Multi-level Data Access Control in Positive Energy Districts

Sidra Aslam, Viktor Bukovszki, and Michael Mrissa

Abstract Energy transition in the built environment requires collaborative action of interdependent actors coordinated on multiple levels of governance. Many of these actors operate in domains closely linked to a specific geographical or institutional scale, making it difficult to facilitate their collaboration. This is especially the case for positive energy districts (PED), an emergent intervention trend in the EU that requires these actors to operate on a scale with a competence vacuum in terms of governance. Actors from individual, household, building, community, city, and national scales need to be able to deliberate and work in a common discursive arena, each carrying their own goals, values, and information. In this paper, we re-imagine this discursive arena as an access-control framework to a multi-level PED database. We present a role-based model to manage interactions with data on PEDs. This includes the identification of actors expected in PED development, a specification of permission requirements based on their roles in PED, based on a PED in Austria developed under the syn.ikia Horizon project.

1 Introduction

The global transition towards decarbonized energy systems is increasingly characterized by a process of decentralization [1]. This creates a challenge in governance,

S. Aslam (✉) · M. Mrissa
InnoRenew CoE, Livade 6, 6310 Izola, Slovenia
e-mail: sidra.aslam@innorenew.eu

Faculty of Mathematics, Natural Sciences and Information Technology, University of Primorska, Glagoljaška ulica 8, 6000 Koper, Slovenia

M. Mrissa
e-mail: michael.mrissa@innorenew.eu

V. Bukovszki
Advanced Building and Urban Design Ltd., 1139 Budapest, Hungary
e-mail: info@abud.hu

J. R. Littlewood et al. (eds.), *Sustainability in Energy and Buildings 2021*,
Smart Innovation, Systems and Technologies 263,
https://doi.org/10.1007/978-981-16-6269-0_46

as more numerous and more diverse actors gain stakes, competences, and responsibilities in transition [2]. Through decentralization, energy increasingly becomes a resource to be managed on multiple levels by interdependent actors, from households and local communities to global, international scales [3]. This means that national governments, enclosed with mechanisms ensuring their democratic legitimacy, are less relevant as an authority to provide accountability—simply because more and more decisions of consequence regarding energy happens outside centralized systems with governmental oversight [4]. If this challenge is not addressed, decisions influencing societal outcomes of the transition process will be less transparent, those responsible less accountable, weakening for example common following through on European goals like carbon neutrality or just transition [1].

This challenge is especially pertinent in the European context considering the trends to achieve transition through positive energy districts (PED) [5]. PEDs are beyond-building scale interventions targeting a net positive energy balance [6]. What is common for these projects, is that they introduce a formal or semi-formal institution between the building and the city scales, where a competence vacuum in governance currently exists [7]. In PED projects across the EU, these are either top-down, government-managed entities, aggregator businesses, or self-governing associations of multiple interdependent parties [8]. It is the latter case, where the issue of accountability could emerge. One study for example has shown, that strategic decisions to invest in public money in building energy refurbishment, renewable production, infrastructure or operational decisions to trade or allocate energy have major impact on individuals and households in and outside the PED, on the city, and on governmental efforts to enact energy transition [3].

New governance mechanisms need to be developed to address the accountability deficit in the multi-level governance of PEDs. In this paper, we propose to take an institutional technology perspective to propose a framework relying on Role-based Access Control (RBAC). The institutional technology perspective simply means that we explore governance capabilities inherent in technological—in this case computational—solutions. RBAC is a computer systems security model allocating permissions to authorized members on the basis of predefined roles [9]. In computer science, this model is widely used to provide differentiated access to shared resources in heterogeneous organizations, which is why it can be explored in multi-level energy governance as well. Thus, the main research question for this paper is: how can RBAC be used to ensure the accountability of PEDs in a multi-level energy governance context?

The rest of the paper is organized as follows: In Sect. 2, we review most relevant work in the area and show how multi-scale energy management currently lacks data access control solutions. Section 3 highlight the need for a privacy solution to protect data along multi-scale management of energy. Section 4 presents our contribution to support privacy-aware data access management along multi-scale management of energy. Finally, Sect. 5 concludes this paper.

2 Related Work

In this section, we review the most relevant existing research on data privacy in smart metering and Positive Energy District (PED). Several techniques have recently been proposed to ensure a privacy for smart meter users. Anonymization [10], aggregation [11], homomorphic encryption [12] and obfuscation [13] are some of the mechanisms that have been explored in the literature. In [14], the authors propose a technique to hide sensitive power consumption data. The proposed solution is based on a rechargeable battery which is connected to the household's power supply and modifies the energy consumption data by adding or subtracting noise in order to ensure privacy guarantees in the term of differential privacy. Moreover, they also consider different constraints on the rechargeable battery such as capacity and throughput.

The authors in paper [15], propose a data privacy-preserving energy management framework that protects the smart meter data privacy of consumers and minimizes the electricity bills. An online control algorithm is designed to protect the privacy-sensitive information of electricity. The proposed algorithm does not require to know the details of electricity statistics such as prices. However, the proposed solution is dependent on a rechargeable battery to protect the usage patterns of electricity consumer. Similarly, an online control algorithm to control the battery operations is presented in [10]. The proposed solution protects the data privacy of smart meter and reduce the electricity cost by using batteries. It cut down the electricity bill, without disclosing the statistics of the load requirement and the electricity prices. It has an advantage to protect the privacy of consumer's energy usage.

In [16, 17], authors ensure user's energy consumption data privacy by integrating renewable generation into energy management. The proposed solution is based on binary input and output loads to consider the energy management policies that achieve the trade-off between privacy and energy efficiency. If the battery has a higher capacity, then information leakage rate is lower. In [18], the authors provided a survey of approaches focusing on customer privacy protection in smart grids. It is important to protect the metering data from external attackers and to control how electricity suppliers or distribution system operators use this data. The results conclude that to guarantee privacy for the residents energy data should not be visible at all.

The electricity privacy issues (e.g. theft of electricity privacy data) in smart meter have been discussed in [19]. To overcome this issue, the authors proposed a Monte Carlo simulation-based approach to optimize the electricity cost and to ensure the electricity privacy protection in residential appliance demand resource energy management. The charge/discharge batteries within a fixed time slot are used to ensure electricity privacy protection. However, the battery cost is higher than the electricity bill cost. Table 1 summarizes advantages and limitations of existing work and relates to our identified research problem.

As a summary, existing solutions rely on rechargeable battery as an energy storage device to ensure data privacy in PEDs. Generally, a rechargeable battery requires a higher capacity to store the overall amount of energy data and throughput (the amount of energy that can be charged/retrieved within a given time), thus motivating research

Table 1 Summary of related work analysis

Refs. no	Challenge addressed	Approach	Advantages	Limitations
[15]	Ensure privacy of electricity consumer	Online control algorithm	It does not require prior knowledge of electricity statistics	Dependent on a rechargeable battery
[16, 17]	Ensure data privacy of user's energy consumption	Energy harvesting and rechargeable battery	Ensures user's energy data privacy	Require more privacy schemes; Privacy risk remain
[18]	Customer privacy protection in the smart grids	Customers calculate bills and ensure correctness via trusted computing	Ensures data privacy; Customer only shares final price	Need trusted third party or trusted platform to calculate bills; Lack of trust
[19]	Protect the electric privacy in residential appliance demand resource energy management	Monte Carlo simulation	Optimize the electricity cost; Ensure electric privacy	High battery cost
[10]	Ensure privacy of customer activities	Online control algorithm	Protect the privacy of consumer's energy usage	Does not work without rechargeable battery
[20]	Hide sensitive power consumption data	Storage device such as rechargeable battery and add noise to the data	Ensure data privacy	Requires rechargeable battery

towards managing access to the data without any storage device. Our proposed solution enforces data security and access control without requiring such a rechargeable battery.

3 Motivating Scenario and Research Problem

To answer the research question, we characterize multi-level governance in PEDs as a use case for systems security design. We introduce a simplified scenario common in energy communities—pooled investment in energy assets—that highlights the challenges of database management in energy transition. The energy community model was chosen, as it involves the most decentralization of energy governance, in a form legally recognized in the EU—albeit not yet adopted by all member states [21]. Typically, energy communities formed on pre-existing social networks operate on mutual trust and make strategic decisions through direct negotiations [22]. However, to socially scale them from niche organizations, non-trusted new members, potential investors, and other stakeholders need to be involved [23]. The formal basis for their participation is increasingly some variation of performance-based contracting, and assignment of rules and responsibilities based on measurable performance indicators [24]. Performance-based contracting helps mitigating risk for involved parties by pegging their stakes to a performance that delivers value for them—for instance, a reduction of GHG emissions is valuable for a government, while a reduction of operational expenditures is valuable for investors. Investment in an energy asset, under performance-based contracts means that there has to be both a prediction, and a follow-up monitoring energy-related performance metrics. This translates to the need to collect and process all data ex ante and ex post that influences any performance corresponding to the stakes and objectives of all actors, which is why data security and privacy become relevant.

What is unique for energy transition is the structure of relationships among actors. Typically, potential stakeholders for an energy-related investment appear on multiple scales, each with their own goals and their own input data (Fig. 1). On the individual scale, occupants influence energy performance through their behavior, presence in the building, personal comfort needs, and seek reasonable energy expenditures while

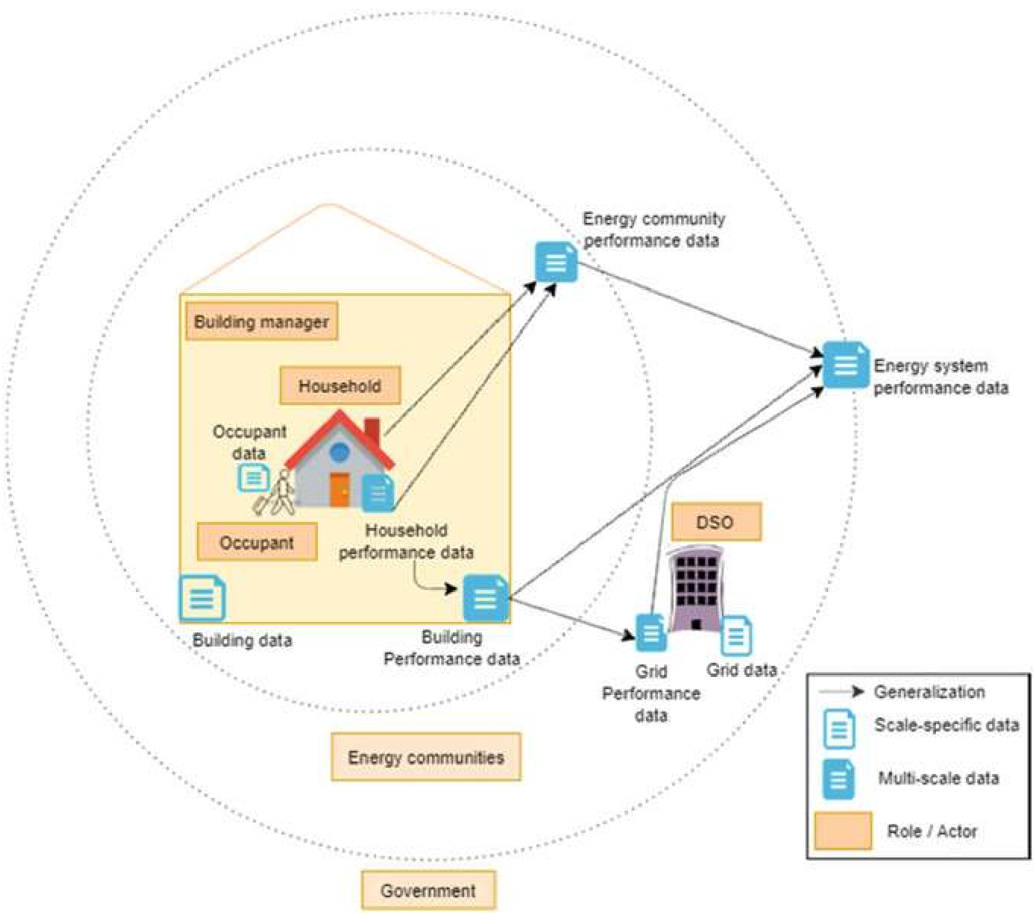

Fig. 1 Overview of the one instance of each actor in the energy management scenario

maintaining a comfortable indoor environment. Multiple occupants form a household, that share the apartment, which is typically the unit for billing energy expenditures on the basis of their energy consumption. Households and other functional units in building are represented by building management, who seek to minimize costs while keeping dissatisfaction at reasonable levels. Multiple buildings in an energy community are connected to a microgrid, alongside energy production and storage capacities jointly owned by the community members. The community may operate in island-mode, completely independent of the energy market, but it is more common that they are connected to a larger grid. This grid is operated by a distribution service operator (DSO) that seeks to balance demand and supply to avoid grid congestion at any given time. Finally, public authorities may have two distinct roles in the investment: they provide regulatory oversight to make sure the new energy system complies to the law, and they incentivize projects with an environmental or social benefit.

In terms of data sharing, two kinds of data are expected: scale-specific, and multiscale data. Scale-specific refers to data that appears in the domain of a specific actor, while multiscale data can be (dis)aggregated across scales. For example, schedule of occupancy, appliances load, window-to-wall ratio, centralized storage capacity, network geometry, cap & trade policy are scale-specific data from individual to government scales. Energy consumption and GHG inventories on the other hand are data aggregated from individuals to national scale. The range of both types of data depends on the traded performances, i.e. the metrics upon which performance-based contracts are written on.

The goals are represented as key performance indicators, while the key metrics describe the most critical input data to calculate the KPIs.

In this simplified scenario, an energy community decides to invest in the deep energy retrofitting of their building stock, which the local government decides to financially support. Deep energy retrofit is a systemic approach to energy retrofitting, which considers multiple, interdependent interventions covering HVAC system, building envelope, building operation, on-site renewables, and other solutions to deliver multiple, energy- and non-energy benefits [25]. The scenario can be broken down to a planning and follow-up phase. During planning, community members (households) decide on how to allocate their investment funds to reduce their energy costs, while the local government prescribes a minimum share of on-site renewable energy production in exchange for support. This brings in intermittent, decentralized energy production to the local grid, which has to be balanced by a DSO. As such, the energy community makes a separate agreement to shift loads to production peaks to minimize the feed-in of energy into the grid. Note that in reality, both the energy community and the government have more objectives due to the multiple benefits of energy investment, the indicators are merely chosen for simplicity. The performance indicators and the metrics they are mainly derived from in the context of the investment are summarized in Table 2.

To make these traded relationships possible, several personal, and sensitive data must be either fed into a modelling engine (in planning phase) or monitored (in follow-up phase). These data-sharing challenges can be summarized as follows:

Table 2 Overview of the data model of decision-making, derived from actor goals

Actor	Key performance indicator	Key metrics
Occupant	Operational expenditures	Final energy consumption
Household	Operational expenditures	Final energy consumption
Building	Operational expenditures	Final energy consumption
Community	Internal rate of return	Savings on operational expenditures, investment size
DSO	Supply cover factor	Self-consumed on site production, total energy produced on site
Government	Renewable energy ratio	Total primary energy consumption, total energy produced on site from renewable sources

1. Continuous personal data on occupant behavior is required to accurately calculate energy consumption on any scale, and to diagnose occupancy-related performance issues.
2. Sensitive demographic data, home appliances, and lighting loads are required to be audited once before investment and whenever they change in the follow-up phase to calculate energy consumption on any scale. The latter two are at the discretion of the household, while the former is personal.
3. Building management is a trusted third party that manages metered data, and information on the building systems. Building managers should be accountable to households, but they must follow professional standards in handling building data, meaning scale-specific data should be accessible for households.
4. Energy community is an organization pooling competences and responsibilities of households. Their collective, negotiated decision-making defines the rules of data management, but these should be accountable to each household, meaning scale-specific data should be accessible for households.
5. The community and the DSO and the community and the government are in bilateral relationships, where the community has compliance reporting responsibilities. Both the DSO and the government may challenge the reporting, to which an arbitration mechanism must exist.

Our scenario highlights the need for access management to privacy-sensitive data, while at the same time allowing actors on different scales to use that data for their activities—meaning for example that DSOs should be able to monitor energy production in energy communities to some extent. However, our multi-scale energy management scenario highlights that actors need to protect their privacy-sensitive data from unauthorized access. There is a need to design a solution that enforces security on data and guarantee that it is not possible to access all energy data and customer statistics from it. Therefore, based on our scenario, our solution must provide fine-grained access control as data can be accessed according to the identified role. In the following, we identified the following scientific locks (SL) that rise from our scenario and the goals of the actors discussed above:

SL1: Fine-grained access control: actors' actions on energy data should be managed using access control models. The proposed solution should ensure data privacy and protect privacy-sensitive data from unauthorized access.

SL2: Data security: data must be prevented from unauthorized access through encryption mechanisms. The proposed framework must ensure that data must not be available to unauthorized users.

To answer these scientific locks, we propose a solution that combines relevant technologies in a single framework. We provide an overview our proposed framework with the help of our motivating scenario.

4 Conceptual Framework

In this paper, we propose a privacy-aware data management framework to support multi-scale energy management. This framework combines RBAC with multiple types of encryption mechanisms as depicted in Fig. 2.

4.1 RBAC Component

First, our framework answers SL1 using a RBAC model to provide authorized access to the data. The RBAC model is comprised of following parameters: user, role, and permission. In a RBAC model users are actors collaborating on energy management/investment. Roles are fixed sets of permissions regulating access to the data. A permission is an authorization to access different levels of data within the specific scenario. For multi-level energy governance, the following users, roles, resources and permissions are proposed.

- **Users**: In our framework, users are the actors corresponding to multiple levels of energy management. Specifically, occupant, household, building manager, community manager, DSO, and government.
- **Roles**: Roles are defined based on the interactions user must have with the data to perform their duties.

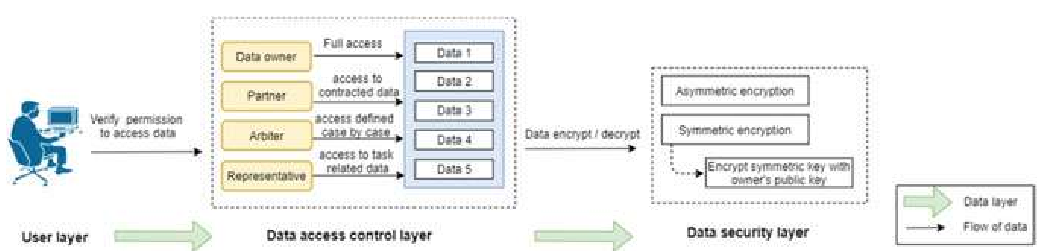

Fig. 2 Overview of our conceptual framework

  - *Data owner*: Each user is an owner to the data originating on their level. For instance, an occupant owns thermal comfort preferences (e.g. 19–24 °C on weekdays between 6 a.m. and 9 a.m.), or a DSO owns data on overall grid balance (e.g. + 10.8 kWh energy surplus on day of interest).
  - *Partner*: partners have limited access to data that is specified in the contract regulating the partnership. Partners access data specifically to hold each other accountable and to monitor contractual obligations. The DSO and the government are both partners to the energy community. The government can, for example access data to check whether the community complies to its green energy targets (e.g. 50% of consumption met by local renewable sources on day of interest).
  - *Arbiter*: the arbiter role defines a trusted third party for the purpose of conflict resolution between contracted partners. They can decide the scope of their data access on a case-by-case basis, if the scope is justifiably needed for arbitration. Thus, the parties in conflict should be able to see what the arbiter accessed, and why in order to contest it. The arbiter has access as long as its mandate dictates. For example, a civil court could access household-level energy consumption (e.g. 24.0 kWh in hour of interest) if the DSO contests the validity of an aggregated energy consumption reported by the community.
  - *Representative*: On some levels there are no autonomous entities, because they represent a collective of lower-level actors. Specifically, building managers and managers of energy communities are appointed by households and carry out the collective decisions of multiple households. As such, they assume a representative role when accessing energy-related data, which means they can access data from lower levels that is necessary for them to carry out their tasks. However, a representative access must always be anonymous, and disaggregated only to the extent their task demands. For example, a building manager can access schedules of occupants (e.g. 80% probability of being at home in hour of interest) to calculate day-ahead energy demand for the whole building.

- **Resources**: resources in this scenario refer to the data generated on each level. In this sense, we define occupant data (e.g. schedules, and comfort preferences), household data (e.g. home appliance performance data), building data (e.g. thermal properties of the building constructions), community data (e.g. total energy produced per day), and grid data (e.g. daily grid balance).
- **Permissions**: permissions are restrictions assigned to each role to interact with resources, i.e. with data on different levels. For example, a DSO user, under the role of partner, can access hourly energy production data (0.35 kWh in hour of interest) of the energy community if it is stated in their contract.
- **Rules and policie**s: rules and policies are in place to control access to data by defining how the RBAC assigns roles to users. In the case of the data owner, this assignment is an authentication of the existence of the data owner role for that specific user, and a verification of permission to access owned data. For other roles, there is an additional step to specify permissions using an access policy, which is unique for each role.

- *Partner access policy*: the partner permissions are specified in the contract approved all engaged parties. For example, in our scenario, a government invests in an energy community if it maintains a quota for producing renewable energy. Then, the access policy adds renewable energy production to the list of permissions of the government.
- *Arbiter access policy*: an arbiter specifies its own permissions if an arbitration process is initiated. For example, the government suspects the energy community overestimates their renewable energy production and a court is involved to investigate. To do so, they decide to need detailed technical data on production equipment, as well as household-level consumption data. The access policy is then adding these requests to the list of permissions to the court, for a limited time period.
- *Representative access policy*: representative permissions are specified by the task they carry out, as given by the collective decisions of the actors they represent. For example, if households in an energy community decide to expand their production capacities to meet their energy demand in peak hours, the community manager would have to know what the peak demand is. The access policy adds peak demand to the list of permissions, as parsed from the community decision.

4.2 Encryption Mechanisms

Second, we address SL2 by using multiple types of encryption mechanisms to enforce security on the data. Our proposed framework design is flexible to allow actors to choose either asymmetric or symmetric encryption method for each data write/read operation. Asymmetric encryption method is comprised of the public and private key pair. A public key is available publicly to encrypt the data, while the private key is only accessible to the key's owner for corresponding data decryption. In our scenario, an actor as a data owner chooses the asymmetric encryption method, then energy data will be encrypted with the data owner's public key. Later, the data owner can access/decrypt this data using the corresponding private key. This can be used for example to ensure that only household can access to their own data.

On the other hand, symmetric key is based on a single key for encryption and decryption. In our scenario, the data owner chooses the symmetric method to allow other actors to read this data upon request. Data owner will encrypt the data by using a symmetric key which will again be encrypted by using the data requester's public key. This way only the data requester can access it later for decryption. This can be used for example to share building-level, or community-level energy performance data with the households.

5 Discussion and Conclusion

In this paper, we illustrate the need for privacy-aware data access control in multi-scale energy management scenario that presents the challenges of this application domain, before discussing related scientific locks. We propose a framework that relies on a combination of role-based access control model and multiple types of encryption mechanisms that enable only authorized actors to access their data. We described advantages and limitations of existing work to highlight the research gap. The limitation of existing work is rechargeable battery that requires higher throughput and capacity to store the energy data.

To the best of our knowledge, our research is the first work that integrates this combination of technologies with PEDs and ensures data security and access control without requiring such a rechargeable battery.

One serious shortcoming of the proposed framework is reliance on a trusted third party to adjudicate conflicts regarding the data. While this limitation may be addressed by combining other technologies once data enters the system (see the following paragraph for future work), tamper-proofing on the sensor, or input side is still necessary to fully eliminate third party involvement. Also, the presented concept is based on the premise of data-based regulation of dynamic relationships, in the form of performance-based contracts. It is thus assumed to be relevant for smart grids, where the maturity of the information system allows and the degree of decentralization necessitates this degree of regulation. While the scenario presented describes a smart power grid, the advent of fifth generation district heating, distributed geothermal energy, and heat pumps does suggest direction towards smart thermal grids [26], where the same framework is applicable.

In future work, we will explore different options for decentralized data management such as blockchain or distributed hash table. Further work can be extended to different access control model e.g. attribute-based access control model, rule-based access control model, mandatory-access control model. Further work can compare what are the advantages and disadvantages of access control model as thy are being developed continuously. Our framework has TTP as an arbiter and we can eliminate it by using decentralized database such as blockchain, and we have a plan to work on it for our next paper. Cost action can help by providing case study and projects for validation of the concept and further development of the framework in real life scenario.

Acknowledgements The authors gratefully acknowledge the European Commission for funding the InnoRenew project (Grant Agreement \#739574) under the Horizon2020 Widespread-Teaming program and the Republic of Slovenia (Investment funding of the Republic of Slovenia and the European Regional Development Fund). They also acknowledge the Slovenian Research Agency ARRS for funding the project J2-2504.

This work is based on Cooperation in Science and Technology activities carried out by the authors as part of the COST Action CA19126—Positive Energy Districts European Network (PED-EU-NET), supported by COST (European Cooperation in Science and Technology).

References

1. International Energy Agency I World Energy Outlook (2018)
2. Goldthau, A.: Rethinking the governance of energy infrastructure: scale, decentralization and polycentrism. Energy Res. Soc. Sci. **1**, 134–140 (2014). https://doi.org/10.1016/j.erss.2014.02.009
3. Brisbois, M.C.: Decentralised energy, decentralised accountability? Lessons on how to govern decentralised electricity transitions from multi-level natural resource governance. Glob. Trans. **2**, 16–25 (2020). https://doi.org/10.1016/j.glt.2020.01.001
4. van Kersbergen, K., van Waarden, F.: "Governance" as a bridge between disciplines: cross-disciplinary inspiration regarding shifts in governance and problems of governability, accountability and legitimacy. Eur. J. Polit. Res. **43**, 143–171 (2004). https://doi.org/10.1111/j.1475-6765.2004.00149.x
5. European Commission: The Strategic Energy Technology Plan—At the Heart of Energy Research and Innovation in Euro. Luxembourg (2018)
6. Bossi, S., Gollner, C., Theierling, S.: Towards 100 positive energy districts in Europe: preliminary data analysis of 61 European cases. Energies **13**, 6083 (2020). https://doi.org/10.3390/en13226083
7. Bukovszki, V., Balázs, R., Mafé, C., Reith, A.: Six lessons learned by considering social sustainability in plus-energy neighbourhoods. In: Waltjen, T. (ed.) In the Neighbourhood. Vienna Congress on Sustainable Building, pp. 26–28. IBO Verlag, Vienna (2021)
8. Gollner, C., Hinterberger, R., Bossi, S., et al.: Europe Towards Positive Energy Districts—A Compilation of Projects Towards Sustainable Urbanization and the Energy Transition (2020)
9. Kashmar, N., Adda, M., Atieh, M.: From access control models to access control metamodels: a survey. In: Lecture Notes in Networks and Systems, pp. 892–892. Springer, Berlin (2020)
10. Yang, L., Chen, X., Zhang, J., Poor, H.V.: Optimal privacy-preserving energy management for smart meters. In: Proceedings—IEEE INFOCOM. Institute of Electrical and Electronics Engineers Inc., pp. 513–521 (2014)
11. Efthymiou, C., Kalogridis, G.: Smart Grid Privacy via Anonymization of Smart Metering Data, pp. 238–243. Institute of Electrical and Electronics Engineers (IEEE) (2010)
12. Bohli, J.M., Sorge, C., Ugus, O.: A privacy model for smart metering. In: 2010 IEEE International Conference on Communications Workshops, ICC 2010 (2010)
13. Garcia, F.D., Jacobs, B.: Privacy-friendly energy-metering via homomorphic encryption. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 226–238. Springer, Berlin, Heidelberg (2011)
14. Kim, Y., Ngai, E.C.H., Srivastava, M.B.: Cooperative state estimation for preserving privacy of user behaviors in smart grid. In: 2011 IEEE International Conference on Smart Grid Communications, pp. 178–183. SmartGridComm 2011 (2011)
15. Yang, L., Chen, X., Zhang, J., Poor, H.V.: Cost-effective and privacy-preserving energy management for smart meters. IEEE Trans. Smart Grid **6**, 486–495 (2015). https://doi.org/10.1109/TSG.2014.2343611
16. Tan, O., Gunduz, D., Poor, H.V.: Increasing smart meter privacy through energy harvesting and storage devices. IEEE J. Sel. Areas Commun. **31**, 1331–1341 (2013). https://doi.org/10.1109/JSAC.2013.130715
17. Koo, J., Lin, X., Bagchi, S.: PRIVATUS: wallet-friendly privacy protection for smart meters. In: Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 343–360. Springer, Berlin, Heidelberg (2012)
18. Finster, S., Baumgart, I.: Privacy-aware smart metering: a survey. IEEE Commun. Surv. Tutor. **17**, 1088–1101 (2015). https://doi.org/10.1109/COMST.2015.2425958
19. Chen, Z., Wu, L.: Residential appliance DR energy management with electric privacy protection by online stochastic optimization. IEEE Trans. Smart Grid **4**, 1861–1869 (2013). https://doi.org/10.1109/TSG.2013.2256803

20. Backes, M., Meiser, S.: Differentially private smart metering with battery recharging. In: Lecture Notes in Computer Science (including subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics), pp. 194–212. Springer, Berlin (2014)
21. Lowitzsch, J., Hoicka, C.E., van Tulder, F.J.: Renewable energy communities under the 2019 European clean energy package—governance model for the energy clusters of the future? Renew. Sustain. Energy Rev. 122 (2020). https://doi.org/10.1016/j.rser.2019.109489
22. Moroni, S., Alberti, V., Antoniucci, V., Bisello, A.: Energy communities in the transition to a low-carbon future: a taxonomical approach and some policy dilemmas. J. Environ. Manage. **236**, 45–53 (2019). https://doi.org/10.1016/j.jenvman.2019.01.095
23. Bukovszki, V., Magyari, Á., Braun, M.K., et al.: Energy modelling as a trigger for energy communities: a joint socio-technical perspective. Energies **13**, 2274 (2020). https://doi.org/10.3390/en13092274
24. Marino, A., Bertoldi, P., Rezessy, S., Boza-Kiss, B.: A snapshot of the European energy service market in 2010 and policy recommendations to foster a further market development. Energy Policy **39**, 6190–6198 (2011). https://doi.org/10.1016/j.enpol.2011.07.019
25. Lohse, R., Zhivov, A.: Deep Energy Retrofit Guide for Public Buildings. Springer International Publishing, Cham (2019)
26. Stănişteanu, C.: Smart thermal grids—a review. Sci. Bull. Electr. Eng. Faculty (2017). https://doi.org/10.1515/sbeef-2016-0030