Gilbert (1979), Loury

(1978), Pindyck (1979, 1980)), and the consideration of risk (Copeland et al., (2005), Young et Ryan (1996)).

At this point, the reader has probably already understood that, if Hotelling's basic assumptions are lifted (fixed reserves, absence of technical progress, no uncertainty…), then the model's empirical predictions for price dynamics become heterogeneous.

In fact, empirical studies testing Hotelling's rule on real data have so far failed to produce a consensus. Lee et al. (2006) describe the price trajectory of non-renewable raw materials[3] over the 1870-1990 period as "stationary around a deterministic trend with structural breaks." Farrow (1985), Heal and Barrow (1981), Tilton (1999) and Cuddington (2000) also fail to confirm the hypothesis of increasing resource prices underlying Hotelling's model. The applicability of Hotelling's model to real data overall raises significant difficulties (cf. Svedberg and Tilton (2006)).

3. Peak models, a more empirical approach with no theoretical basis or predictive gain

3.1. Hubbert's approach (1956)

King Hubbert, a Shell geologist in the 1950s, wrote a paper for a conference in Texas entitled "Nuclear energy and the fossil fuels", which concluded that only nuclear power could ensure the sustainability of the world's energy demand, and that it should therefore be substituted for fossil fuels.

This paper, often quoted but rarely read, has no theoretical basis, which is not a criticism but an observation. Hubbert notes that between the mid-nineteenth century and the mid-twentieth century, the growth rate of coal and oil production in the United States tended to decline over time. More specifically, he notes that the long-period profile of crude oil production in Ohio and Illinois exhibits roughly a bell-shaped profile over this period, with a production peak followed by a subsequent rapid slowdown.

Hubbert, who systematically assumed the stability of available resources, generalized, and considered the bell-shaped profile to be a natural feature of mining.

As a result, his work consists exclusively of estimating peak production and, more importantly, the associated depletion date for mineral resources, based on the current rate of production and the estimated size of reserves. The focus is exclusively on estimating available reserves, such that the cost of extraction, price, risk, rock quality, and technical progress are left unconsidered.

While Hotelling's model was not lacking in rich theoretical intuitions (but suffered from an inconclusive confrontation with real data), Hubbert's approach relies on a few empirical cases, a somewhat dubious generalization, and a proven lack of theoretical construction.

3.2. Peak models

The peak models developed in the wake of Hubbert's work have enjoyed relative success in the literature. In these models, there is only one input that defines peak production: the "Ultimate Recoverable Resources" (URR) that define the total supply over time. URR is an assumed estimate of the total mineral resources an economy can recover from mineral deposits, now and in the future (Prior et al., 2012).

Peak models explicitly assume that other determinants of supply (price, technology, exploration, or production costs) are irrelevant for studying the long-term depletion of non-renewable resources (Tilton, 2018). The quantity demanded in peak models is not a relevant variable if it is greater than or equal to the production of the peak function. This demand condition is implicitly guaranteed by non-decreasing per capita demand. All these assumptions seem very strong, and rather unreasonable.

Peak model calibrations consider different URR scenarios, but changing the URR does not lead to major changes in the peak year (Northey et al. (2014), Sverdrup et al. (2014)), which may provide an impression of robustness. In the case of peak models applied to copper, the literature of the last fifteen years has agreed on a shortage over the next 20 to 30 years (Bardi and Pagani (2007), Prior et al. (2012), Laherrére (2010), Northey et al. (2014), Sverdrup et al. (2014)) across heterogenous URR assumptions.

3.3. Serious criticism

Criticisms of bell-shaped models have been widely debated:

- These models often confuse geological availability with economic availability. The uncertainty of economically available geological stocks is a fact, yet it does not affect the behavior of agents in peak models that consider reserves and resources as fixed stocks (May et al. (2012), Meinert et al. (2016), Wellmer and Scholz (2018)).
- Furthermore, peak models do not consider the effect of technology, which increases the economic availability of reserves, resources, and undiscovered deposits (Kharitonova et al., 2013).
- Peak models often fail to consider the fact that the intensity of use of metallic materials declines as countries develop (Criqui (2013), Crowson (2011), Ericsson and Söderholm (2013)).

All things considered, it is possible to fear that the assumptions of peak models are highly questionable and undoubtedly biased in favor of a pessimistic forecast of the depletion of metallic mineral resources.

In the case of copper, for example, it is a constant that the resource is abundant and that the reserve is being maintained. In 2018, the US Geological Survey (USGS) inventoried the Reserves/Production ratio - expressed in number of years of consumption (since "reserves" are *a priori* a stock while production is an annual flow) as calculated since the beginning of the 20th century. In 120 years of statistics, this ratio has always been relatively constant, fluctuating around 40 years of consumption.

4. A new paradigm? The Cumulative Availability Curve approach

Between Hotelling-style thinking, which employs concepts from economic analysis but suffers from a clear lack of confirmation in the data, and a highly empirical Hubbert-style approach that has no theoretical foundation and no gain in predictive power, is a third way possible?

The Cumulative Availability Curve (CAC) of an exhaustible natural resource is the graph of the function that relates a given price of this resource to the total world stock economically exploitable at this price. This CAC differs from the traditional supply curve in economics textbooks, which describes the flow of goods offered on the market for a given period (usually one year) as a function of price. The CAC corresponds not to a flow over a given period, but to a global stock available for the future. It shows the total quantity of natural resource recoverable in the economic sense of the term as a function of the price level (Tilton and Lagos (2007), Tilton et al. (2018)). However, like the traditional supply curve, the cumulative availability curve (CAC) assumes that, apart from price, all other determinants of metal availability are fixed (exploration and production costs, technological level).

The CAC approach is interesting for prospective exercises on the sustainability of metal demand. Indeed, the shape of the curve depends on geological factors that have occurred in the past, and not on events that may or may not occur in the future: it can therefore be traced relatively objectively.

The combined calculations of CAC and global demand trends[4] have led to the reasonable conclusion–with all due caution when it comes to projections–that global lithium demand should remain sustainable over the century, even with optimistic demand and conservative supply assumptions (Yaksic and Tilton, 2009). Once again, caution is called for in this kind of exercise, as geology and extraction techniques can sometimes lead to major surprises.

However, the CAC paradigm for assessing the sustainability of global demand for metals does not enjoy complete consensus on how to assess mineral resource depletion.

For some, the ability of markets to provide the necessary signals to compensate for resource depletion is not assured. High external social and environmental costs of mining are not internalized by markets (Segura-Salazar and Tavares, 2018). Price trends do not appear to signal mineral resource depletion, as price trajectories do not clearly differ between geologically abundant and scarcer minerals (Henckens et al., 2016).

Other critics argue that the opportunity cost paradigm may overestimate the role of technology in offsetting depletion (Gordon et al., 2007; Humphreys, 2013).

On a more fundamental aspect, we find two methodological limitations to the CAC approach. Firstly, the CAC is a purely accounting method - not an economic one, i.e., it does not include maximization behavior like Hotelling's model. Secondly, the CAC approach is a partial equilibrium analysis, not a general equilibrium one. The gradual depletion of mineral resources is assumed to drive up prices, curb demand, increase substitution, promote recycling, and encourage new sources of supply made possible by technology (carbon nanotubes, etc.). The CAC method does not include any price loop effect, where demand growth would be held back by soaring prices. This is a potentially important channel for analyzing the sustainability of global demand for a metal.

5. Market models and short-term price variations

The models of Hotelling, Hubbert, and their heirs generally did not consider metal demand as an explanatory factor for the price profile of the resource. Thanks to new econometric and statistical tools, the correlation between short-term phenomena, often but not exclusively linked to demand shocks, and long-term dynamics has enjoyed renewed interest in the literature since the 2000s, in the wake of the significant rebound in commodity prices observed at the turn of the century.

The first branch of this literature studies price cycles by breaking them down into transitory and permanent components. In general, this literature confirms the existence of price cycles affecting all commodities, while transitory shocks affect different commodities differently. Metal prices in particular are significantly influenced by short-term cyclical shocks.

The second branch focuses on the drivers of commodity prices, breaking down price changes into aggregate demand, commodity-specific demand, and commodity-specific supply shocks. Most of these studies concern oil prices. The literature on the drivers of metal prices is less abundant, but there is greater agreement that aggregate demand is the main determinant of short-term metal price shocks.

5.1. Price cycle models

Research into the existence of price cycles common to several commodity groups only really developed in the early 2000s, in the wake of the 60% surge in energy commodity prices between 1998 and 2001. This literature generally breaks down price movements into transitory and permanent components. This includes short-term cycles (business cycles), medium-term cycles (8 to 20 years) and possible "supercycles", which concern many commodities and last several decades. Short- and medium-term cycles are fueled by transitory shocks that can have several origins: recessions (e.g., the global financial crisis of 2007-2009), accidents (e.g., Vale's accident in Brazil in 2019, which disrupted iron ore supplies), conflicts or terrorist attacks.

For metals, the cyclical component of shocks accounts for a much larger share of their volatility than for other commodities: the variance is twice as high for metal prices as for those of energy and agricultural goods (Baffes and Kabundi, 2023).

5.2. Drivers of prices

The literature studying the drivers of commodity price shocks generally relies on the seminal study by

Kilian (2009) and his Structural Vector Autoregressive (SVAR) econometric model with sign restrictions to identify the relative importance of different shock drivers. Using data on commodity prices, demand and supply, price shocks are decomposed into aggregate demand shocks, commodity-specific supply shocks and commodity-specific demand shocks.

Global shocks to world demand include worldwide recessions (such as that associated with the 2008-09 global financial crisis) or pronounced expansions linked, for example, to industrialization or urbanization (e.g., China in the years 2000-2010). Commodity-specific supply shocks include accidents, strikes, conflicts, cartel production decisions, government policies and weather events.

Commodity-specific demand shocks are generally considered as a residual component of the SVAR model and reflect the influence of inventories (resulting from government stockpiling, producer stocks and market purchases), technological changes, shifts in consumer preferences, and government policies (e.g. carbon tax).

Stuermer (2018) and Jacks and Stuermer (2020) suggest that, in the case of metals and unlike hydrocarbons, aggregate demand shocks and commodity-specific demand shocks play a more sensitive role than supply shocks, and that their impact has increased over time.

Beyond the VAR approach, recent literature confirms that, on average, demand shocks have relatively little effect on long-term price trends. Thus, Ulloa (2015) shows through unit root tests conducted on numerous time series that, for copper, demand shocks affect only short-term price movements. Similarly, Wets and Rios (2015) model copper prices using a structural model that separates short- and medium-long-term dynamics and conclude by mentioning that their approach “should be applicable to a wide range of commodities”. However, since 2015, no studies applying the Wets and Rios (2015) model to other metals have emerged, probably due to a lack of data, either in terms of price or production time series length, or reliability.

* * *

Today, there are two main ways of studying the depletion of mineral resources and the sustainability of global demand for metals. The fixed-stock paradigm used by peak models assumes that the supply of metal ores is predefined and intangible: from this, the life of reserves is deduced according to future demand scenarios. This seemingly logical approach runs into serious methodological difficulties. It ignores prices and costs, technical progress, and recycling, and fails to consider that physical reserves that are available may not be effectively exploitable in economic terms.

The other approach to the sustainability of world demand for metals takes a more economic approach, with prices playing a central role the so-called CAC approach. This approach studies changes over time in what a company is prepared to pay for an additional ton of metal, depending on the geological resource and the economic conditions under which it can be mined.

Market models are used to study, often econometrically, short-term variations in metal prices. Theoretical and statistical approaches suggest that their effects on medium- to long-term prices remain to be proven.

The future in this field will probably continue to reflect on the one hand the effects of depletion of mineral reserves, which influence the shape of the CAC curve and the speed at which the world economy moves along it; and, on the other, the effects of technological progress, which reduce extraction costs. In this respect, Hotelling had the right intuitions, but had not necessarily modeled them in the most effective way to study the sustainability of metal demand.

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Footnotes

[1] Pindyck (1978b) argues in favor of replacing the word "exhaustible" with "non-renewable", since the concepts of reserves and their depletion are ultimately economic rather than geological or physical notions. This is where a strong tension arises between economists and geologists in their mode of reasoning, which we shall return to later: the former are more likely to consider that exploitable reserves of primary metal are not so much fixed by nature as variable according to various economic parameters.

[2] Demand is not considered in Hotelling's intertemporal modeling: the producer observes a price based on market conditions (raw material stock and discount rate) and adjusts his extraction rate based on these parameters alone. This approach is justified by the assumption that short-term market fluctuations (linked to the interaction between supply and demand) do not significantly affect the net value of the resource over the long term (see section 5).

[3] Aluminum, coal, copper, iron, lead, natural gas, nickel, oil, silver, tin, and zinc.

[4] The CAC gives no indication of the speed with which the global economy is consuming available stocks to the point of exhaustion.

What 'Value Added' do Utility Regulators Provide?

BY JACKIE ASHLEY AND DAVID MORTON

INTRODUCTION

In 2022, following a discussion with Mongolia's utility regulator on the importance of evaluating utility performance, a delegate asked how regulators, in turn, evaluate their own performance.

It was surprisingly difficult to respond to this question. Traditional metrics used by regulators - such as turnaround time of proceedings or cost of regulation - seemed to fall woefully short of measuring our value added. By those metrics alone, no regulation would be the most preferable option.

Economics 101 tells us we get paid for adding value to the marketplace. So, what is the value added that utility regulators provide?

In order to articulate the key deliverables of utility regulators, we reach back in time to the seminal work undertaken by James Bonbright (1988). These deliverables could be used as a basis to measure a utility regulator's value added, and therefore provide further insight into a utility regulator's performance.

BONBRIGHT AND REGULATOR DELIVERABLES

The economic regulation of public utilities was put in place to address the risk to society arising from natural monopolies and dates back to the early 20th century. Bonbright's, *Principles of Public Utility Rates*, first published in 1961, was built around a model of vertically integrated electricity monopolies and approached ratemaking largely as an exercise in balancing the ability of utilities to attract capital with those of ratepayers, all within a 'public interest' framework. As Bonbright stated in *Principles of Public Utility Rates,* the complete or qualified observance of the principles of rate-making policy subserve the public interest.[1]

Bonbright's (1988) *Criteria of a Fair Return* provides a starting point for developing the key deliverables of a utility regulator. To begin, we reword Bonbright's criteria to focus on the key regulator deliverables as follows:

Bonbright Fair Return Criteria	*Key Regulator Deliverables*
1. Ensure financial stability	1. Ensure the financial stability of regulated utilities
2. Encourage efficient managerial practice	2. Motivate utilities to operate efficiently and in the public interest
3. Promote consumer rationing	3. Encourage smart energy use
4. Providing a reasonable stable and predictable rate level to ratepayers	4. Aim for rates consumers can count on, without surprises
5. Ensure fairness to investors	5. Promote a fair playing field for all involved in the utility sector

These deliverables relate to the core mandate of utility regulators - addressing monopoly risk to ratepayers and society at large while ensuring utilities can raise sufficient capital to do the job they are required to.

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Where the regulator has other responsibilities (such as market facilitator) additional deliverables may be required.

Each of these 5 deliverables is described in more detail below.

1. Ensure the Financial stability of Regulated Utilities

Bonbright (1988) states that among these five principles, a high place - perhaps even first place - must be given to ensuring a utility is financially stable:

> Setting rates below a level that allows a utility to recover its legitimate operating expenses plus a return on investment sufficient to maintain sound corporate credit will, in the long run, result in a company that is unable to live up to its obligations to serve the community.[2]

Bonbright also states that there can be other negative impacts to customers if the financial stability principle is not met, including a higher cost of financing, worsening reliability, and higher costs overall if it results in a deviation from least cost long-term planning.

Indeed, government-owned utilities facing financial distress often signify a jurisdiction that lacks an effective independent regulator. Examples of this issue can be seen in both Papua New Guinea and Sri Lanka.[3]

Scott Hempling, professor at Georgetown University Law Center where he teaches public utility law, identifies eight questions courts have asked to assess whether utility rates are sufficient to maintain financial stability:

- Is the revenue sufficient to expand service and maintain working capital?
- Is revenue sufficient to ensure that service to customers will not be impaired?
- Is cash flow sufficient for operations and debt payment?
- Does the debt-equity ratio reflect financial strength?
- Are the bond ratings sufficient to maintain financial integrity?
- Is the quality of earnings - specifically, contribution work in progress and allowance for funds used during construction as a percentage of net income - sufficient to maintain financial integrity?
- How strong is the interest coverage ratio?
- Are there other factors affecting company value?[4]

These could be used to determine, for each regulated utility, whether there is a financial viability problem.

However, this does not mean that the utility regulator's solution to financial viability issues should always be a rate increase – regulators are under no obligation to guarantee the returns of utilities facing competition pressures – they simply provide the utility the *opportunity* to earn a fair return.[5]

Great Britain's regulator, Ofgem, further states that it is important that the regulatory framework does not provide excessive returns, reward inefficiency, or 'bail-out' a company that has encountered financial distress as a result of its own behaviour.[6]

Regulator responses to identified financial viability issues may therefore include a variety of approaches, such as rate increases, rate smoothing, asset write-downs, or where financial viability issues are a result of government-imposed restrictions on rate increases, alerting the government to the problem.

2. Motivate utilities to operate efficiently, and in the public interest

The second deliverable is to motivate utilities to operate efficiently, and in the public interest.

Regulators have a unique ability to be able to use financial incentives to encourage a utility to move in one direction or another. However, to use this tool effectively the regulator has to have both a clear understanding of what desired utility outcomes are, whether it has the jurisdiction to incent those outcomes, and the tools it can use to incent a utility to deliver them.

Public Interest Outcomes

For effective regulation, it is crucial that the regulator has a good understanding of what public-interest-driven outcomes (within the constraints of their regulatory mandate) should look like for each utility they regulate. Scott Hempling suggests the purposeful regulator ask themselves:

> Do I have a definition of "public interest"? Have I made my definition transparent by articulating it to my fellow commissioners and the parties who appear before my commission? Is my definition consistent with my fellow commissioners' definition? If not, have I worked out the differences?[7]

The Public Interest Toolkit describes the approach used by the newly formed New Zealand Electricity Authority to define its role (the link downloads the article). This Toolkit could assist regulators looking to develop their own public interest definition.[8]

The Toolkit includes a Public Interest Checklist, which could be used to help define outcomes that are within the scope of an economic regulator. For an economic regulator these outcomes include:

- Meeting legal requirements
- Fairness (prices that avoid undue discrimination)
- Economic efficiency (efficient utility operation and investment decisions, efficient customer decisions, innovation)
- Reliability and Safety
- Customer Satisfaction

Supporting economic efficiency is a key deliverable for an economic regulator. However, the clean energy transition is making it harder to identify what efficient outcomes in the public interest should look like.

For example, while the utility regulator has traditionally been agnostic regarding a customer's fuel choice, it may now be in the public interest to encourage customers to switch to cleaner fuels when making investment decisions. The need for regulators to get better visibility into these new risks is described in a recent article 'Stuck in the 1950's: Updating Regulatory Mandates for the 21st Century'.[9]

In addition, while economic regulators may not be responsible for addressing broader social issues, given their primary role as a stand in for the competitive market, public interest consideration suggest they do need to consider public acceptability of their decisions.

Investors in competitive markets are increasingly looking at environmental, social and governance (ESG) matters as a critical element to building a more sustainable business. Regulators therefore also need to consider what these social expectations are, whether to incent utilities to meet these expectations and, if so, whether the utility is delivering on them.

Regulatory framework

Once the regulator has identified the desired outcomes for each utility it regulates, it can assess whether the existing regulatory framework provides appropriate incentives for utilities to achieve these outcomes.

The regulator has a suite of tools available to it to provide a regulatory framework that encourages efficient utility managerial practice. However, the regulator must be knowledgeable about how those frameworks operate. As Malcolm Sparrow states:

> The regulator should be master of all the different regulatory structures - knowing the strengths and weaknesses of each model - and adept at determining which models would work best for different classes of risk.[10]

Sparrow stresses that there is no one 'best' regulatory approach for a particular industry, or even within a single company. He states that within each company there are multiple risks, and no reason to assume that a model suitable for one class of risk is the best model for other classes of risk.[11]

So, what are some of the tools that utility regulators have in their toolkit? These can include:

- *Cost of Service Regulation*: The regulator reviews the utility's budget and allows the utility the opportunity to recover its approved costs plus a return on investment through rates. This model only mildly incentivizes the utility to find operational cost savings between rate cases and provides a strong incentive to favor building assets over demand side alternatives.
- *Multi-Year Tariffs*: Rate levels are set based on a formula over a multi-year period (for example, annual increases linked to inflation) to encourage the utility to seek operational cost savings. Service level metrics, such as reliability and customer service, ensure that cost savings are not achieved at the

expense of service quality. This incentivizes the utility to find operational savings but can discourage investments in innovation and energy efficiency. A variation of this approach caps controllable costs (instead of rate levels) to remove the energy efficiency disincentive, but can also discourage beneficial electrification.

- *Performance incentive mechanisms:* This can be an 'add-on' to the two approaches above. The utility is allowed to earn additional amounts if certain outcomes are met (such as meeting energy efficiency targets, reduced connection time for distributed generation or undertaking meaningful customer consultation).
- *Rules and Penalties*: The regulator can develop rules that the utility must comply with, such as mandatory reliability standards.
- *Risk-based frameworks:* For risks such as cybersecurity, extreme weather, and wildfires, the regulator could also include risk-based frameworks, such as those described in the *Hackers and Extreme Weather* article.[12]

The regulator may also decide not to regulate a utility at all (for example where it is customer owned or not providing a monopoly service) or only regulate in certain circumstances (for example, if a complaint is received).

This is not a complete list of all regulatory tools available. For example, Great Britain's regulator Ofgem identified in 2010 that the existing regulatory framework did not support innovation and so made significant changes as a result, which included an innovation stimulus package.[13]

The key point is that the regulator considers whether the existing regulatory structure is providing utility management with the correct incentives to elicit the desired performance. If it does not, the regulator may want to address it.

Case Study – Great Britain Regulator

An example of a regulator currently reviewing its suite of regulatory tools in light of changing circumstances comes from Great Britain.

In response to decarbonization goals, Great Britain is creating a new entity who will be responsible for natural gas and electric long term system planning – called a Future System Operator. These system plans will specify the network infrastructure needed to meet long-range net zero targets at the least overall cost to consumers.[14]

Great Britain's electricity and gas regulator (Ofgem) is reviewing its regulatory framework in light of this change. Ofgem states that the Future System Operator (and not the utility) will now possess detailed expert system knowledge of assets and demand conditions, and so this allows it to consider regulatory frameworks that were previously off the table.[15]

This includes consideration of a 'Plan and Deliver' regulatory framework, where grid expansion occurs in line with top-down system plans prepared by the Future System Operator. This is intended to reduce the risk that needed investments are not built.[16]

While this may seem like a step backwards -from the incentive regulation currently used towards a more prescriptive approach - it demonstrates how regulatory frameworks can and should evolve with changing market conditions.

3. Encourage Smart Energy Use

The third deliverable of a utility regulator is to encourage smart energy use, which Bonbright calls the 'consumer-rationing criterion'.

Bonbright describes this as having rates that encourage all consumption for which ratepayers are ready to pay avoidable, marginal cost, and deter any consumption for which ratepayers are not prepared to pay these costs. Total revenues should also cover total costs.

As Scott Hempling articulates:

> Customers are not passive recipients of utility services. They create the demand that causes utilities to incur costs. Just as individual driving habits ease or impede the traffic flow, smoothing or slowing everyone else's trip, customer consumption influences the utility's cost structures, operations, capital plans and financing. Alert customers help make markets competitive, while indifferent customers support inertia—that powerful force that keeps the incumbent in place.[17]

So, how does the regulator know if it is encouraging smart energy use? Regulators can look at whether a utility, through its rate design and energy efficiency/electrification programs, is providing the right incentives to its customers.

Bonbright (1988), when discussing his rate design principles, states that efficiency is best supported when rates reflect marginal costs to the extent feasible. However, while this approach is theoretically sound, customers may not respond efficiently to accurate pricing signals due to behavioural biases, inattention, and transaction costs. Customer income levels can also affect price elasticity.[18]

In addition, even in competitive wholesale energy markets with transparent locational marginal prices, identifying the marginal cost of externalities (such as environmental emissions) and lumpy regional distribution investments can be difficult.

For example, utilities could end up in a circular situation of designing rates with only a small peak/off-peak differential on the basis that the customer response will be too small to defer network costs.[19]

As a result, the approach supported here is to adopt a more holistic approach. Instead of just evaluating the utility's rate designs to see if they signal the appropriate marginal costs, the regulator could consider whether existing rates are promoting efficient consumer behaviour.

For example, would there be a net benefit from higher marginal rates (to promote energy efficiency), lower electricity marginal rates (to promote electrification), or different peak/off-peak differentials (to promote load shifting)?

Hempling states that utility regulators should regularly research and identify the best customer practices, then act to induce those behaviors.

Bonbright also supports this view, stating that it is virtually impossible to exaggerate the importance of the behavioral modification function of prices on all economic agents, noting that rates are often based on historical costs yet have their most profound impact on future behaviours.

The regulator should also consider other tools to promote smart energy use, such as utility targeted energy efficiency or fuel switching programs. The article 'Effectiveness and Balance' describes how regulators can evaluate utility energy efficiency programs to determine if they promote smart energy use.[20]

Other questions a utility regulator could ask in determining if utility rates/programs encourage smart energy use include:

- Net metering rates: Is the retail rate a reasonable proxy for the value of electricity produced by the distributed generator (including network and ancillary benefits)?
- Electrification rates: Are these rates set between incremental costs (at a minimum) and stand-alone costs? Do these rates take into account customer competitive options?
- Electric Vehicle (EV) rates: Do the rates set for public charging stations reflect the benefit a utility may receive if they increase EV adoption and so increase revenues from home charging?

The regulator will also need to ensure utility rate offerings meet public environmental, social and governance expectations. As Bonbright notes, the development of sound ratemaking policy is cause for a resort to wise compromise, for it is not an exact science but a judicious blending of alternative goals.

4. Aim for Energy Rates Consumers Can Count On, Without Surprises

The fourth deliverable of a utility regulator is to aim for energy rates that consumers can count on, without surprises (stable and predictable).

Utility regulators have tools to promote rate stability that companies in competitive markets do not have. This includes allowing the utility to defer costs or revenues to future periods. However, caution should be exercised in using these tools as they could distort pricing signals and raise intergenerational equity considerations.

The regulator could therefore consider whether the regulatory framework provides the optimal level of rate stability, while preserving price signals to customers, appropriately balancing risks between customers and the utility, and supporting intergenerational equity.

In addition, the regulator can play a role in supporting rate predictability by ensuring rate designs are understandable to customers, and by educating customers of any anticipated significant future rate increases. This becomes more important as the clean energy transition puts upward pressures on rates.

5. Promote a Fair Playing Field for all Involved in the Utility Sector

Bonbright states that the first four principles are consumer focused – things that a customer would want anyway. The last principle is instead focused on supporting the history of ratemaking law as a means of protecting owners of public utility properties against confiscation of their assets.

Specifically, utilities have an obligation to serve customers in their territories, and the regulator has an obligation to allow them the opportunity for a fair return. Anything less than an opportunity to earn a fair return amounts to confiscation. The regulator should ensure it is delivering on this obligation for each utility it regulates.

The energy transition is raising questions about the appropriate regulatory approach to ensure fairness to investors, for example around potential stranded assets for gas utilities and the risk of building in advance of load that may not materialize, especially for electric utilities. For example, Ofgem states, "When considering depreciation we will focus on how best to balance the costs paid by existing and future consumers, taking account of the expected economic life of assets and uncertainty in the future use (and usefulness) of assets."[21]

The utility regulator mist be alert to these issues and ensure that risk follows the reward.

KEY TAKEAWAYS

The purpose of this article is to respond to the Mongolian regulator's question – how do utility regulators evaluate their own performance?

This is not an easy question to answer. As Scott Hempling states:

> Measurement of value is necessary, but the currency of value is elusive. Let's keep thinking.[22]

This article aims to contribute to this thinking by describing five key output deliverables of utility regulators, based on the seminal work of Bonbright (1988):

1. Ensure the financial stability of regulated utilities
2. Motivate utilities to operate efficiently and in the public interest
3. Encourage smart energy use
4. Aim for rates consumers can count on, without surprises
5. Promote a fair playing field for all involved in the utility sector

We encourage utility regulators to evaluate their own performance against these deliverables. Evaluation against these deliverables enables regulators to focus their limited resources on areas where they can provide the most value - what gets measured, gets done.

Footnotes

[1] Bonbright, p. 27.

[2] Bonbright, J. et. al. (1988). *Principles of Public Utility Rates*

[3] Papua New Guinea: Nepal, R. et al (2023), The National Research Institute Papua New Guinea. *Independent Power Producers and Deregulation in an Island-Based Small Electricity System*, p. 2, 5, 12. Sri Lanka: https://www.ifc.org/content/dam/ifc/doc/mgrt/sri-lanka-cpsd-full-report-final.pdf (p. xv, 53, 54) and https://economynext.com/how-sri-lankas-electricity-tariffs-are-expected-to-be-revised-interview-111873/.

[4] Hempling, S. (2013). *Regulating Public Utility Performance: The Law of Market Structure, Pricing and Jurisdiction*, p. 232-233

[5] Market Street R. Co. v. Railroad Commission, 324 U.S. 548 (1945

[6] Ofgem (2017), Guide to the RIIO-ED1 electricity distribution price control, p.59

[7] Hempling, S. (2013). *Preside or Lead? The Attributes and Actions of Effective Regulators*, p. 203-209

[8] Ashley, J. et al. (2021). IAEE 2021 Conference. An Energy Regulator's Public Interest Toolkit (link downloads article)

[9] Nock, M. (2023). IAEE Energy Forum. *Stuck in the 1950's: Updating Regulatory Mandates for the 21st Century*

[10] Sparrow, M. (2020). *Fundamentals of Regulatory Design*. Chapter 5

[11] *Ibid.*

[12] Ashley, J. et al. (2021). IAEE Energy Forum. *Hackers and Extreme Weather: Using a Risk Based Framework to Protect Consumers from Both*

[13] Ofgem (2018). *RIIO-2 Framework Decision*, p. 30-33

[14] Ofgem (2022). *Future System Operator: Government and Ofgem's response to consultation*

[15] *Ibid.*

[16] Ofgem (2023). *Consultation on frameworks for future systems and network regulation: enabling an energy system for the future*

[17] Ofgem (2017), Guide to the RIIO-ED1 electricity distribution price control, p.59

Hempling, S. (2013). *Preside or Lead? The Attributes and Actions of Effective Regulators*, p. 203-209

[18] Cserekllyei, Z. (2020). *Energy Policy. Price and income elasticities of residential and industrial electricity demand in the European Union*

[19] Nock, J. (2022). IAEE Energy Forum. Rate Setting for an Electrified World

[20] Ashley, J. et al. (2020). IAEE Energy Forum. *Effectiveness and Balance: A Canadian Regulator's Approach to Review of Energy Efficiency Funding Proposals*

[21] Ofgem (2010), RIIO: A New Way to Regulate Energy Networks, p. 36, 40

[22] Hempling, S. (2013). *Preside or Lead? The Attributes and Actions of Effective Regulators*, p. 203-209

Powering the Future: EVER Monaco 2023, a Conference on Electromobility and Sustainable Development of Territories and Cities

BY DIEGO CEBREROS AND CHRISTOPHE BONNERY

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Electric systems are being transformed, and having the right tools to integrate electromobility and local energy production in cities and territories has become a pressing need. Indeed, more than ever, local governments have a role in designing both their energy and transportation systems. Thus, there is a role for local governments to create territorial organizations that can prepare the electric and transportation systems for climate change and energy sobriety.

The difficulty of coordinating energy and transportation for territories and cities has become more complex than ever. There are several interdependencies that planners need to consider. Notably, the speed and uncertainties regarding future technological innovation, business models, and regulation of mobility and electric systems increase the difficulty of designing plans for the future. As a consequence, in its role as a platform for technical and expert discussion of the relevant aspects of energy economics, the **International Association of Energy Economists (IAEE)** organized the roundtables of the **EVER Monaco 2023** conference, which was held on Monaco the 11 and 12 of May 2023.

The conference roundtables' objectives were twofold: first, to acknowledge the growing importance of local government's role, opportunities, and challenges in the future of mobility and electric systems, and second, to emphasize the crucial role of technical discussion for fostering knowledge sharing among various stakeholders, such as the industry, academia, and public authorities. The conference was organized around panel presentations and debates that gave the floor to renowned speakers and conference participants, including representatives from municipal governments, territorial planning agencies, Electric Vehicle (EV) manufacturers, energy providers, and sustainability experts. Indeed, the diversity of actors facilitates the identification of several critical aspects related to the interactions between territories, cities, and electromobility.

All the presentations revolved around three main topics: energy sobriety and electromobility, adaptation of territory networks, and local renewable energy production.

One of the points of discussion which was fundamental in setting the context of the conference was the recent regulation to ban from the year 2035 onwards the sale of vehicles with internal combustion engines in favor of electric vehicles. A panel of actors from the automotive and energy industries highlighted the importance of being prepared for a surge in EV adoption. Indeed, the rate of EV adoption is expected to continue, and this growth will likely change mobility patterns, given that drivers will transition from fuelling their vehicles at gas stations to recharging them with electric chargers. Consequently, to deal with these changes, a proposed strategy was to identify measures to encourage the optimal development of charging infrastructure according to the changes in mobility behaviors and the new opportunities presented by electromobility. For example, it is well known that charging infrastructure needs to be deployed to reduce owners' range anxiety. In the second phase of the deployment of charging infrastructure, once the range anxiety is addressed, also infrastructure should be designed to encourage local energy production from solar energy, thereby providing incentives to install charging infrastructure where EVs are parked. For instance, this could allow for the improvement in the utilization of local resources if EVs can leverage the highest peak of local renewable energy production.

The emergence of new business models that harness the opportunities for integrating electromobility into electric systems might increase the value of the territories and cities. Indeed, most speakers emphasized this point throughout the conference. However, presenters had different opinions on the subject, as there was no consensus on which should be the dominant type of business model. Several business models were presented, from charging points and mobility operators to energy aggregators. Nevertheless, presenters agreed on a fundamental notion: all business models require a reliable "smart grid" and a network of charging infrastructure with standardized charging protocols, interoperability, and accessibility that ensures a seamless experience adapted to customers. For example, in the business case of Vehicle-to-Grid (V2G), a technology that enables to use of EVs as decentralized storage, it was emphasized that charging infrastructure and EVs will need to have bidirectional capabilities, in addition to reliable and secure communication between EV owners, aggregators (who control the vehicles as a single entity), and the grid operators.

A significant highlight of the event was the opportunity to showcase success stories from cities and regions that successfully integrated electromobility and combined it with local energy production into their territory planning. The presentation of case studies provided tangible examples of the positive impacts of a strategic approach to electromobility implementation and the related challenges, and local energy policy. For example, representatives of Vendée, a department in the west of France, shared how Vendée created the capabilities to encourage local energy production that was inexistent 20 years ago. Today, 25% of total energy production is covered by either wind farms within the department or decentralized solar energy. Yet, several challenges were also shared regarding reducing the administrative costs for reinjecting energy to the grid and regulating self-consumption.

Overall, the conference unveiled different perspectives and experiences on the policies implemented and required for the sustainable development of territories. Local governments must consider the design of policies that go beyond the typical policies used to incentivize EV adoption, such as reduced parking fees for EV owners. Indeed, leveraging solar and wind power, in combination with EV adoption, is the new challenge that local communities face to reduce their carbon footprints and achieve significant cost savings in the long run. Stakeholders and conference participants agreed that despite the positive momentum in electromobility adoption, challenges still require careful consideration and innovative solutions. Uncertainties related to technology and regulation, limited funding for infrastructure development, lack of standardized charging infrastructure, and public resistance to change were among the most mentioned hurdles that industrial actors, cities, and territories currently share.

Looking ahead, the future of the integration of electromobility with the energy system, considering territorial and city planning, appears promising. The conference showcased the immense potential of collaboration, knowledge exchange, and decision-making for organizing territories and cities with a sustainable lens. Despite the uncertainty previously mentioned, by continuing to share best practices and lessons learned and fostering partnerships, cities, and territories can pave the way for sustainable, liveable environments that prioritize citizens. The event was a valuable learning opportunity, highlighting key lessons from the private and public sectors. Flexibility and adaptability were critical attributes of policymakers for territorial planning. Indeed, there are several innovative technologies and emerging trends to keep up, such as V2G.

Programme: https://www.faee.fr/en/89-conferences.html#/conf/314/1

Photos: https://www.faee.fr/fr/89-conferences.html#/conf/314/2

Is LNG a Bridge Fuel in the Mitigation of Global Warming: A Critical Review of Studies at the EDF, NRDC, and Bloomberg

BY MARC VATTER

Abstract

I review research saying that exports of LNG from the U.S. are, on the whole, as dirty as coal, in terms of methane leaks and emissions of CO_2 during liquefaction. I show these concerns to be based on misinterpretation of data, unrealistic assumptions, and omissions of key metrics, and, therefore, invalid.

Introduction

Several studies (see references) have examined the effect of liquefied natural gas (LNG) production, storage, transport, and combustion on emissions of methane (CH_4) and other greenhouse gases (CO_2 and NO_x). Substitution of natural gas for coal and oil in electric generation and transportation has done much to lower emissions[1], but some observers question whether LNG represents the same kind of "low hanging fruit" or "bridge fuel" in the mitigation of global warming that pipeline gas does.

Here, I review and critique mainly studies done through the Environmental Defense Fund (EDF), the Natural Resources Defense Council (NRDC), and Bloomberg News that criticize LNG because of emissions of CH_4 and CO_2.

Upstream emissions of methane

A crucial input to the different LNG studies, though it affects emissions from both pipeline gas and LNG, is the rate of emissions of methane associated with its production, storage, transport, and combustion.

> Looking at the full lifecycle of coal, gas and LNG, a study in 2019 by the U.S. National Environmental Technology Lab (NETL) found that U.S.-produced LNG shipped from the U.S. Gulf [Coast] to Rotterdam in the Netherlands, would produce between 20% and 53% less GHG [greenhouse gas] emissions over 100 years than burning lignite coal sourced in Europe and burned in a European power plant. For exports of LNG to China, U.S. LNG would generate between 21% and 54% less emissions than regionally sourced coal.
>
> A study by the American Petroleum Institute (API), using updated emissions modeling available in 2020, indicates that U.S. LNG exports to China, Germany and India would generate, on average, 50.5% fewer lifecycle greenhouse gas emissions than coal-fired power.
>
> U.S. environmental groups dispute the findings favorable to LNG exports. Environmental Defense Fund (EDF) questions a key assumption of NETL's analysis, namely the relatively low methane leakage rate for the production and transmission front-end segments of the lifecycle. NETL's study uses a methane leakage rate of 1.2%, based on production of unconventional (fracked) natural gas in the Marcellus and Utica basins in Pennsylvania and Ohio. But EDF points out that much of the U.S. gas that is liquefied comes from the Permian Basin in Texas and New Mexico, where it has been tracking methane emissions by satellite and mobile ground-level monitors *since 2018*. EDF has found emissions of methane are, on average, more than 3.5%.[2] [emphasis added]

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This quote comes from an article published in January 2021. In 2018 and 2019, flaring of gas in the Permian spiked because of rapidly increasing production that interacted with congestion of takeaway capacity in pipelines.

> Record-high oil and gas production from West Texas' Permian Basin also has led to record-high waste and pollution in the form of gas flaring.
>
> As companies drill for oil, they're also pumping out large volumes of associated natural gas that frequently has nowhere to go because of temporary pipeline shortages in the region. So they're opting to simply waste the gas by burning it off in a practice known as flaring until new outlets can carry their energy products to market.
>
> Norwegian research firm Rystad Energy estimates that Permian flaring averaged a record of 407 million cubic feet per day in the third quarter of this year and will keep rising next year up to at least 600 million cubic feet a day. The current flared gas amounts are worth more than $1 million per day.[3]
>
> In 2018-19, midstream players in the Permian Basin rushed to satisfy the demand for pipeline capacity driven by booming oil and gas production. The associated natural gas production had reached ~17 billion cubic feet per day (bcfd) and robust drilling activity and moderate gas prices had pressurized the midstream operators to expand the existing pipeline infrastructure network, particularly in the Delaware basin [a part of the Permian]. By early 2020, Gulf Coast Express and Carlsbad Gateway Pipeline came online and the natural gas transport capacity outstripped supply, albeit by a much smaller margin due to comparatively robust gas prices, as well as increased gas-to-oil ratios from aging wells in the Permian.
>
> Permian associated gas production increased from 15.7 bcfd in 2020 to 18.2 bcfd in 2021. It surpassed

> the pre-Covid natural gas production levels of ~17.4 bcfd in March 2020. Most of the increase in associated gas production is attributed to the increase in takeaway capacity recently. In 2021, two major gas pipeline projects, the Permian Highway and Whistler projects, came online to increase takeaway capacity from the Permian Basin by roughly a quarter…[4]
>
> Flaring fell sharply in March and April of 2020 before flattening out. In August of 2021 it fell again to 380 MMcfd. At a current price of $4/Mcf, this would amount to $1.5 million/day lost revenue. It's still a lot of money wasted every day.
>
> The results are clearly basin-dependent… The Marcellus Shale, the queen of U.S. shale basins, is gas-only and allows less leaks in their gas production. The Permian and Bakken are mainly oil, and operators tend to flare the associated gas…[5]

EDF's critique of the 2019 NETL study is based mainly on anomalously high and, in the long run, unprofitable emissions of CH_4 during the three-year period 2018-20. The methodological challenge of separating "signal" from "noise" in a sample consisting mostly of what would be outliers in a longer sample would be Herculean. One can surmise that leak rates in the long run are below EDF's estimated 3.5%.

According to Swanson et al. (2020), the NRDC study[6],

> Because methane is such a potent GHG, calculated lifecycle emissions for exported LNG are *strongly influenced* by the analytical assumptions made for the amounts of methane that leak or are otherwise released (e.g., via flaring) from the wells, pipelines, valves, compressors, and processing facilities through which the gas passes during its life-cycle. [p. 25; emphasis added]

I focus mainly on methane leaks here because of the strong influence noted by the NRDC. Some studies estimate a "breakeven" point, in terms of the methane leak rate, at which U.S. LNG exports emitted just as much in the way of standardized GHGs as coal; a leak rate below the breakeven point indicates that substitution of LNG for coal in electric generation would reduce global warming. According to the NRDC, "the Carnegie Mellon study estimated that the 'breakeven' point at which U.S. LNG exports emitted as much greenhouse gases as coal in the near-term time frame was a methane leakage rate of 3.0 percent. The 2014 NETL study reported a lower breakeven point of 1.4 to 1.9 percent methane leakage."

The latter are the low end (20 year) breakeven points for U.S. exports to Asia and Europe, respectively, reported in Table 61 on page 14 of NETL's 2014 study. NRDC does not mention the corresponding 100 year breakeven points of 4.6% and 5.8%, reported in the same table. Moreover, though they use many data from the 2019 NETL update, wherein the 20 year breakeven rates were raised to 3.1% and 3.6%, and the 100 year breakeven rates were raised to 8.2% and 9.1%, respectively, the NRDC researchers chose to conclude that LNG was as dirty as coal, from a climate perspective, using only the outdated, 20 year, 2014 NETL breakeven rates:

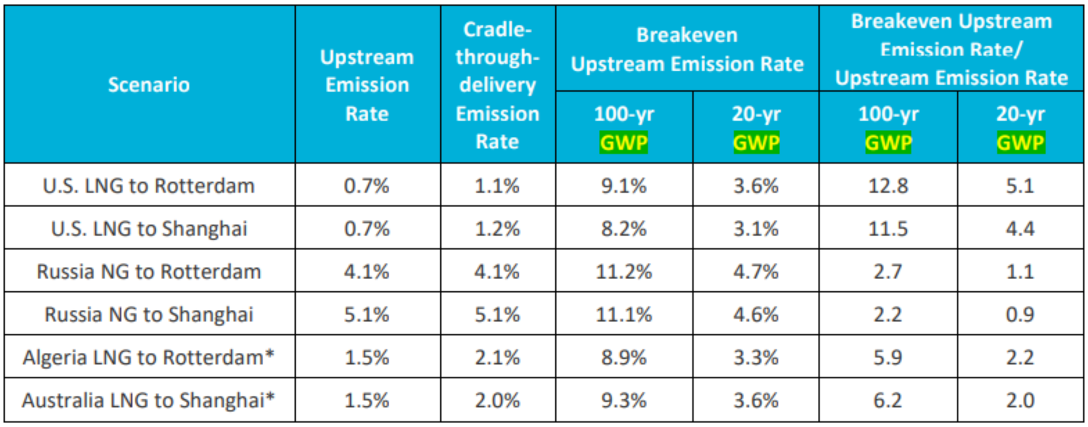
> The Carnegie Mellon study estimated that the "breakeven" point at which U.S. LNG exports emitted as much greenhouse gases as coal in the near-term time frame was a methane leakage rate of 3 percent. The 2014 NETL study reported an even lower breakeven point of 1.4 to 1.9 percent methane leakage. These rates are solidly within the range measured for methane emissions from the North American gas production and processing industries. Therefore, unless methane leakage rates are kept at very low levels, replacing coal-fired power plants with gas plants fueled by imported U.S. LNG may actually provide little or no climate benefit to either the importing countries or the world. [p. 14]

Here is a relevant excerpt from the 2019 NETL study:

> Exhibit 6-8 shows the upstream and cradle-through-delivery methane emission rates for all scenarios. It also shows the breakeven upstream emission rates for each scenario; breakeven rates were calculated by comparing the expected results for natural gas to the expected results for coal. The breakeven rates for the 20-yr [global warming potential] are lower than those for the 100-yr GWP because methane has a higher GWP over 20 years than it does over 100 years.

If I divide methane leaks from natural gas systems, abandoned oil and gas wells, and stationary and mobile combustion reported by the Environmental Protection Agency (EPA) for 2020 by natural gas production reported by the Energy Information Administration (EIA),

Exhibit 6-8. Coal and Natural Gas Breakeven for U.S. LNG and Russian Natural Gas Scenarios



Scenario	Upstream Emission Rate	Cradle-through-delivery Emission Rate	Breakeven Upstream Emission Rate		Breakeven Upstream Emission Rate/ Upstream Emission Rate	
			100-yr GWP	20-yr GWP	100-yr GWP	20-yr GWP
U.S. LNG to Rotterdam	0.7%	1.1%	9.1%	3.6%	12.8	5.1
U.S. LNG to Shanghai	0.7%	1.2%	8.2%	3.1%	11.5	4.4
Russia NG to Rotterdam	4.1%	4.1%	11.2%	4.7%	2.7	1.1
Russia NG to Shanghai	5.1%	5.1%	11.1%	4.6%	2.2	0.9
Algeria LNG to Rotterdam*	1.5%	2.1%	8.9%	3.3%	5.9	2.2
Australia LNG to Shanghai*	1.5%	2.0%	9.3%	3.6%	6.2	2.0

**Scenarios not included in Exhibit 6-9 and 6-10*

I get a leak rate of 0.94%.[7] Alvarez et al. (2018) refer to the same sources, but include emissions from natural gas systems, petroleum systems, stationary combustion, abandoned oil and gas wells, mobile combustion, and petrochemical production because they are interested in the entire oil and gas supply chain.[8] The 2015 values for the sum of these, divided by production of natural gas, gives a CH_4 emission rate of 1.44%. Multiplying 1.44% by 1.6 equates to their independent estimate of 2.3%.

> Methane emissions from the U.S. oil and natural gas supply chain were estimated by using ground-based, facility-scale measurements and validated with aircraft observations in areas accounting for ~30% of U.S. gas production. When scaled up nationally, our facility-based estimate of 2015 supply chain emissions is 13 ± 2 teragrams per year, equivalent to 2.3% of gross U.S. gas production. This value is ~60% higher than the U.S. Environmental Protection Agency inventory estimate, likely because existing inventory methods miss emissions released during abnormal operating conditions. [abstract]

Treating the categories listed above as representing emissions of methane associated with *all domestic production and combustion of oil and gas* replicates Alvarez et al.'s 60% adjustment.

The EPA and EIA data referred to by Alvarez et al. for 2015, updated data for 2020, and the 60% adjustment are shown in Table 1, where I also calculate the emissions rates from production, storage, and transport of natural gas production and combustion, excluding those associated with petroleum systems and petrochemical production, since little of the latter contribute to the LNG supply chain. When I apply the 60% adjustment to those, I get emissions rates of 1.9% in 2015 and 1.5% in 2020.

The NRDC study [p. 11] mischaracterizes the Alvarez et al. (2018) emissions rate of 2.3% as being associated with natural gas alone, when, in fact, it is associated with all *oil* and gas: "A recent study of methane emissions for the U.S. gas supply chain estimated that 2.3 percent of gross U.S. gas production is lost as leaks or intentional releases." This error of interpretation overstates the rate associated with production, storage, transport, and combustion of natural gas by 2.3 – 1.9 = 0.4% in 2015, and, implicitly, by 1.9 – 1.5 = 0.4% in 2020. EPA has separated emissions associated with oil from those associated with natural gas, and, if they have done a good job of this, the fact that the two are complements in production should not give reason to lump oil back in with gas for the purpose of estimating emissions associated with the use of LNG. (I lump them together in the case of abandoned oil and gas wells because EPA has not separated them.) Thus, even the low, outdated 2014 NETL breakeven rates (1.4 to 1.9) that the NRDC selects are not "solidly within the range measured for methane emissions from the North American gas production and processing industries".

Oil and gas are also substitutes in consumption, and prices of substitutes move together, so any policy based on estimated emissions from LNG that mistakenly include emissions from oil that, thereby, reduces the supply of LNG will raise the demand for oil, among other things inefficiently offsetting reductions in emissions from lower supply of LNG, while raising the price of the necessity that is energy, as well.

The NRDC study includes a caveat regarding declining emissions rates from U.S. production, storage, and transport of natural gas:

> Our analysis is based on currently reported quantitative data, assessments, and models. It is possible that future life-cycle GHG emissions from LNG exports could be reduced using a number of strategies, including decreasing methane leakage during all life-cycle stages; decarbonizing LNG shipping and the electricity grid in exporting countries; and using carbon capture, utilization, and storage (CCUS) in electricity generation facilities powered by imported LNG. It is likely (and to be hoped) that implementation of some or all of these strategies will progress during the coming decades. However, for this analysis we chose to use recent, published, empirical emissions data rather than to make speculative quantitative assumptions for various emissions reduction strategies in the future. [p. 23]

NRDC acknowledges the possibility of declining leak rates in the future, but does not mention the historical downward trend shown in Figure 1, where I report the metric shown for 2015 and 2020 in line J of Table 1, which is based on the unadjusted government data, for the historical period beginning in 1990 and a simple extrapolation of the historical trend to 2050. The 2020 rate of 0.89% falls about midway between NETL's

Table 1: Emissions of methane in the U.S. associated with oil and gas

	kt of CH4 emitted	2015	2020
A	natural gas systems	6,686	6,596
B	petroleum systems	1,579	1,609
C	stationary combustion	340	317
D	abandoned oil and gas wells	285	276
E	mobile combustion	85	88
F	petrochemical production	7	13
G	MT of natural gas produced	692,934,323	855,019,747
H	Emissions of O&G supply chain/NG production	1.4%	1.2%
I	with Alvarez et al. (2018) adjustment	2.3%	1.9%
J	Emissions from NG production, transport, and combustion/NG production	1.2%	0.9%
K	with Alvarez et al. (2018) adjustment	1.9%	1.5%

A-F U.S. EPA, Trends in U.S. Greenhouse Gas Emissions and Sinks, 2019 and 2022
G U.S. EIA, U.S. natural gas gross withdrawals, Source Key N9010US2, given in MCF, with MMBtu = 1000*1.037*MCF and MT = MMBtu/49.2579
H [1000*(A+B+C+D+E+F)/0.90718474]/G
I H*1.6
J [1000*(A+C+D+E)/0.90718474]/G
K J*1.6

upstream and "cradle through delivery"[9] emission rates for U.S. LNG delivered to Rotterdam or Shanghai, and well below any of the breakeven rates shown in their Exhibit 68, and also well below the three percent breakeven rate estimated at Carnegie Mellon. If I apply the Alvarez et al. (2018) 60% upward adjustment, as in line K of Table 1, the resulting emission rate of 1.42% in 2020 would still fall well below all of the breakeven points from NETL in 2019 and Carnegie Mellon.

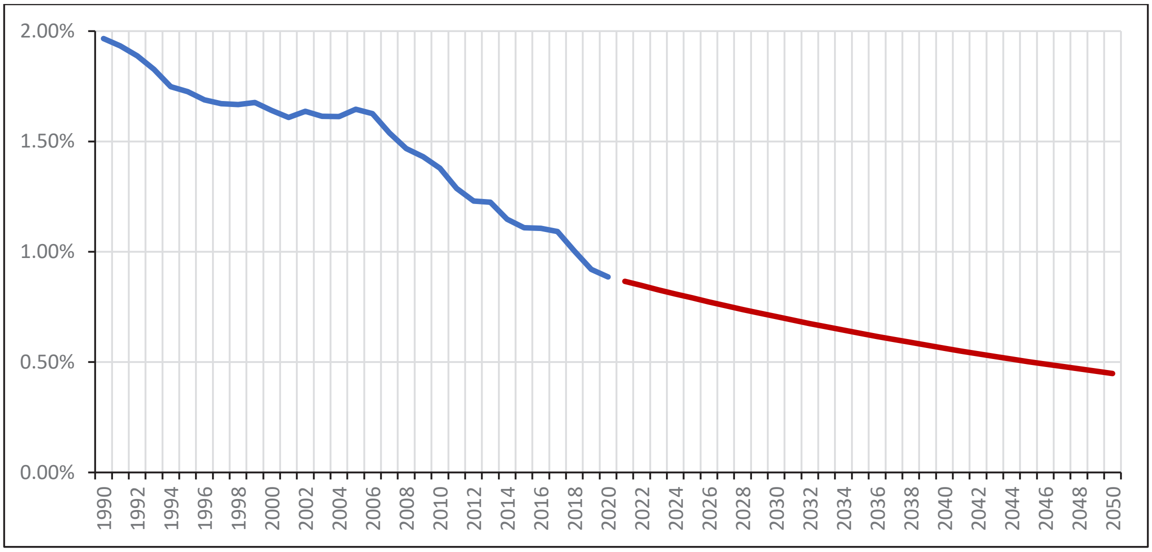


Figure 1: CH_4 production and combustion emissions / production

With or without the Alvarez et al. adjustment, the extrapolated trend is more reasonable than assuming that emission rates would remain constant. The equation for the trend is $R_t = 0.978R_{t-1}$, where R_t is the emissions rate in Year *t*, a constant term, if added, would not be statistically significant at the 90% level, and the 95% confidence interval for the stochastic trend is $0.978 \pm 2.262*0.0075 < 1$, so one can reject NRDC's assumption using standard statistical criteria.[10] A simple reason for this is that venting and flaring are typically unprofitable in the long run.

> The [International Energy Agency] identified the five most cost-effective methods for reducing the industry's scope 1 and 2 emissions. The leading method is cutting methane emissions from oil and gas operations.
>
> The second most important measure is an overall elimination of non-emergency flaring, a practice that sent about 500 mt of CO$_2$e into the atmosphere in 2022. The IEA suggests bringing the excess gas to consumers via new or existing pipeline networks, converting it into compressed or *liquified natural gas*, or reinjecting it into reservoirs to increase pressure. [emphasis added]
>
> ...while eliminating flaring would cost the industry $70 billion today, it could also generate $91 billion in revenue by 2030.
>
> The IEA estimates that 15% of energy-related emissions, or 5.1 billion mt of CO$_2$e, stem from upstream and midstream oil and gas activities – from extracting the fuels out the ground to delivering them to end users. But that 15% is also the lowest hanging fruit for reductions.
>
> "These emissions can and should drop by more than half by 2030, and it's one of the cheapest ways of cleaning up the energy system," IEA Energy Analyst Peter Zeniewski said in a tweet...[11]

"Speculative" is not a fair characterization of the expected decline in emissions rates; there are good theoretical and empirical reasons to expect continued improvement. Given the trend, emissions rates in the production of natural gas would continue to fall farther below NETL's breakeven points, and below half a percent before 2050.

It does not appear to me that LNG is as dirty as coal, at least in terms of the strong influence of upstream leaks of methane.

Emissions of CO$_2$ during liquefaction

A second climate-related criticism of LNG as a bridge fuel in the process of mitigation of global warming centers on CO$_2$ emitted in the process of liquefaction. Table 2 uses estimates from Traywick et al. (2020) that "Not all [U.S.] export terminals are completed and in use, but if they were, simply operating them could spew 78 million tons of CO$_2$ into the air every year, according to data compiled by Bloomberg from environmental filings. That's comparable to the emissions of 24 coal plants, or 18 gigawatts of coal-fired power".

In Table 2, I monetize emissions at \$100/tCO$_2$, based on Vatter (2022), but also a not uncommon value. I monetize energy from both LNG and coal using futures prices in Europe for December 2026, a long term expectation that is not excessively influenced by recent volatility. I measure energy from LNG as equal to that from exports in 2021, likely overstating the rate of emissions if combined with Traywick et al.'s 78 million tons, since full operation of the liquefaction plants had not obtained in 2021. I use a heat rate for gas-fired generation of 8,000 Btu/kwh. I use a plant factor of 0.53 for coal-fired generation from EIA (2022b), and an emissions rate of 1.0235 tCO$_2$/MWh, which is the U.S. national average for 2021, from EIA (2022c). This gives emissions from coal of 86 million tons, nine percent

Table 2: Comparison of CO_2 emissions during liquefaction with those of combustion of coal in the generation of electricity

Row	Variable	Value	Source	Comment
A	$/tCO$_2$	100	Vatter; https://papers.ssrn.com/sol3/papers.cfm?abstract_id=3821603, accessed December 26, 2022	
B	tCO$_2$/year for USGC liquefaction	78,000,000	Bloomberg; https://www.bloomberg.com/news/articles/2020-01-23/gas-exports-have-dirty-secret-a-carbon-footprint-rivaling-coal-s, accessed December 26, 2022	
C	$/year CO$_2$ damages USGC liquefaction (A*B)	7,800,000,000		
D	$/MMBtu for LNG at TTF for December 2026	12.06	NYMEX; https://www.cmegroup.com/markets/energy/natural-gas/dutch-ttf-natural-gas-usd-mmbtu-icis-heren-front-month.html, accessed December 26, 2022	
E	US LNG exports in 2021 (bcf)	3560.82	EIA; https://www.eia.gov/energyexplained/natural-gas/liquefied-natural-gas.php, accessed December 26, 2022	
F	MMBtu/Mcf	1.037		
G	US LNG exports in 2021 (MMBtu; 1,000,000*E*F)	3,692,570,340		
H	Heat rate for natural gas (Btu/kwh)	8,000	Power Magazine; https://www.powermag.com/utilities-and-industry-continue-learnings-around-benefits-of-heat-rate-improvement/#:~:text=For%20existing%20gas%2Dfired%20combined,3%2C412%20%2F%200.46%20%3D%207%2C400)., accessed January 6, 2023.	
I	GWh from US LNG exports in 2021	461,571		
J	$ value of US LNG exports in 2021 at TTF (D*G)	44,536,090,871		
K	$ value of CO$_2$ damages/$ value of LNG exports (C/J)	0.1751		A kind of upper bound, since exports corresponding to the 78,000,000 in emissions would be expected to be higher than exports in 2021.
L	Coal fired capacity with equivalent emissions (GW)	18	Ibid, Bloomberg	
M	Plant factor for coal	0.53	EIA; https://www.eia.gov/electricity/monthly/epm_table_grapher.php?t=epmt_6_07_a, accessed December 26, 2022	
N	Annual GWh for equivalent coal (L*M*8,766)	83,628		
O	CO$_2$ emissions rate for coal 2021 (tCO$_2$/MWh)	1.023516375	EIA; https://www.eia.gov/tools/faqs/faq.php?id=74&t=11, accessed December 26, 2022	
P	tCO$_2$/year for equivalent coal (1,000*N*O)	85,594,259		
Q	$/year CO$_2$ damages for equivalent coal (A*P)	8,559,425,891		
R	$/mt of coal in Europe for December 2026	154.15	NYMEX; https://www.cmegroup.com/markets/energy/coal/coal-api-2-cif-ara-argus-mccloskey.settlements.html, accessed December 26, 2022	
S	kwh/mt coal	2,712	How Stuff Works; https://science.howstuffworks.com/environmental/energy/question481.htm#:~:text=Although%20coal%20fired%20power%20generators,kWh%20or%202%2C460%20kWh%2Fton., accessed December 26, 2022	
T	$/year value of equivalent coal (1,000,000*N*R/S)	4,753,948,971		
U	$ value of CO$_2$ damages/$ value of equivalent coal (Q/T)	1.8005		
V	Relative economic CO$_2$ damage intensity of LNG (K/U)	0.0973		
W	Relative energy content of LNG for equivalent emissions of CO$_2$ (I/N)	5.52		

higher than Traywick et al.'s 78 million tons. According to Hong and Slatick (1994), lignite, assumed to be used in Europe but rarely used in the U.S., is five percent cleaner, in terms of CO_2, partially offsetting the discrepancy.

Row K shows the dollar social cost of CO_2 emissions from liquefaction as a fraction of the dollar value of the energy from the LNG: 0.1751. Row U shows the dollar social cost of CO_2 emissions from coal-fired generation as a fraction of the dollar value of the energy from coal: 1.8005; about ten times the ratio for LNG, as shown in Row V. This factor of ten does not depend on the monetary cost of emissions. For the roughly equivalent emissions, the electric energy generated using U.S. exports of LNG is five and a half times the electric energy from the coal, as shown in Row W. Even under an assumption (2021 exports) that makes LNG seem dirtier than it really is, in terms of emissions of CO_2, there is ample economic reason to substitute LNG for coal based on internal social value, and to substitute LNG for coal based on emissions of CO_2 per Watt hour of electricity generated.

Conclusion

Exports of U.S. LNG to Europe are much cleaner than European coal, when either is used to generate electricity there, inasmuch as cleanliness depends on the rate at which methane leaks from production, storage, transport, and combustion of natural gas. EDF erroneously applies anomalously high leak rates in the Permian basin to a long run issue, leak rates that are very likely profitable to lower in the long run. That NRDC researchers concluded that U.S. exports of LNG are as dirty as coal results from their ignoring NETL's breakeven leakage rates for periods longer than 20 years and, moreover, from ignoring NETL's higher 2019 updated estimated breakeven leakage rates, in favor of its outdated 2014 estimates, from attributing emissions of methane that are actually associated with petroleum with production, storage, transport and combustion of natural gas, and from the implausible assumption that the long term downward trend in the rate at which methane leaks from production, storage, transport, and combustion of natural gas would immediately level off, despite the prevalence of leaks in the Permian Basin that are very likely profitable to repair in the long run.

Taking Traywick et al.'s conclusion that the CO_2 emissions of liquefaction are similar to those of European coal, when used to generate electricity there, as given, there is still a tremendous positive difference between the internal social value of energy from LNG and that from coal, as measured by the market value of the fuel relative to the damage costs of emissions. Since energy is a necessity, a significant share of the value of the LNG would accrue to poorer people. The big difference in market values obtains in large part because the electricity generated from the LNG in question is much greater than the energy that would be generated from the coal: For equivalent emissions, U.S. exports of LNG can be used to generate at least five and a half times the electric energy from the coal. EDF's, NRDC's, and Bloomberg's overestimating emissions related to LNG could cause policymakers to miss the low hanging fruit of mitigation that substitution of LNG for coal represents and, thereby, accelerate global warming.

Inasmuch as the cleanliness of U.S. exports of LNG to Europe depends on leaks of methane in production, storage, transport, and combustion of natural gas and emissions of CO_2 during liquefaction taken together, U.S. exports of LNG to Europe are both much cleaner than European coal used to generate electricity there and of much greater net social benefit per unit of GHGs emitted.

Acknowledgements

I thank Bill Sweet for raising my awareness of this issue. I thank God for the opportunity to do work that I love.

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Footnotes

[1] McLaughlin and Disavino (2022).

[2] Adler (2021).

[3] Pipe Exchange (2018).

[4] Gupta (2021).

[5] Palmer (2022).

[6] Swanson et al. (2020).

[7] Environmental Protection Agency (2019), Environmental Protection Agency (2022), and Energy Information Administration (2022a).

[8] Stationary and mobile combustion do not include flaring; emissions from flaring are counted as emissions from natural gas systems; see the last sentence on page 2-16 of EPA (2022). On page 2-31, the 2022 EPA report says "Stationary combustion emissions of CH4 and N2O are also based on the EIA residential fuel-consuming sector." On page 232, in Table 211, "stationary sources" of CH4 emissions related to electric power "Includes only stationary combustion emissions related to the generation of electricity".

[9] Perhaps not a well-chosen metaphor, as the sequencing for a baby goes the other way.

10 The critical value and standard error correspond to a sample size of ten because EPA does not report data for all years.

[11] Muldor (2023).

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IAEE ENERGY FORUM – Vol. 33 First Quarter 2024

IAEE Energy Forum
Energy Economics Education Foundation, Inc.
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