newTRENDs

D4.4

Recommendations for better design of energy-demand modeling based on policy makers' needs

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Executive Summary

The European Union-funded newTRENDs project aims to recognize and model the influence of New Societal Trends on energy demand, and hence develop scenarios of their future development. The goal will be achieved by combining qualitative and quantitative cross-sectoral modeling and by exploring how energy demand models can be improved to represent new societal trends.

This report provides policy-driven and policy makers' needs driven recommendations for energy demand-side models, with particular focus on FLEX (prosumagers and big data related to the built environment), PRIMES-TREMOVE (transport including shared economy solutions for mobility), FORECAST-Industry (modeling circular economy for the deep decarbonization of industry) and FORECAST-Tertiary (digitalization in the services sector). The presented recommendations concern policy instruments and areas chosen based on the previous newTRENDs project’s deliverables (D4.1 and D4.3). The suggestions are based on the analysis of literature on policy instruments and models performed within the scope of the four cases that are linked to the newTRENDs Focus Studies: on Prosumagers, Circular Economy, Shared Economy and Digitalization. These recommendations can be used to inform the model improvements undertaken in newTRENDs work packages WP5-7 and beyond.

The present report is an outcome of Task 4.4 "Recommendations for improving energy-demand models to appropriately represent New Societal Trends" in WP4 "Policy needs and policy analysis for Influencing Energy Demand Arising from New Societal Trends". The task aimed to bridge the assessment of the demand-side models in Task 4.3 and the focus topics in WP5-7. It accommodated the assessment of the demand-side models: FLEX, PRIMES-TREMOVE, FORECAST-Industry and FORECAST-Tertiary in Task 4.3 and focused on yet unexplored topics in WP5-7 (all WPs are described on the newTRENDs project website[1]). Results of Task 4.3 fed Task 4.4 which then translated them into recommendations of which improvements might be conceivable to model the impacts of policies on New Societal Trends, as well as their impact on energy demand in a more encompassing manner.

Emerging New Societal Trends will certainly have a significant impact on how we live, move, produce, work and therefore use energy. Considering the current environmental crises, it must be ensured that these trends do not have negative consequences for the environment, and on the contrary, lead to reduced energy consumption of energy and raw material. The four case studies described in this report provide information on the development of trends in the areas of prosumagers, circular economy, shared economy and digitalization. Taking into account both the pace of development of these trends, their potential impact on energy demand and the needs diagnosed in Deliverable 4.3 (Kochanski et al., 2022), the following set of the most important recommendations was prepared

1 https://newtrends2020.eu

for the implementation of specific policies in energy demand modeling for energy demand-side models:

- Modeling of energy communities should consider additional distinction for collective self-consumption and energy consumption, not only in a single household but in multiple houses working in an energy community for various tariff and tax designs, which could improve energy prices input;
- Modeling of material flows in the construction sector should consider Green Public Procurement (GPP) criteria for circularity in the building sector in a holistic manner, addressing both the overall impact of a building and the environmental characteristics of its individual components. It could be built using findings and benchmarks from the JRC Technical Report "EU GPP criteria for the design, construction, renovation, demolition and management of buildings" (Donatello et al., 2022a). It is also worth to consider the Level(s) calculation method (Dodd et al. 2021 and Donatello et al., 2020), both described in section 4 in this report;
- Modeling of shared economy in transport should consider adjusting the influence and importance of the different aspects when opting for a shared mobility option, as it was shown that preferences and the traditional model of private mobility are less important than mobility habits and spatial niches for site-based policy measures. It should also explore the possibilities of enabling car sharing in less urbanized areas with prioritization for convenience;
- Modeling of data centers should consider the exploitation of excess heat for district heating in a particular location together with water resources and air humidity. Even though they are not directly connected with the energy use in the data center, they can affect the cost of cooling system operation;
- All models should consider climate risks, as in Europe we can already observe extreme climatic events and rising temperatures. These events can have a major impact on energy demand and specific aspects also mentioned in the investigated cases on energy communities, circular economy, shared economy in mobility, as well as data centers. For example, the efficiency of photovoltaics for prosumers, air conditioning demand in buildings and for energy communities, additional private transport use in periods of high temperatures/climate extremes, and additional energy needed to run data centers (Hosseini et al., 2022; Romitti et al, 2022).

The above key recommendations of this report and deliverable D4.4 show that despite the great effort already put into regulating and accelerating the transformation in the four analyzed areas, there are still substantial gaps to be addressed, which may significantly contribute to further acceleration of the green and digital transition. If the trends are accompanied by the right policies, they could also be a cost-effective way to reduce energy demand by enabling businesses and individuals to participate in creating smart grids, decreasing emissions from daily transportation in the cities, greening the investments through public procurement or minimizing the carbon footprint of data centers. Nevertheless, the regulations introduced may also have some negative impact on vulnerable social groups that should also be taken into account. Energy demand models can help work out the limits for the regulations and help project possible outcomes.

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1. Introduction and aim of the study

The ability to transform energy into a useful form as well as the use of the Earth's resources is at the heart of our civilization. However, with the increasing demand for energy and the exploitation of the Earth's finite resources, the world is plunging deeper into an environmental crisis, of which the climate crisis, among others, is arguably the greatest challenge. In order to mitigate climate change, we need to change the way we produce, transform and use energy, and how we exploit our planet. The environmental crisis along with the coronavirus pandemic provides new perspective and rationale to change our behavior, create more resilient societies and support affordable and clean energy. The latest crisis in the EU's power market also shows the need for acceptable energy costs and long-term security of supply. At the same time, ongoing changes such as globalization, information and technological revolution are changing the way we interact within society. At the intersection of these two ideas, there are new, emerging societal trends that will largely define how we use energy at home, at work, how we travel and how we behave as consumers. In this project we explore the New Societal Trends defined as societal developments arising from general megatrends (trends having an effect on a global scale), which can potentially have large (positive or negative) impacts on energy consumption, as well as cross-sectoral demand shifts. Our individual behaviors collectively have an immense impact on our resources and the energy system on a national, European and global scale.

At the same time, these trends could lead to an increase in energy demand as the behavioral response to increase consumption elsewhere owing to the reduction in consumption of a certain activity. For example, the digitalization trend - working from home may lead to an increase in transport demand if remote locations are chosen etc. Digital technologies and algorithms are very energy consuming, and can thus increase energy consumption and associated emissions.

The project also considers the rebound effect, which was observed during the implementation of resource-saving and energy-efficient technologies. The mentioned effect is a specific paradox of the energy efficiency upgrade, leading to a lower effect than expected and in rare cases, even to opposite results. Due to this phenomenon, the rebound effect needs to be considered, because the effectiveness of energy-saving and energy efficiency become questionable in the improvement policy. Shortly, the rebound effect leads to an increase in overall consumption of resources in response to a decrease in their specific consumption (Font Vivanco et al., 2016). In this report, the rebound effect is investigated in the case of shared transport for previously car-free residents when they became users of car sharing (section 5.3.2 in this report).

Since many environmental responses are not economically feasible, or are faced with various barriers, these processes require regulatory support to obtain appropriate momentum. Interactions between public policies and these trends are affected by various factors which makes it a multi-objective challenge in which environmental, social and market competitiveness is considered. For this reason, there is a need for a proper analysis and quantification of the impacts that these New Societal Trends and related policies have on our environment and our way of using energy.

The newTRENDs project aims to increase the qualitative and quantitative understanding of the impacts of New Societal Trends on energy consumption and to improve the modeling of energy demand, energy efficiency and policy instruments. Four models are used in the project. The FLEX (prosumagers and big data related to the built environment), PRIMES-TREMOVE (transport including shared economy solutions for mobility), FORECAST-Industry (modeling circular economy for the deep decarbonization of industry) and FORECAST-Tertiary (digitalization in the services sector) models serve as a means of simulating these trends and their consequences - by implementing them into energy demand modeling one can provide feedback to policy- and decision- makers on how to optimize these activities.

New societal trends are observed in areas of producing, consuming and managing (e.g. storing) renewable energy (prosumaging; section 3), circular economy (section 4), shared economy (section 5) as well as digitalization (section 6). The identified trends within four core areas of newTRENDs project are considered by the following research questions of newTRENDs Work Package 4, which focuses on policies related to New Societal Trends:

- What policies can enhance the demand decreasing trends of New Societal Trends? (task T4.1)
- What are the demand-side policy needs at European level? (task T4.1)
- How to quantify the impact of behavioural interventions for residential energy conservation from high-frequency energy consumption data? (task T4.2)
- How far are demand-side models able to quantify energy demand-side policies impacting on New Societal Trends? (task T4.3)
- How can energy-demand modeling be improved to appropriately represent New Societal Trends? (task T4.4)

The last question is answered in this report, which provides recommendations for progressively and comprehensively modeling the influence of policies on New Societal Trends and their impact on energy demand. In this report, we highlight four focus studies regarding these New Societal Trends: on prosumagers, circular economy, shared economy (with an emphasis on sharing mobility) and digitalization. We present examples of relevant policies and measures. Based on these findings, we also draw recommendations for implementing them in energy demand models. These recommendations consider:

- The energy communities (section 3) – the provided suggestions can support the newTRENDs WP5 Focus Study: Prosumagers and big data (new data sources) in energy demand models related to the built environment
- The GPP in the buildings sector (section 44.1) and data centers' location (section 6) – the provided suggestions can support the newTRENDs WP6 Focus Study: Circular economy and digitalization in energy demand models related to the sectors of industry and tertiary

* The electric vehicles in European smart cities (section 5) – the provided suggestions can support newTRENDs WP7 Focus Study: New Societal Trends in Transport and Tertiary Sector – The Impact of the Shared Economy.

The chosen methodology uses literature research and desk studies in cases identified as relevant to consider in the model to make it more useful regarding policy making and current legislation needs. The models are described on the dedicated newTRENDs models webpage (https://newtrends2020.eu/models).

2. Methodology

2.1 Structure

In the previous tasks of newTRENDs, the demand-side policy instruments and policy requirements related to four distinct new societal trends (prosumaging, digitalization, circular economy and low-carbon industry, and sharing economy) were analyzed. According to the results obtained, the topics for the cases in four societal trends were identified and shaped to address the scope of the corresponding model to provide homogenous and comparative results of the cases, the common framework in the discussion about cases among the partners was followed:

- Why is this case important?
- What is the social/economic/technical challenge that the EU policy could or should address?
- What could be the EU intervention (policy instrument) in this policy area?
- How is this type of policy instrument modelled at the moment according to the literature?
- What information concerning this case (i.e. modeling outputs) could assist the EU policy making?
- What input data could be used for modeling of this case?
- How could this case be modelled in the models participating in newTRENDs (and possibly in other models)?

In the end, each case has a dedicated chapter structured as follows:

1. Case description including:
   a. Importance of the case;
   b. Predicted social/economic/technical challenge that the EU policy could address using the case;
   c. Possible EU intervention (policy instrument) in the policy area covering the case.
2. Summary of information concerning the case potentially assisting the EU policy making.
3. Overview of current modeling regarding this type of policy instrument.
4. Recommendations for newTRENDs models with (when possible):
   a. Outline of useful input data for case modeling;
   b. Prospective course of actions/method to model the case.

2.2 Methods

2.2.1 Desk research

The available data sources, especially the EU-level legal acts chosen for the case, were analyzed. The planned scope of the case was summarized and presented to the modeling teams to decide how and which targets and indicators can and should be included in the potential modeling of the case. The policy instruments were previously chosen and consulted in the consortium during the work on D4.1 (Kochanski et al., 2021).

2.2.2 Literature research

Literature research was conducted to get familiar with the current state of knowledge of the four cases and ensure that this report builds on other reviews in the area. The goal was also to identify gaps in knowledge and unresolved problems in the fields defined in the cases. Additionally, research on modeling approaches was performed to potentially provide recommendations to further develop the theoretical framework and the methodology.

If needed and possible, a systematic review was conducted to analyze how chosen policy instruments were modelled according to the literature. Additional conclusions were drawn regarding the knowledge gaps and areas that could be used as input for the newTRENDs models. Finally, the literature-based recommendations were adjusted to the scope of the model and the information found. The literature study was mostly focused on current studies published after 2019 and investigating energy demand during/after the pandemic and energy crisis.

3. Prosumagers

3.1 Importance of prosumagers and energy communities

Due to the significant reduction in the price of photovoltaic (PV) installations and the benefits for consumers of having autonomic power generation source, greater independence from the grid and decoupling from electricity prices, as well as prosumer installations are on the rise throughout the European Union (EU). This trend has been further strengthened by the energy crisis following the invasion of Ukraine and the accelerated push towards energy independence in Europe. The European Commission place prosumers among the most important actors of future smart grids. Prosumaging installations, apart from benefits for the consumer, will also be able to provide demand response services if they are combined with energy storage. Accelerating investment in such initiatives can play an important role in the context of the EU's energy and climate policy. Prosumerism can make a significant contribution to meeting the targets in terms of the share of renewables in gross final energy consumption. Another reason to focus on prosumerism is the potential policy of mandatory energy targets in new buildings, which impose the obligation to install photovoltaic panels (or other renewable source of energy) during the construction of a new building. In this context, the focus of this case study is 'Improving energy-demand models towards representing prosumagers and energy communities.

The case was chosen based on the direct connection with other newTRENDs WPs and the prosumaging trend growing in Europe. Prosumagers are the focus in newTRENDs WP5 modeling. The added value will come from analyzing them together with and without energy communities, which are not explicitly targeted in newTRENDs WP5. However, newTRENDs recognized this trend as important and worth covering in D4.4 as well as identify needs for model improvement. Right now, the model pivot on the research question is: How will the behavior change in household influence energy consumption and technology adoption at both the individual household/building and national level?

Identified instruments together with the definitions and relevance of prosumagers and energy communities were already described in D4.1 (Kochanski et al., 2021). and further qualified as policy instrument not considered in the model, but still potentially important in D4.3 (Kochanski et al., 2021). Those are soft instruments that can be categorized as voluntary approaches and unilateral commitments of the private sector:

- Renewable Energy Communities (RED II, art. 2 (16))
- Citizen Energy Communities (ED, art. 2 (11))

The policy background of these instruments was investigated in newTRENDs Task 4.1. Assistance in policy making can be developed in areas of:

- relations between public support for prosumagers (net metering, subsidies) and energy demand (risk of energy demand increase);

- impacts of prosumagers' charges stringency on energy demand.

Moreover, the parameters resulting from energy demand models that could be useful in the policy making process were indicated, which include:

- share of energy consumers in the residential sector that are renewables self-consumers, which can be fed to the model to mirror the local environment;
- specific share of energy consumers equipped with electricity storage facilities can be modelled in the FLEX model: Modeling the Prosumaging Behavior of Households and the Impact on Energy Consumption and Technology Adoption.

The case focuses on EU Member States and multi-family housing. The outcomes can help in recommending future regulations favorable for prosumagers and the energy community based on the model's predictions. The scope is also narrowed by the operation parameters included in the FLEX model regarding the building (geometry; heat transmission parameters; internal gains; effective window area; building mass (heat inertia) and technology (boiler (incl. electric heating element); space heating and hot water tank; space cooling technology; PV and battery; vehicle; and smart energy management system).

The case centers around:

- the internal and external drivers of prosumagers and energy community in Europe (section 3.2 in this chapter);
- policy gaps interesting for policymakers, stakeholders and citizens:
    - relations between public support for prosumagers and energy demand;
    - impacts of prosumagers' charges stringency on energy demand.

3.2 Summary of information regarding RED II and ED concerning prosumagers and energy communities

3.2.1 Prosumagers

While the European Commission does not provide the definition of prosumaging in official legislation[2], this phrasing is gaining more and more coverage among scientists and energy professionals in order to differentiate it from prosumers. Prosumaging is considered a refined and more developed concept of prosumerism. On top of their traditional role of producing and consuming energy, prosumagers can use storage technologies to accumulate the surplus of produced energy for later use, but also, in principle, they are set to interact with the grid and can be also engaged in demand response programs, as well as other flexibility-related activities. PV panel–storage system can also lead to a higher

2 Directive (EU) 2018/2001 provides a definition of a "renewables self-consumer" who generates renewable electricity for its own consumption, and who may store or sell self-generated renewable electricity, provided that, for a non-household renewables self-consumer, those activities do not constitute its primary commercial or professional activity.

independence from external energy suppliers from the consumer perspective. While the possibility of prosumagers disconnecting from the grid entirely is explored, it seems that it is not currently the best option regarding economic viability (Khalilpour & Vasallo, 2015). There are economic benefits of staying connected as prosumagers and being able to provide abovementioned demand-side services to operators such as peak shaving and balancing of the grid. Also, having an electric car connected to the charger while not in use can constitute additional storage capacity for providing these services (vehicle to grid). This solution is beneficial both for the operator by increasing resilience and robustness of the grid due to the greater possibility of its balancing and lowering or increasing the energy demand depending on the need, and it is also profitable for the prosumagers, since providing these services should normally be paid or compensated for in the electricity bill.

Individual prosumaging can be further extended by pooling the prosumagers into larger groups and even create an energy community (even though an energy community can exist without prosumagers). Those groups could be less dependent on external factors and weather conditions and be self-sustaining for the most part of the year. With the potential pooling of prosumagers, new relations can emerge, such as peer to peer energy transfers and prosumager-grid manager relations (Darani et al., 2021). The European Commission aims to make the energy markets more liberal and encourage prosumaging – mainly due to the high decarbonization rates that the process provides (Directive EU 2019/944).

3.2.2 Energy communities

An energy community is a group of local energy consumers presenting collective energy actions like generation, distribution, supply, aggregation, consumption, sharing, storage of energy, and even electromobility, as well as provision of energy-related services bringing economic and environmental, and/or social community benefits to their members and/or the local areas. The stakeholders can also be included in the decision-making (Lazdins et al., 2021). Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) can be distinguished within the energy communities.

For a long time, energy communities had an informal status and since 2019 are recognized as full actors of the European energy system. The social and economic aspects of energy communities derange the conception, modeling, planning, and operation of the energy system both in terms of energy sector decentralization and digitalization. There are still gaps that require modeling important for distribution system operators, suppliers, energy community planners, regulators, academics, and others.

The barriers for the energy community were identified by Lazdins et al. (2021) in four areas:

- Policy
  - monopoly-based energy policy and institutional monopoly owned by existing industry and infrastructure,

    - weak intellectual property rights protection and lack of renewable energy sources (RES) support activities;
- Socio-cultural
    - inefficient use of land for RES,
    - lack of awareness of the benefits of using RES and weak communication between involved parties;
- Informational and awareness
    - the impact of variables and uncertainties on energy production,
    - lack of reliable energy generation and demand data,
    - lack of modeling solutions,
    - lack of skilled professionals and lack of RES awareness;
- Market failures
    - underinvestment in market R&D activities,
    - low quota prices of greenhouse gases emission,
    - energy generation and utility companies' monopoly,
    - RES solution unaffordability and high renewable market risks.

According to the RED II Directive, Art. 3 (1), at least 32% of gross final consumption of energy in 2030 should be from renewable energy sources, and the revised directive presented by the Commission in the Fit for 55 package increases this target to 40%. In May 2022, the Commission proposed in its Communication on the REPowerEU plan (COM/2022/230 final) to further increase this target to 45% by 2030. In addition, according to the Governance Regulation, countries should present their national contributions to these targets in their National Energy and Climate Plans (NECP).

Deployment of private PV micro-installations can significantly contribute to the achievement of these goals. This solution is attractive from several perspectives (redistribution of investment costs - using private capital) and technical aspects (improving resilience of the grid and providing demand-side services to the grid). Thus, renewables share the obligation and may influence other policies at the national level, as well as encourage funding that will allow prosumerism to develop more rapidly. According to the findings of SolarPower Europe, most countries refer to prosumerism in their NECPs and indicate the general need to develop this area and provide basic enabling policies, but only a few of them indicate specific goals for prosumer development (SolarPower Europe, 2021). Furthermore, 672 GW of solar power capacity is predicted by 2030, partially owing to the REpowerEU, which is also expected to be further increased due to the EU's more ambitious targets for 2030 (SolarPower Europe, 2022).

There are also challenges in the transposition of the EU framework. Even though low-income and energy-poor households could benefit from participating in RECs owing to affordable energy tariffs and energy efficiency measures. EU legislation highlights RECs' social role in energy poverty alleviation and specifies the participation of all social groups in RECs, especially those underrepresented in community members. Hanke et al. (2021) collected data among 71 European RECs and studied how they were engaged in the social role focused on showing practices for improving participatory procedures to enable vulnerable groups' participation and distributing affordable energy and energy efficiency to vulnerable households.

Frieden et al. (2020) presented how the Clean Energy package aims to integrate the energy market which would include, for instance, the provision of flexibility by active consumers and energy communities. In this context, full integration in national frameworks and the energy market would include a good understanding of the role of energy communities to create system benefits. So far, the assumed system-benefits of energy communities largely include the introduction of local grid tariffs, equally addressing cost-reflectiveness. This static approach may also provide some incentives, in particular for the local balancing of production and consumption. Integration in dynamic flexibility markets could provide even stronger incentivizes to provide specific system benefits. In the longer run, fully embedding energy communities in the energy policy and market structures could allow benefiting most efficiently from their technical but also socio-economic potential.

Backe et al. (2022) showed that energy community development decreases total electricity and heating system costs in the transition towards a decarbonized Europe. Moreover, they predict that less generation and storage capacity expansion would be needed on a national scale to achieve climate targets after energy community expansion. However, at the same time, a conflict of interest between optimizing energy community flexibility towards local cost minimization versus European cost minimization was discovered. Actions and more scenarios should be considered to avoid the conflict and support legislation in promoting sustainable, effective transformation.

3.3 Overview of current energy community modeling

Overall, the FLEX model helps answer selected policy questions and should be able to respond to them regarding consumer behavior. Furthermore, it can identify the potential of energy communities. The capacity to model real-time pricing is already implemented, allowing to include behaviors such as load shifting. As the requirement to recognize the needs to minimize energy costs in energy community was pointed out in D4.3 at case study in the presented report was investigated. However, the communal approach and joint efforts of the energy community to lowering the energy demand so far were not the most emerging issues in the FLEX and will not be implemented in the model. Within the work on the model, the frameworks and supporting tools to enable an energy market favorable for prosumagers and energy communities are being considered for modeling in the iteration of the FLEX model (details will be presented in D5.4). As of September 2022, the FLEX model considers the cost minimization of a single building. The modeling team planned to perform a post analysis of the modeling results, where it will be checked how much energy can be sold by a certain household and if energy is needed at the same time by other households. That could prove the benefit of energy communities modeling and show the need of their existence in the European energy sector. The FLEX model seems unique regarding the integration of prosumaging behavior and operation, including a broad range of technologies and investment decisions.

Current modeling of energy communities is focused on particular domains (e.g. power grids and systems, building system simulation, power system simulation Kazmi et al. (2021)) and tools dedicated to the specific domains:

- energy system modeling tool – Calliope by Bartolini et al. (2020);
- optimizing the utilization of the local energy technology portfolio (Zwickl-Bernhard & Auer, 2021);
- thermal energy sharing (Abdalla et al., 2021);
- power sharing (Di Lorenzo et al., 2021);
- electricity demand (Fazeli et al., 2011)
- other useful tools can be used for
    - Data visualization and dashboarding Visualization (Matplotlib, Seaborn, Plotly Dash; Interactive dashboarding)
    - Panel and Streamlit Modeling and forecasting Time series modeling (Darts, Sktime, Facebook Prophet);
    - Machine learning modeling and clustering: Scikit-learn, Tensorflow, PyTorch, Pycaret etc.
    - Design and operational optimization (Convex optimization: Pyomo, Gurobi, PuLP, CVXPY; Non-convex optimization: Nevergrad; DEAP; Reinforcement learning: City Learn project, ChainerRL, KerasRL, TensorForce (Bartolini et al., 2020; Kazmi et al., 2021).

Different kinds of supporting instruments are:

- models for optimal community energy planning (Bakhtavar et al., 2020);
- business models for energy community (Iazzolino et al., 2022);
- agent based modeling (ABM) that can be used to predict the effectiveness of different renewable energy options in creating a successful zero energy community (Mittal et al., 2019);
- tools, reports and papers aiming to support a local, community-led renewable energy revolution in Europe (https://www.rescoop.eu/toolbox/all/all/all/online-tool);
- methodology for modeling net zero communities (Bucking and Cotton, 2015).

The only model identified and operated with respect to the RED II and energy community functions defined in it was the mixed-integer linear program (MILP) minimizing investment and operational costs implemented in PROSUMER, a microgrid and energy community planning tool developed in-house at ENGIE Impact (Alaton et al., 2020).

On the other hand, a model created by Mutani et al. (2018) working on data input using the electric consumption of residential users of 1,201 municipalities in Italy (north-west region, Piedmont) revealed that for those communities the main energy-related variables are the characteristics of the building itself (already included in FLEX) but also the socio-economic environment characteristics of the municipality (to some extent represented in the FLEX in the behavior model in the model input). The linear regression model forecasting the residential annual electric consumption at a municipal scale identified that the most important socio-economic variables are: level of education, yearly average income and the average number of members in a family. The number of students and owners of fixed income also had an impact on energy consumption. The first one was positively correlated and the second was very significantly negatively correlated with energy consumption (Mutani et al., 2018). However, those results should be revaluated as the users' behaviors and energy consumption could have been changed by the pandemic and the Mutani et al. (2018) study concerned only one Italian region, so it does not have to be relevant for other energy communities.

3.4 Recommendations for energy community modeling

The scope of the case was narrowed down to the aspects of multi-housing area in the EU, building and technology parameters that can serve as input to the FLEX, and policy gaps mentioned in section 3.1 of this chapter. The literature review resulted in finding only one model focused on the legal provision of energy community in EU. The conclusions can be summarized as follows:

- Modeling the energy community-related legal provisions just started and the design of cost-reflective and fair network tariffs for energy communities is one of the most challenging modeling aspects;
- Inadequate energy community network tariffs can lead to excessive energy community adoption and non-desirable outcomes for the grid (Abada, et al., 2020);
- Both the REDII and the Internal Electricity Market Directive (IEMD) entitle members of Renewable Energy Communities (RECs) and Citizen Energy Communities (CECs) to "share ... renewable energy that is produced by the production units owned by that [energy community]." Therefore, regulators and distribution system operators (DSOs) face the challenge of establishing frameworks that enable not only sharing, but also designing financially sustainable network tariffs. Those should recuperate network costs and avoid unintended cross subsidies;
- Energy communities face operational and planning challenges (e.g. optimization of resources in the presence of peer-to-peer sharing).

Recommendations regarding the modeling and policy regulations can be condensed to the need to distinguish from individual self-consumption, collective self-consumption, and consumption from the grid. These are crucial to calculate the financial impact that different tariff and tax designs can have on the different stakeholders related to an energy community (participants, the community as a whole, the DSO and the traditional energy supplier).

The following additional indicators used by Torabi Moghadam et al. (2020) in their methodological approach for mainstreaming energy communities could be integrated into the models:

- Environmental:
    - Primary energy saving,
    - Global CO_2 emission reduction,
    - Local NO_x emission reduction,
    - Local PM_{10} emission reduction;

- Economic
    - Payback period,
    - Investment cost,
    - Public incentives,
    - Savings on energy expenditure,
    - Labor cost,
    - Labor cost by a social cooperative,
    - Material cost,
    - Material cost purchased on the territory,
    - Running cost,
    - Type thermal account access vs. Energy efficiency certificate;
- Technical
    - Increase of plant system efficiency,
    - Installed power reduction;
- Social
    - Architectural impact.

Outcomes of desk studies recapped in sections 3.2 and 3.3 of this chapter were evaluated regarding the compatibility with FLEX: Modeling the Prosumaging Behavior of Households and the Impact on Energy Consumption and Technology Adoption. The main information that can be incorporated in the model regards additional distinction (individual self-consumption, collective self-consumption, and consumption from the grid) for various tariff and tax design and could make advance in terms of energy prices input.

Even though there are not many examples of energy community modeling, some aspects speak in favor of FLEX, such as optimization of resources and operation of technologies in not only annual but also hourly resolution.

The PROSUMER model distinguished between self-consumption, collective self-consumption, and consumption from the grid, which makes it more useful regarding the various tariff and tax designs and connected to the provisions of the EU Directives referring to Renewable Energy Communities (RECs) (RED II, art. 2 (16)) and Citizen Energy Communities (CECs) (ED, art. 2 (11)) (Alaton et al., 2020). The model showed the energy sharing in RECs and CECs and the tariffs encouraging to work as an energy community without multiplying subsidies.

Therefore, the energy-demand modeling of energy community should:

- consider using the collective consumption and energy consumption distinction not only in a single household (as it is already implemented in the FLEX model) but in multiple houses working in energy community;
- use input and potential output of other energy community modeling approaches that could be sourced from data bases outlined and briefly described by Kazmi et al. (2022). The article highlights the significance of commonly used open-source datasets and tools that are already available for EC, i.e. ADRES, DRED, CoSSMic;
- consider more socio-economic aspects in input data after conducting or getting familiar with broad European studies on the impact of a socio-education degree, yearly average income and the average

number of members in a family on post-pandemic energy consumption.

4. Circular economy

4.1 Importance of GPP criteria in buildings considering circularity

The circular economy (CE) is a way of production and consumption involving sharing, leasing, reusing, repairing, refurbishing and recycling existing materials and products as long as possible to extend the life cycle of products. There are many approaches to CE, but it is the 9R standing for *Refuse, Rethink, Reduce, Reuse, Repair, Refurbish, Remanufacture, Repurpose, Recycle* that can be used as schemes in the design, manufacture and development of energy systems and infrastructure, which can also provide resource efficiency significantly supporting the CE. The 9R framework is an environmentally preferred hierarchical approach for closing material loops (Kirchherr et al., 2017).

Public procurement is a process by which public authorities (government departments, regional and local authorities or bodies governed by public law) purchase works, goods or services from companies. Green public procurement (GPP) was developed and defined as a process whereby public authorities seek to procure goods, services and works with reduced environmental impact. Public procurement ranges from roughly 10% to as high as 30% of gross domestic product of the Member States (MSs), with 14% average for the EU, implying the considerable potential for using these relatively highly regulated and monitored expenditures to implement new standards for green investments. On the one hand, greening these investments can have a direct impact on reduced energy demand, increase circularity and lower demand for raw materials. On the other hand, there is still no robust, clear framework for implementing and operating GPP at the EU level, and implementing GPP elements remain voluntary. Although some of the barriers relate to the implementation (education, administration and business), management (reporting and monitoring) and the development of clear and appropriate indicators, modeling the impact of CE could indicate both the impact that GPP will have on energy demand and the economy, and specific areas in which the implementation of GPP is a priority.

The construction sector requires not only significant quantities of energy-intensive basic materials, but also the amount of construction waste has increased about one fifth since 2004 (Eurostat Waste Statistics; Le Den et al., 2020). Additionally, the potential for improvement in the CE context is high. Therefore, this sector, and buildings in particular, is a focus area in the newTRENDs-project. Consequently, the policy case: "Modeling of Green Public Procurement criteria for the design, construction, renovation, demolition and management of buildings" was created by focusing on CE in EU buildings. For this case, material circularity recommendations and targets were recognized in five areas according to the JRC Technical Report: "EU GPP criteria for the design, construction, renovation, demolition and management of buildings" (Donatello et al., 2022a):

- inventory of building elements, technical systems, construction products and materials purchased,
- Construction, Demolition and Excavation Waste (CDEW) management,
- design for adaptability (chosen for the case in this report),
- design for deconstruction (chosen for the case in this report),
- operational waste management.

The 9R framework was used as a base for the CE in this case study. Thus, the case centers on the environmental impact of construction materials in the entire life cycle and the policy targets regarding the phases of design and construction in the above-mentioned areas of design for adaptability (scoring matrix) and design for deconstruction (level indicator). Furthermore, the case was chosen based on its links to other WPs in the project and strong interest in CE in Europe, as well as high impact on energy efficiency and climate neutrality that can be achieved owing to the decrease in the buildings' emissions and energy demand. The modeling of CE for buildings will be set out in WP6. The corresponding energy demand-side policies and EU instruments as well as policy needs were described in D4.1 (Kochanski et al., 2021). Also, in D4.3 GPP was mentioned as an instrument that would be relevant for modeling and has not yet been implemented (Kochanski et al., 2022).

The case focuses on the Members States and material circularity. The outcomes will support improvements in the modeling by suggesting potential data inputs and potential modeling approaches relevant for policy making. The scope is also narrowed by comparing CE measures with criteria for use or the end of life (EOL) regarding the different types of material substitution, material efficiency and recycling. The case includes phases of the building process and indicators that are important in the 9R framework.

4.2 Summary of information regarding the JRC Technical Report on GPP criteria for buildings

The JRC Technical Report: "EU GPP criteria for the design, construction, renovation, demolition and management of buildings" presents a brief introduction to the basic tenets of GPP concerning buildings and the types of requirements that contracting authorities can use to purchase environmentally friendly products and services in the construction sector (Donatello et al., 2022a). The document was used for the case study as it offers evidence-based scientific support for the European policymaking process in GPP in the building sector. GPP were not yet modeled within the newTRENDs project, but they are considered as being identified in other project's deliverables as a promising tool supporting energy efficient building. Further, during the qualification of policy instruments according to their role in the model performed in D4.3, two areas of intervention were still not considered in the current modeling of the construction industry, but can be potentially important (Kochanski et al., 2022):

- Assessment of the environmental impact of construction materials in the entire life cycle (which will be the focus for the case);
- Extending the use phase of a building by its repurposing (including modular buildings).

The JRC report includes 7 central themes with 38 initial criteria proposals. The criteria are organized according to a building life cycle, irrespective of whether the project starts with an existing building, a derelict site or a greenfield site. It is noted which type of project(s) the criterion is suitable for (Donatello et al., 2022a):

1. Energy consumption and greenhouse gas emissions
2. Material circularity
3. Efficient use of water resources
4. Occupant comfort and wellbeing
5. Vulnerability and resilience to climate change
6. Life cycle costing
7. Biodiversity

The criteria chosen in the JRC report are lined up with the Level(s) framework of indicators for assessing the sustainability and benchmarks. They have been set by taking into account relevant Green Building Certification schemes, the EU policy and good practice established in the EU building sector, as well as the EU Taxonomy for environmentally sustainable economic activities. Level(s) also ensure a common language for the building transformation process in line with the EU's sustainable initiatives. The Level(s) framework function in areas of resource use and environmental performance; health and comfort; cost, value and risk. It uses 16 indicators based around 6 macro-objectives (European Commission, 2021a) within which the resource efficient and circular material life cycles, the optimized life cycle cost and value are the most important. Level(s) framework distinguishes four groups of Level(s) users divided into the following areas: planning, design, financing, execution. The examples of how Level(s) interacts with global and other EU sustainability initiatives can be found on the Level(s) webpage[3].

The designs for adaptability and deconstruction are two areas within 'Material circularity' predestined for modeling as the building should be treated as an asset for documenting the effects of different building design interventions, including adaptability and renovation measures and deconstruction. Adaptability score and deconstruction score are connected to other norms and represented by the indicators 2.3 and 2.4, respectively. The comprehensive description together with the unit of measurement; system boundary; calculation method and reference standards for indicators 2.3 (Dodd et al., 2020) and 2.4 (Dodd et al., 2020) can be found in dedicated reports on these Level(s) indicators. The GPP criteria include the core criteria for easy GPP application of GPP with a pivot on the environmental performance of a product (aimed at keeping administrative costs for companies to a minimum) and comprehensive criteria, including further aspects or higher levels of environmental performance (dedicated for the authorities that want to support environmental and innovation aims to a greater extent; Donatello et al., 2022a).

3 https://environment.ec.europa.eu/topics/circular-economy/levels/lets-meet-levels/how-levels-applies-you_en

4.2.1 Design for adaptability

A well implemented design for adaptability can facilitate the improvement of the building's lifespan and value on the property market. At the same time putting emphasis on opportunities for recovering, reusing and recycling materials at the EOL stage (European Commission, 2021b).

Adaptability requirements are incorporated in the international standards for construction, but are often ambiguous. These standards need to be framed case-by-case, according to consumer needs as well as the construction/renovation scenario. However, Level(s) provides a step-by-step process to define the specific measures to extend the utility of buildings. Even though, it often conflicts with present-day practices and business models (European Commission, 2021b).

GPP criteria for adaptability have been defined and used also in the indicator 2.3 of Level(s) guidance (scoring matrix). According to the core GPP criteria, the building design should acquire an adaptability score of a minimum of X/100 points (example of a scoring matrix with scoring rules and weighting factor as well as points to determine X is included in Donatello et al., 2022a) by including characteristics easing changes to internal space distribution and to the routing or type of building services (Donatello et al., 2022a). According to the comprehensive GPP criteria, the building design should acquire an adaptability score of a minimum of X+10/100 points by including additional characteristics that ease changes to the building façade and structure (Donatello et al., 2022a).

Indicator 2.3 was designed to help achieve significant environmental benefits through extending the useful life of buildings. The emphasis was on buildings' structures and façades as having the most apparent environmental impacts. The indicator provides a semi-quantitative assessment of the design of a building that could facilitate future adaptation to changing occupier needs and market conditions. Indicator 2.3 measures the design and servicing aspects of particular relevance, identified based on market research and experience (Dodd et al., 2020). The calculation method in Level(s) is a transitional calculation method, partly based on the building flexibility calculator provided by BREEAM Netherlands and the Dutch Real Estate Norm (REN). The Level(s) methodology defines a scoring matrix for quantifying the adaptability of office buildings (can be found in indicator 2.3's user manual). Such estimations can be also performed with regards to the flexibility and adaptability criterion ECO 2.1 criterion published by German Green Building Council's (DGNB) (Donatello et al., 2022b). Moreover, the method references to the principles and design aspects that are included in EN 15643-3, EN 16309 and ISO 20887. Level(s) can be applied at each stage of a building´s life cycle at:

- Level 1. Qualitative assessments and reporting on the concepts – recognizing how the design of a building could facilitate future adaptation to changing occupier needs and market conditions.
- Level 2. An intermediate level, quantitative assessment – facilitating setting design targets or the stage of making design decisions and comparing design options for their relative adaptability.

- Level 3. Monitoring and surveying of activity – enabling comparison of the final as-built design with the design plans. That can be a starting point for a long-term building monitoring.

The JRC report uses different criteria depending on the nature of the building procurement activity in question. It is shown how the building project stages defined in the 2016 EU GPP (Dodd et al., 2016) for office buildings line up with Common Procurement Vocabulary codes and the main types of activities involved (Donatello et al., 2022a).

The assessed aspects differ for offices and residential properties. For the former one the focus is on flexibility within the office market, as well as flexibility to change of use within the property market (Table 1. Office building checklist of adaptability design concepts; Table 6. Office building scoring and weighting system for adaptability design aspects in Donatello et al., 2020). While for the latter - the potential to adapt to changing family and personal circumstances over time, as well as the flexibility to support a change of use (Table 2. Residential building checklist of adaptability design concepts; Table 5. Residential adaptability design aspects related to life changes in Donatello et al., 2020).

According to JRC, adaptability can be also found as the aspects of the social performance framework for a building in EN 15643-3 with the main features of ability that accommodate individual user requirements, changes in user requirements, technical changes and changes of use. EN 16309, connected to EN 15643-3, brings assessment and communication details regarding the adaptability of a building against different scenarios within the EN 15978 life cycle framework. EN 16309 also contains other social performance aspects, such as indoor air quality and thermal comfort that could be part of the concept of "adaptability", but in the JRC report those were included in the EU GPP criteria structure, under different themes, not within indicator 2.3.

4.2.2 Design for deconstruction

Design for deconstruction seeks to extend the utility of building materials by considering future opportunities for recovery, reuse and recycling. Level(s) Indicator 2.4 makes it possible to compare how easily building materials are reused and recycled in a variety of scenarios. It supports designers and architects in assessing how materials will be recovered when the building reaches its EOL. By featuring circular approaches to the use of materials, they can reduce the construction sector's embodied life cycle impact and natural resource consumption. At the design stage, Level(s) supports professionals in embedding reuse and recycling plans into the building project from the start. For example, by defining steps and measures to simplify the separation of materials at each life cycle stage (European Commission, 2021b).

GPP criteria for deconstruction have been defined and used also in the indicator 2.4 Level(s) guidance (level indicator). According to core GPP criteria, the building design should achieve a minimum circularity score of 40% by mass and 40% by cost and be exemplified using the calculation method for indicator 2.4 in Level(s) as well as be accompanied by a design for deconstruction report incorporating an inventory of the different building elements, components and materials used in circulation. In the comprehensive GPP criteria the score is raised to 60% (Donatello et al., 2022a).

Indicator 2.4 provides a quantitative assessment of the degree to which the design of a building could facilitate the future reuse, recycling or recovery of building elements, components and constituent parts and materials. It therefore provides a link to the contribution of the building to the CE, and the practical potential to access the material value reported under Module D of indicator 1.2 of the Level(s) framework. The indicator considers the ease of disassembly for a minimum scope of building elements, as well as the ease of reuse and recycling for these elements and their associated parts and materials. The details are described in Dodd et al. (2021).

The Level(s) methodology defines a scoring method for quantifying the design for the deconstruction of buildings, similarly to the TEC 1.6 criterion published by DGNB (Donatello et al., 2022b). The results are a 0-100 (maximum is the best design easing full reuse) score for the applicable building elements and components. It can be weighted by mass or by value of the components. There is additional reference to the principles and design aspects incorporated in ISO 20887.

The Level(s) calculation method asks users to judge what is the best outcome for all elements, components, parts and materials of the building in their defined scope. There is a guide showing how the Excel sheet should be filled out and how the scores are calculated in the indicator 2.4 dedicated document (L2.2. Step 8 in Donn et al., 2021). Similar to the adaptability criteria, Level(s) can work at:

- Level 1. Qualitative assessments and reporting on the concepts – understanding how the design of a building could facilitate ease of future deconstruction in order to access, disassemble and dismantle parts and materials. Also scrutinizing the range to which these building parts may be recovered for either reuse and/or for recycling.
- Level 2. An intermediate level, quantitative assessment – facilitating setting design targets or the stage of making design decisions and comparing design options for their deconstruction potential
- Level 3. Monitoring and surveying of activity – enabling comparison of the final as-built design with the design plans. That can be a starting point for preparing the technical content of a building passport/building material bank record.

4.3 Overview of current GPP modeling in buildings

The potential impacts of an EU-wide mass-scale application of the JRC Technical Report on GPP criteria for buildings have not yet been modeled by the available energy-demand models in the EU. Current modeling of GPP in the building sector with focus on CE concentrated more on the roles of actors and the regulatory framework. The EU identifies the building sector as key for GPP. Representing a source of one third of all waste generated in the EU, construction and demolition generate one of the largest waste fractions by volume. Moreover, construction materials account for half of all raw materials used globally. Given that buildings are complex systems, it is recommended that GPP approaches address both the overall impact of a building and the environmental characteristics of individual components (Mayer et al., 2019; Donatello et al., 2022a).

4.3.1 GPP in the building sector

GPP can play an important part in financing and be used in the EU to evaluate the bids in terms of their environmental impact and integration of sustainable practice. Therefore, GPP could be considered in the models focused on sustainable building and show actors and decisions favorable for material use in the 9R framework. The GPP for the building sector is not yet included in the modeling in the EU, especially regarding the criteria from the JRC report and Level(s) as those are relatively new tools and benchmarks. At the same time, there is no doubt that unified GPP criteria have a big chance to support CE in the sector. A study by Pellegrini et al. (2021) of the regulatory framework at the international, European, and national levels pointed out need for the implementation of GPP, environmentally sustainable processes, as well as waste minimization and management. The main drivers for the process were listed as:

- promotion of sustainable strategies to be achieved with regulations and by Public Clients through design requirements as well as call for tenders' criteria;
- inclusion of sustainable strategies into company business models and procedures to maintain and increase their competitiveness;
- launch of information Modeling and Management (IMM) methodologies to support the implementation of sustainable strategies.

A review of the recent (2017–2020) and relevant (Web of Science- and Scopus-indexed) empirical sources by Lă ză roiu et al. (2020) confirmed the scarcity of reviews covering GPP regarding environmentally responsible behavior and sustainability policy adoption. There is no literature information, also due to the recent introduction of Level(s) giving possibilities to assess performance at the design and construction stages, yet it has not been implemented in the models (European Commission, 2022). The authors suggest additional research to explore the role of GPP in the automated algorithmic decision-making processes in smart cities, sensing and computing technologies, network connectivity systems, and the Cognitive Internet of Things to fulfil public administration's changing requirements. The review presents important highlights for GGP, namely (Lă ză roiu et al., 2020):

- the way it drives the CE;
- construction and building materials;
- measures for procurement of sustainable innovation;
- environmental policy objectives in terms of energy, pollution, carbon footprint, and climate change;

- its dimensions regarding environmental policy mechanism for production and use of sustainable goods and services;
- its dimensions regarding integral component of sustainable development and performance.

Similar outcomes were derived by Çimen (2021). The author states the Construction and Built Environment (CBE) are especially neglected under CE and demonstrates that CBE-CE literature remains at an early stage despite recent growth in academic interest. 90% of CBECE literature was published between 2017 and 2020 and was mostly conducted in China, published by the Journal of Cleaner Production. “Operation” and “Design” are the most and least studied construction stages, respectively. “Waste Valorization” is the most studied CE subject in the “Material” scale at the “Construction” stage, which confirms motivation for the case study in this report. Çimen (2021) advises to consider the diversity of stakeholder type, motivation, and their influence on lifecycle stages in the CBE-CE analyses.

The above conclusions are confirmed by Yu et al. (2022) revealing a lack of integrated policy-making framework for implementation. To respond to this issue, the authors propose a bi-directional policy-making mechanism for policy implementation and evaluation, in which current knowledge gaps are covered and serve as theoretical guidelines for public and private actors to understand more complex CE policy-making in reality. Yu et al. (2022) also want to merge CE policy-making into the construction industry by exploring the synergistic effect of CE policy packages on the construction life cycle, as well as creating a streamlined, transparent, and collaborative policy-making environment based on Information & Communication Technologies. The above-mentioned recommendations can be also used in modeling as to support CEs in the building sector. The involved actors will not only need the criteria and targets, but mostly real-life enablers for using materials at the different stages of R9. Anastasiades et al. (2021) presented barriers in the implementation of GPP for building, revealing that recycled and reused materials are not valued by as high as new components by potential buyers in the construction industry prices of circulated elements are higher than those of new ones.

4.3.2 Shaping political background for GPP

The situation can be changed by shaping the political background and making sure that recirculated materials meet the same standards and demands as new ones. In a different study, zu Castell-Rüdenhausen et al. (2021) presented CE actors in the construction sector and those were mainly representants of construction and EOL phases with focus on waste management. The actors benefit from the national and local political picture and above all the policies implemented via GPP requirements. It was already known that policies are a major driver for CEs in the construction sector by setting recycling targets. It was also discovered that many of the barriers identified by the actors can be controlled by online digital tools for trade and improved traceability. The price and availability of recovered and/or reusable materials/components are still bottlenecks for reuse and recycling as the virgin materials that are cheaper and more accessible. Many business opportunities benefit from the national and local policy landscapes; thus CE policies can drive the transition to a CE in the construction sector.

On the other hand, work of authorities and policy-makers focused on the whole value chain can be an enabler for the real-life implementation of the criteria and targets in the construction sector linked to actual increase in circularity. Level(s) can benefit support authorities, policy-makers and procurers in meeting climate and recovery objectives, i.e. (European Commission, 2021a):

- by integrating circularity and lifecycle thinking into national/regional/local policies, reducing whole life carbon cost effectively via public procurement, setting up regulation and sustainable finance;
- by evaluating the financial and environmental impact of sustainable building projects within the areas of Level(s) framework;
- by merging sustainability into urban planning, also in the construction and renovation of public buildings and the monitoring and regulation of sustainability and environmental performance of buildings managed by the private sector;
- by placing existing assessment and certification programs with the Level(s) common language

Soto et al. (2020) recognized a driving role of the GPP for building renovation (GPPBR) in achieving climate goals by 2050. Recommendations, according to their outcomes, include disseminating knowledge among the involved parties as well as drafting specifications to develop other specific and advanced technical procedures to assist GPPBR professionals in the practice. Unfortunately, the results of Testa et al. (2012) showed that awareness of the GPP toolkit does not support public authorities developing GPP practices and neither does the ISO 14001 certification. Additional motivation and support for public authorities could be added by the dedicated modeling tools or outputs focused on the best practices to achieve the target and meet criteria presented in the JRC Technical Report on GPP criteria. There is need for more effective and coordinated actions and policies promoted by the European Commission. The design strategies for reversible building are generally in private initiatives, driven by market competitions, rather than by public incentives. **The application of circular business models and the creation of circular networks among the operators of the value chain is still lacking.** Moreover, the use of life-cycle tools to assess the environmental effectiveness (sustainability) of circular strategies is rarely applied. There is a need for research in the fields of digital supporting tools and environmental assessment (LCA), circular relationships and business models and the definition/training of new expertise related to CE enabling aspects (Giorgi et al., 2022)

In May 2021 the European Commission released a report on “Implementation and best practices of national procurement policies in the Internal Market” (Report from the Commission COM/2021/245). The report indicates that both individual MSs, as well as aggregated projects conducted by the Commission had significant problems with collecting relevant data and their comparison. This indicates a further need to harmonize the approach to Public Procurement, because governance and monitoring of progress in implementing measures for GPP are and will continue to be a key aspect allowing for appropriate responses in the event of insufficient measures.

4.4 Recommendations for the modeling of GPP criteria in buildings

Considering GPP along the building value chain would be useful with regards to the standard and common language for the involved actors and connected to the provisions of the JRC Technical Report "EU Green Public Procurement (GPP) criteria for the design, construction, renovation, demolition and management of buildings". Thus, it is recommended to evaluate to which extend it can be considered within the focus study in the JRC report which is lined up with the Level(s) framework of indicators for assessing sustainability, while the benchmarks have been set by taking into account relevant Green Building Certification schemes, the EU policy and good practice established within Europe in the building sector. Level(s) enables advisors to incorporate lessons learned into future building projects. Moreover, developers can use sustainability performance factors when making property investment decisions. When it comes to deconstruction and the waste from on-site construction, processes call for new ways of working, organization and demolition. Lots of organization still needs to adapt both concepts. It is also important due to lack of proper momentum in the EU and MSs in implementing these policies. It can be the result of inadequate guidance from the European Commission and problems in terms of standards and administrative problems such as determining adequate evaluation criteria and standards or lack of training for administration and business. Although the most important barriers to GPP implementation appear to be beyond the capabilities of energy demand side models, some models for the sectors could show where the greatest improvements are needed, hence where is the greatest urgency for action and on this basis provide a reference for priority areas for implementing GPP.

GPP modeling in previous years could have been presented as relatively easy. For example, the methodical approach by Majernik et al. (2017) simplified the GPP modeling to the development of a green order and its implementation into a GPP process opening with the criteria for evaluating tenders and ending with closing the contract (Figure 2. Processing of green public procurement as support for sustainable production, consumption and green growth in the mentioned article). Currently, the building industry considers the linear economy, from programming to the “in-use” phases and differentiates it from the material lifecycles, while to embrace the circular CE, the asset EOL shall be considered as a phase, being an integral part of the lifecycle of buildings (Charef, 2022). Based on theoretical foundations, Charef (2022) organized holistically two scales, the asset lifecycle phases and the material flow, whether new or recovered, while previously it was mainly focused on improving technological solutions (Çetin et al., 2021; Charef, 2022).

Modeling of GPP criteria in buildings should:

- be holistic, i.e. treat buildings as complex systems in line with GPP criteria addressing both the overall impact of a building and the environmental characteristics of individual components;
- use finding and benchmarks from the JRC Technical Report "EU GPP criteria for the design, construction, renovation, demolition and management of buildings" and merge, CE policy-making into the construction industry especially regarding including new trends and solutions in ICT and the synergistic effect of CE policy packages on the construction life cycle (Yu et al. (2022);
- draw and extract from the model of "Major roles in the re-use process and their interaction" presented in ‚Level(s) indicator 2.4: "Design for deconstruction" (Dodd et al. 2021 - Figure 2) and include actions and actors to overcome the barriers revealed by Anastasiades et al. (2021) as well as the diversity of stakeholder type, motivation, and their influence on lifecycle stages in CBECE analyses described by Çimen (2021) that were presented in section 4.3;
- incorporate standards for the adaptability requirements based on the Level(s) methodology providing a step-by-step process to extend the utility of buildings. The buildings should be evaluated case-by-case, according to consumer needs as well as the construction/renovation scenario;
- include proper rationale to be applied when considered which EOL outcome is most appropriate for each building element, component, or part (Dodd et al. 2021, see Figure 4: General logic applicable for deciding on best outcomes for building elements, components, parts or materials);
- include specific design aspects listed for indicator 2.3 (Tables 1-5 in Donatello et al., 2020);
- include the inputs listed for Level(s) indicator 2.3. and 2.4 in the dedicated documents (Dodd et al. 2020; Dodd et al. 2021)
- create a way to facilitate the calculation method from the Level(s) (Dodd et al. 2021 - L2.2. Step 8: Filling out the Level(s) excel calculator) as well as scoring for indicator 2.3 (based on Table 6: Office building scoring and weighting system for adaptability design aspects in Donatello et al., 2020);
- not only enable calculating the needed scores, levels and checking if the set targets are achievable, but also indicating the ways to achieve those targets with GPP highlights developed by Lăzăroiu et al. (2020) presented in section 4.3 in this chapter.

5. Shared economy

5.1 Importance of energy demand and support for the electrification of an EU city using car sharing

One of the most dynamically developing branches of shared economy is transportation. Despite the increasing interest in car sharing, carpooling, ridesharing, e-scooters etc. in the European market, especially in large cities (Hansen, Grosse-Dunker, & Reichwald, 2009, Roblek et al, 2021), sharing economy in transport is a solution that can still be developed with the support of regulations at the regional, national or European level (specific for the form of transport, local market and regulations). Regarding shared economy in transport, it is important that this concept develops towards a low-emission path (Fanchao & Gonçalo, 2022; Ortega Hortelano et al., 2022).

The case "Modeling of the impact on energy demand and support for the electrification of an EU city using car sharing" focuses on cars in the urban environment in the EU in the PRIMES-TREMOVE model. Additionally, a brief overview of the current situation is presented. The case was chosen based on the direct connection with the WP7 and possibilities created by the shared economy for transport for improving of energy efficiency in transport and climate neutrality.

The energy demand-side policies in the EU, policy makers engaged in the process and the policy needs were described in D4.1 (Kochanski et al., 2021). During the qualification stage of the policy instruments, according to their role in the PRIMES-TREMOVE model as presented in D4.3, two areas of intervention were identified that are not yet explicitly considered in the model, but could be potentially important (Kochanski et al., 2022): informing policy makers on the impacts of car sharing and carpooling policies on:

- urban mobility, in particular, individual car ownership levels;
- energy demand and use as well as inform policy makers on the impacts of car sharing and carpooling on electrification, and in the extension on energy demand and use (i.e., whether there is interplay of carpooling/sharing with electrification, and therefore support also other energy/climate policies that focus on electrification).

This case study investigates the second policy need listed above. The case supports the framework and assumptions based on the European documents (Energy and smart cities[4], Sustainable transport for smart cities[5], Digital single market and smart cities[6]) on the smart cities' development together with the

4 https://energy.ec.europa.eu/topics/research-and-technology/energy-and-smart-cities_en

5 https://ec.europa.eu/transport/themes/urban_en

6 https://ec.europa.eu/digital-single-market/en/smart-cities

Digital Europe program and Fit for 55 ambitions regarding emission reduction by 2030.

Indicators resulting from energy demand modeling that could be useful in the policy making process were presented in D4.1 as:

- shared mobility energy use and its structure by type of energy source
- share of various types of vehicles (and vehicle technologies) covered by the sharing economy in the total fleet (which will also be of interest in the case)
- share of transport activity covered by the sharing economy.

The current overview of policy regarding car sharing in Europe is included in the JRC report 'Research and innovation in car sharing in Europe'. The latest policy developments can be summed up as stricter emission objectives combined with further support of greener transport. At the same time, the Sustainable and Smart Mobility Strategy encourages a comprehensive policy to stimulate demand for zero-emission vehicles together with innovative solutions for a more sustainable and healthier urban mobility. The European Urban Mobility Framework points out the need for a more decisive EU action on urban mobility to shift from the traffic flows approach to the one based on moving people and goods more sustainably, with a bigger role of collective and public transport as well as progressive active mobility options. The policy makers underline that public transport and shared mobility services should complement each other (Ortega Hortelano et al., 2022).

The PRIMES-TREMOVE projects the penetration of a wide range of technological transport options within market conditions (prices, policies, different agents, etc.) also taking technical characteristics (of technologies and of the system) into account (e.g. such as vehicle efficiency, range of electric vehicles (EVs), or availability of alternative fuel infrastructure and their development over time). The model can support EU policy regarding the electrification of urban transport in many aspects. Even if the transport in smart cities should be modeled at the local level, the outputs of PRIMES-TREMOVE can be useful for such smaller scale approach as it distinguishes urban trip types. This may, for example, relate to the penetration of EVs. Moreover, a successful city's car sharing scheme can also serve as an input to the model to estimate the impact of certain EU policies.

With the global shift towards low-carbon, CE is needed to meet Green Deal goals and achieve energy resilience. To ensure Europe's competitiveness and address the increasing mobility needs of people and goods, the Commission's low-emission mobility strategy sets clear and fair guiding principles for the MSs (A European Strategy for low-emission mobility). The main elements of the Strategy related to the shared economy and smart cities are (European Union, 2016):

- to increase the efficiency of the transport system – making the most of digital technologies, smart pricing and further encouraging the shift to lower emission transport modes
- to speed up the deployment of low-emission alternative energy for transport (i.e. advanced biofuels, renewable electricity and renewable synthetic fuels and removing obstacles to the electrification of transport)

- cities and local implementing incentives for low-emission alternative energies and vehicles, encouraging modal shift to active travel (cycling and walking), public transport and/or shared mobility schemes, such as bike, car sharing and carpooling, to reduce congestion and pollution.

On the demand side, one challenge for the EU policy related to electrification is the connection of the car sharing policies with recharging infrastructure. Their optimal positioning requires not only investments, but also coordination and balancing interests between city and stakeholders. Policy stimulus intend to increase the social acceptance, encourage the change to use EVs and facilitate specific parking spaces for car sharing vehicles, while the user motivation will be to reduce maintenance and management costs on the operator side (Cohen and Kietzmann, 2014; Kalasova, 2019). Details regarding the policies and EVs market can be found in the IEA report (2021). Framework and legal assistance in data collection can make the monitoring of sharing schemes more efficient and allow adjustment measures if needed (Ortega Hortelano et al., 2022).

5.2 Summary of information regarding shared mobility and smart cities

Knowing the policy gaps and defining the case to study section 5.1 of this report, the next step was to gather information available in the area of shared mobility in smart cities with particular interest in car sharing and EVs. Although many examples of local shared mobility policies can be found, it appears that regulation at national and EU levels is lacking. Hence, policy fragmentation persists, with a multitude of local solutions across the EU MSs but little integration. The abundance of shared mobility initiatives signals a need for greater uniformity, which could be achieved with national and EU-level regulation. Harmonization of policy across the EU could support local authorities as enablers of shared mobility. This is particularly important in the context of procuring car sharing or bike sharing in such a way that it supports multimodal transport (e.g., enables citizens to perform the “last mile” using said services). Harmonization can also play a role in the context of digitalization. Digital platforms are crucial for the implementation of shared mobility initiatives, as they provide coordination mechanisms for matching demand with supply. The EU, which plays an active role in shaping the digital economy, could thus facilitate implementation. Moreover, EU-level policy would promote shared mobility across MSs and incentivize them to implement relevant policies. Further, the EU could facilitate the dissemination of knowledge from already existing local initiatives to support national and local authorities who have yet to introduce such policies. Moreover, the evidence suggests a need for greater public-private collaboration. While there is an abundance of public providers of shared mobility solutions, the authorities can play a role in ensuring that the environmental and social aspects are addressed by the services.

Surprisingly, little information circulates on shared mobility in the context of transport-related social exclusion. In a report by the European Parliament, the authors note that the social dimension of public transport in general has received little attention in academic literature and policymaking (Lodovici & Torchio, 2015). In shared mobility initiatives such as car sharing, there lies an opportunity to address the problem of transport-related social and economic exclusion while simultaneously addressing material and energy efficiency. Public transport networks, although significant in mitigating social disparities in urban spaces, often do not extend far enough into the suburbs and small towns to ensure reliable and frequent transport modes for everyone. Citizens who do not own a vehicle are therefore often excluded from accessing urban spaces on a regular basis. Car sharing schemes should learn from the example of the impact of public transport on social exclusion, and avoid, particularly fostering sharing mobility in rural areas (also with the case analyzed on EVs – infrastructure mentioned in section 5.3.1 of this report). Public authorities could address this gap by either providing the services in partnership with companies or otherwise incentivizing them with policy measures to extend operations to less urbanized areas.

In view of the above, we are investigating how local governments across the EU address the proliferation of shared economy in the transport sector and what best practices could be drawn from these experiences for providing the policies on higher, national, and European levels.

To link smart cities and mobility we need to define how they are connected within the concept. In this report, we use the definition by Caragliu et al. (2011) who believe that smart city “investments in human and social capital and traditional (transport) and modern (information and communications technology - ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance.”

In smart cities, the most common sharing economy forms are services and the most popular are the sharing of transport and housing resources in the Customer to Customer (C2C) and Business to Customer (B2C) models. The areas of the smart cities can be listed as (Jonek-Kowalska and Wolniak 2022):

- sustainable city mobilization – EVs for public transport, calm traffic (parking spots), cycling development;
- intelligent buildings and areas – incorporate and manage local and renewable sources of energy, using information and telecommunication technologies, intelligent city lights;
- integrated infrastructures and processes in energy, ICT and transport, reducing internet carbon footprint, intelligent heating, cooling, etc.

The shared economy is part of the third generation of smart city referred to as a sharing smart city. Sharing reflects the co-creation of a city by its inhabitants and is an unquestionable tool for creating smart cities. It allows for the expansion of the potential of a smart city, and the main task of city stakeholders is to change communication behavior (Spagnolli et al., 2018).

There are many European initiatives in the area of mobility in smart cities. One of the most interesting ones regarding the involvement of stakeholders is Driving Urban Transitions to a Sustainable Future (DUT)[7]. DUT is a European partnership of more than 60 partners from 27 countries, involving national and

[7] https://jpi-urbaneurope.eu/driving-urban-transitions-to-a-sustainable-future-dut/

regional policy makers, funders and urban-related policy agencies to invest in urban R&I as well as strengthen the European innovation eco-system for urban transitions. DUT aims to create a strong community around urban transitions and to establish a well-known research and innovation platform that will help cities become more sustainable, inclusive and livable. The mobility is crucial for proper functioning of cities and was in the center of the Pecar and Papa's (2017) article on Intelligent Transportation Systems enabling modern smart cities solutions, both in cargo as well as passenger transport. It was showed that using Europe's Smart Specialization Strategy and the Slovenian smart specialization strategy the main issue for implementation and improving the real efficiency of transportation in the smart city is the critical mass/acceptance rate of users/citizens. DUT focuses on calls for different aspect like Positive Energy Districts (PED), the 15-Minute City (15mC) and Circular Urban Economies (CUE).

5.3 Overview of the current modeling of shared transport - car sharing in smart cities

Shared cars and other means of shared transport are becoming a common sight across Europe, however, mostly in urban areas. With more companies adopting this business model, it seems to be increasingly attractive in terms of economic feasibility (Kalasova, 2019). Research shows that shared economy in transportation has significant untapped potential for energy savings and can reduce transportation energy use as well as greenhouse gas emissions (Yin et al., 2021). However, the main driver for its development remains purely economic. For now, the concept is operating mostly solely on market principles with little to no targeted regulations, especially on the national level. Certain regulations could be introduced to support shared transport development while also shifting the focus to sustainable objectives.

5.3.1 Car sharing– EVs

An important aspect will therefore be to increase the attractiveness of these solutions to maximize the savings effect, and energy models can provide valuable input to assess different policies at a European or national level. A particularly interesting business model for a non-European market and free-floating EV sharing systems modeling concerning customer adoption depending on service coverage at preferred destinations was presented by He et al. (2016). It is a mathematical programming model that incorporates details of both customer adoption behavior and fleet management (including EV repositioning and charging) under imbalanced travel patterns.

Convenience is also important in smart cities. DUT introduced a call for the 15-Minute City Transition Pathway (15minC). The concept is not new, but it was getting more attention lately and it is grounded in the idea that habitants should be able to cover the vast majority of their daily needs by walking and cycling within a 15-minute radius, while travelling larger distances by other forms of sustainable transport. DUT wants to rethink the existing mobility system and urban morphology with an aim to support sustainable mobility choices, redistribute urban space and transform citizens' daily activities. All to create more climate neutral, liveable and inclusive cities.

One example of a 15mC with EVs is Milan as it has revaluated the city function after the pandemic with a Transit Oriented Development paradigm (Abdelfattah et al., 2022). The city would be transformed to a walkable one with soft mobility modes or micro-mobility devices. In 15mC there would be no need to own a car and car sharing, and car polling could encourage the transition.

In the same city, other researchers conducted a study to investigate the spatial pattern of a potential demand for EVs (Pucci 2021). Pucci (2021) focused also on the demand relevance in defining diversified and site-based EV policies regarding a fair transition into low carbon mobility. The study shows that preferences and a traditional model of private mobility are less important than mobility habits and spatial niches for site-based policy measures aiming to be more selective and efficient than simple replacement of polluting cars with EVs. At the same time, the author states that the same policy measure can produce very different or even opposite effects regarding sustainability and equity in various spatial contexts, such as it was for densely urbanized areas and attempts to encourage the EV while the sharing services were more attractive (Salvia & Morello, 2020).

- In high density urban settlements with a good public transport supply, policy measures should be concentrated on reducing car ownership and promoting shared use of EVs, at the same time increasing vehicle occupancy rates and multimodal integrations. It should be accompanied by private car restriction policies including EVs i.e., congestion charge. Additionally, EVs sharing solutions and fast-recharging infrastructures should be placed in transport corridors.
- In medium density settlements with infrastructure corridors and transport interchanges marked with the last mile problem affecting private mobility, policy measures should be focused on stimulating the transfer from the car to public transport. It can be done by animating mobility hubs around suburban railway stations and EVs parking area services.
- In low density areas with high car intensity, policy measures should maximize the environmental benefit of EVs and reduce adaptation barriers. Those can be solutions like financial supports for purchasing EVs or distribution of fast charging points.

Models could explore the possibility of implementing regulations at the national level and whether these solutions significantly influence energy demand. One important factor in terms of shared mobility is convenience. In addition to measures that relate directly to the economy, it is also necessary to include measures that increase the convenience of use, such as the use of bus lanes, special parking lots or their connection with other means of transport.

5.3.2 Car sharing

The 15mC is also aiming to minimize the number of private vehicles in the cities, which can be achieved using car sharing. The Integrated Car-Sharing Action Plan in Bremen was the most effective among the car sharing plans in the cities analyzed by Kuss and Nicholas (2022) and was able to replace 15 private cars with one shared car (Glotz-Richter, 2016).

While the use of car sharing in highly urbanized areas is booming, it is significantly underdeveloped in less urbanized areas. High dispersion and low concentration of potential users reduce the economic feasibility of this business. Moreover, rural areas have a higher level of car ownership than urban ones. Research from Germany has shown that car sharing could gain significant interest in less urbanized areas if designed to adequately address the residents' needs. For instance, due to the high dispersion of residents, it is important to create car sharing stations and to monitor if vehicles are distributed correctly, in order to ensure access for all potential users (Mrso 2021). Shared mobility in villages could contribute to reducing transport exclusion, increasing car use and reducing emissions per km. The models could explore the possibilities of enabling car sharing in less urbanized areas.

It should be noted that apart from the facilities and incentives, shared transport could also be linked to certain constraints. Transport sharing could be based on sustainable solutions such as EV, bikes etc. while discouraging the use of polluting means of transport, i.e., choosing between EVs and internal combustion engines (ICEs). In extreme situations the choice may increase energy consumption, due to the flows of consumers from more sustainable solutions (public transport) to more suitable for them, but less environmentally friendly ones. This will both contribute to increasing the attractiveness of the electric car market and increasing awareness of such solutions. Although, it will also contribute to the development of infrastructure, which is key for the deployment of low emission transport. Luckily, the economic choice including the attractiveness of EV vs. ICE can be based on the modeling output. Such option is already implemented in TRIMES-PRMOVE and those alternatives can be investigated to avoid polluting options.

Additional literature research on car sharing confirmed that most articles using modeling involve mobility business models for the sharing economy (i.e. Cohen and Kietzmann, 2014). The sharing economy has produced different kinds of business models and it will evolve as technology develops and users' behavior changes. The progress needs to be included in transportation planning, balancing the need for modal choice and equality of service provision. Authorities in areas of transport and planning can collaborate with commercial car sharing providers to set up pilot schemes that can be monitored and evaluated, which can result in tailor made solutions after recognizing the willingness of citizens to join car sharing and carpooling schemes in the local context and community (Standing & Standing & Biermann 2018).

Standing & Standing & Biermann (2018) distinguished the facilitators of car sharing as:

- trust – a critical feature of sharing models, as many potential users or users will only have confidence in a company/product after a trustworthy person's recommendation. In ride-sharing it mainly focuses on the drivers and safety issues;

- adequate regulation – protecting consumers, but also feasible for the business;
- handy technology platforms that are easy to use with additional benefits provided by the immediacy and convenience of ICT. The likelihood of finding a suitable ride in carpooling grew dramatically owing to the social media, moreover there are high chances to match the interests of carpoolers based on crowdsourced data (Berlingerio et al.,2017);
- rethinking the value of ownership - ownership for a very long time has been the most desirable way to have access to products. However, the rise in the number of consumers preferring to pay for access/possibility to share products and services rather than to buy them is also observed (Scaraboto, 2015).

The barriers for car sharing were also identified (Standing & Standing & Biermann 2018):

- over-regulation;
- lack of trust (until recommended by someone they trust);
- set-up costs and lack of profit;
- deep-rooted norms and values like independence, private space or status.

Car sharing can help reduce vehicle ownership, which can result in lower total miles travelled on average by vehicle (Circella et al., 2016). It has been demonstrated that vehicle ownership among members of urban car sharing programs is lower, while biking, and walking transits cover higher frequency and distances (Mishra et al., 2015). Car sharing effectiveness in reducing car ownership and use was also showed by Nijland & van Meerkerk (2017). Car sharing reduces vehicle ownership, which can result in the increased use of public transport. However, it could also have the contrasting effect when car sharing is used instead of public transport (Le Vine et al. 2014). A rebound effect for previously car-free residents was noticed by Lettenmeier et al. (2019) when the same residents became the users of car sharing.

Unfortunately, it is still unclear how the sharing economy will affect private car use and demand for public transport, which should be considered in terms of local community and infrastructure. The interesting conclusions can be drawn from the paper by Glotz-Richter (2016) and his case study of Bremen. The city requires car sharing operator to meet certain standards that can help not only to reduce the traffic and energy demand, but also improve the service standard and convenience of the ride. The 'Blue Angel' certification calls for:

- a tariff structure based on time and mileage (i.e., no free kilometers) and encouraging short usage periods,
- low-emission, low-noise vehicles,
- regular care and maintenance of vehicles,
- high service quality (24-hour reservation, 24-hour car pickup and return).

Moreover, having less traffic and cars can help reclaim city spaces for walking-friendly and green areas. Bremen changed its parking requirements in building regulations for new developments with a higher standard for bicycle parking and a choice for the developer to provide parking or offer mobility management options – including car sharing. Another interesting idea implemented in the city since 2013 was to put smaller car sharing stations (mobil.pünktchen) in very narrows streets in order to relieve the parking stress there (Glotz-Richter 2016).

In Bremen, car sharing was linked to the public transport not only in terms of distribution, but also promotion as the car sharing stations are marked on the public transport map of the city. Car sharing widens the service of public transport and creates a more reasonable ridership base for public transport, as well as less car-dependent lifestyles (Glotz-Richter 2016).

Anthopoulos and Tzimos (2021) also see a role of smart carpooling services in helping smart cities minimize traffic congestion and gas emissions. At the same time, the authors notice the chances created by smart systems for the service, like enabling real-time ride matching, providing interconnection with public transport and city mobility services (tolls, parking), secure transactions among participants as well as assimilating reputation services.

There were also attempts of modeling the transportation aspects during the pandemic by Turoń et al. (2021). Their paper offers conclusions regarding sustainable transport management including electric bike-sharing system, electric scooter and moped-sharing system as well as electric car sharing systems that can be the base for recommendations for cities and transport service operators and be implemented after a lockdown caused by the pandemic. The outcomes can also be used in transport modeling and the creation of new policies, business models, and sustainable development recommendations.

If the implementation of shared mobility in European smart cities aims to achieve not only decarbonization but the well-being of the citizens, it should consider the fair shared city concept used in shared economy in Vienna described by Vith and Höllerer (2020) and car sharing cases reported by Rathenau Instituut (Freneken et al., 2017)

The main drivers of shared transport are rather similar for all European cities (according to Standing & Standing & Biermann, 2018):

- **Ride-sharing**
    - Affordability,
    - Environmental reasons,
    - Leisure without engaging with traditional companies,
    - Less traffic congestion,
    - Less spent on road infrastructure.

Indications for policy - develop governmental position on relationship with ride-sharing companies.

- **Carpooling**
    - community building,
    - Environmental reasons,
    - Lower costs.

Indications for policy – prepare regulations encouraging on reducing congestion and demand for parking.

- **Car sharing**

- Affordability,
- Owning feels like a burden,
- Less expensive than to own.

Indications for policy – prepare regulations encouraging on reducing car ownership rates in cities.

5.4 Recommendations for shared mobility modeling

The model developments undertaken in the modeling framework of PRIMES-TREMOVE aim to project potential developments of sharing mobility options under certain scenario conditions (e.g. decarbonization), capturing in a stylized manner targeting sharing mobility policies within the broader decarbonization context. The modelers noticed that to better represent the conditions under which a user will choose a shared mobility option the modeling should be based on a better understanding of individual preferences and how they are made (in existing car sharing schemes), as well as trip characteristics, i.e. different trip types that cars are used for leisure and commuting. Regarding energy costs, these influence the cost of the service that will make it less or more attractive compared to an alternative option. It is also a cost-effective dilemma between an EV and a ICE.

At the same time, infrastructure availability (and charging times), similarly as in non-car sharing modeling, acts as a barrier (or an enabler) of the EV uptake. Probably, unlike ownership, for some shared mobility schemes fast recharging times (or high range EVs) will be needed. Conversely, for an individual a low range e.g. for commuting to work, the already available infrastructure may be adequate.

5.4.1 Shared transport

Even though environmental reasons are frequently assumed to be strong drivers of transport sharing modes, the literature review by Standing & Standing & Biermann (2018) revealed that economic and convenience benefits are more important for participants of the shared economy. The authors point out that policy developers and planners must be aware of the drivers, facilitators and barriers and continually revisit developments as the users' behavior can and does change. Lately, access to mobility is getting more valuable for user than car ownership and related benefits. This could be explained by the burden and cost of ownership that millennials try to avoid.

The sharing economy has made an impact on transport in just a few years and it varies in different countries, cities and demographic groups (Steg et al., 2018). The forecasting in this area cannot be a case of extrapolating from how it has developed so far because people appropriate technology according to the benefits they perceive it will provide, and as they adopt and use technology, they find new uses for them. The constant development in this area means that aspects accepted by people today will be different to what is acceptable in the future. At the same time, other drivers (e.g. energy prices, energy policy) are also being developed over time and lead to the need for modeling rather than extrapolating the trend. This led to the need for an adaptive model that can be used to answer given inquires and predicted various scenarios for different targets regarding energy demand and sharing mobility types.

The motivation for moving to a sustainable energy system is driven largely by the will to protect the environment with the biosphere and to enhance human well-being. There are ethical reasons for protecting the biosphere, but reducing environmental problems such as anthropogenic climate change is of benefit to humans. For example, traveling by public transport is seen as less pleasurable than traveling by car, but changing the context of this action can enable sustainable behaviors to lower the costs and barriers for the action. The behaviors can be encouraged by targeting individual factors influencing behavior, including knowledge and motivations, like environmental consideration they affect, status, identity considerations, and social norms. It is important to remember that sustainable behavior and lifestyle changes, should enhance rather than degrade individuals' quality of life. Therefore, the policy should also include gradual change not mandated revolution in the form and type of transport used in the cities. Acting sustainably can enhance quality of life by making people feel they are doing something meaningful when engaging in behavior that benefits others and the environment (Steg et al., 2018).

Shared mobility might play a key role in the transition towards a more sustainable European mobility system (Lukasiewicz et al., 2022). However, it is hard to achieve, as a variety of stakeholders are involved. The shortage of resources, the unwillingness to share benefits and opposite interests can lead to conflicts. Moreover, new services such as electric scooters sharing — adding pressure on the existing, limited infrastructure and in the absence of clear regulations — can generate additional frictions. The assumptions of sustainable development depicted in Agenda 2030 for Sustainable Development (UNPF 2015) are aimed at prosperity and attention for all stakeholders (Lukasiewicz et al., 2022).

5.4.2 Car sharing – EVs

The scope of the case was narrowed down to the aspects of EVs in the smart cities in the EU and policy gaps mentioned in sections 5.2 and 5.3 in this chapter. The conclusions for EVs in the European transport can be summarized as follows (European Roadmap Electrification of Road Transport, 2017):

- The success and the rate of market penetration of EVs will strongly depend on the degree of usage and perceived suitability for usage of these vehicles in urban areas.
- Range, durability, reliability requirements and recharging of shared EVs will result in much different requirements than for individually and privately owned vehicles – including modified legislative frameworks. Research is needed to further improve the whole operation system of EVs in urban areas. Activities have to focus on those topics with the highest contribution to achieving 2030 targets regarding: vehicle technologies, infrastructure technologies and traffic system

technologies (Internet of Things, automation, vehicles and charging infrastructure).

- A significant increase of acceptance of EVs can come only via further and significant cost reductions and elimination of range disadvantages. Major research efforts are needed in the near and far future regarding batteries with significantly improved high energy density batteries and further improvements in efficiency. The broad spectrum of activities should include: disruptive steps in battery technologies development, meaningful advancements of e-powertrain technology, and best use of connectivity.
- The electrification roadmap was created for EVs in cities including R&I, demonstration and framework.

Regarding the aspects of electrification in EU cities (urban trip types) using car sharing that can serve as input to the PRIMES-TREMOVE, and policy gaps mentioned in the deliverable 4.1 in the newTRENDs project, the conclusions can be summarized as follows:

- a very important aspect for implementation and improving the real efficiency of transportation in the smart city is the critical mass/acceptance rate of users/citizens;
- the degree of usage and perceived suitability for usage of the EVs in urban areas strongly influence the success and the rate of market penetration of EVs;
- challenges for EU policy makers are connected to the shift to EVs and the need for installing recharging infrastructures and optimal positioning requiring not only investments, but also coordination and balancing interests between city and stakeholders. Including different technical characteristics of EVs, related infrastructure as well as barriers and enablers for sharing mobility options previously described in section 5 of this report (e.g. range and/or fast charging points, parking spaces, convenience factor etc.) is recommended in the modeling.

Recommendations regarding the modeling and support for policy regulations can be summarized as:

- The model could consider adjusting the weight of the different perceived and non-perceived aspects (costs) as it was shown that preferences and a traditional model of private mobility are less important than mobility habits and spatial niches, i.e. trip type for site-based policy measures.
- It would be extremely valuable for the modeling scheme to investigate how the sharing economy affects private car use and demand for public transport, i.e. competition of car sharing with private mobility on the one hand and car sharing and public transport on the other.
- The model could explore the possibility of implementing sharing mobility regulations at the national level and whether these solutions significantly influence energy demand. The model could attempt to replicate local government policies addressing the proliferation of shared economy in the transport sector to the possible extent and be used as a proxy for government intervention and in particular on urban

trips. The best practices could be drawn from the experience in European cities presented in this report and possibly further modeled and evaluated in connection to the future prognosis for the transport sector. Certain regulations could be introduced based on the models' outcomes to support shared transport development while also shifting the focus on sustainable objectives, like measures increasing the convenience of use, such as the use of bus lanes, special parking lots or their connection with other means of transport.

- The model could explore the possibilities of enabling car sharing options also in less urbanized areas with prioritization for convenience.
- The model could investigate the different role of car sharing and/or inter-connections with related policies at different regional levels (not only defined as rural and urban, but also characterized by the density of vehicles etc.) to capture thus far unexplored factors in the shared mobility sector.

Additional indications for the policy regarding:

- Ride sharing - develop the governmental role in relationship with ride-sharing companies.
- Carpooling - prepare regulations encouraging reducing congestion and demand for parking.
- Car sharing - prepare regulations encouraging reducing car ownership rates in cities

6. Digitalization

6.1 Importance of the Code of Conduct for Energy Efficiency Data centers

As the energy demand of Data centers (DCs) increases, there is a greater need of minimizing the DCs' environmental impact. On average up to 50% of the total energy consumption of DCs can be assigned to cooling (Oro et al., 2015]), which entails a Power Usage Effectiveness (PUE) of at least 2. The direct air free cooling is beneficial in any location reducing the energy consumption of the entire DC, between 5.4% and 7.9% (Depoorter et al., 2014). Free cooling technologies and Power Utilization Effectiveness in European DCs are summarized in Bertoldi et al. (2017). The power demand of DCs is linked to ambient conditions and their geographical location. The DC location significantly affects its energy demand primarily because of the integrated free cooling technology and its renewable energy supply potential. The energy mix of the electrical grid also affects indirect (upstream) CO_2 emissions, primary energy consumption and the energy cost.

The Case "Modeling of Code of Conduct for Energy Efficiency Data centers regarding the energy consumption for energy demand assessment" will focus on the location of the DCs in Europe. It will also look into the trends in relocating them. Additionally, the evolution and changes for the best method recommended in "The European Code of Conduct (CoC) for Energy Efficiency in Data centers over the years 2020-2022" is analyzed.

The case was chosen based on the direct connection between the FORECAST-Tertiary model and the necessity to investigate the reasons for locating DCs in the EU and outside the EU (with access for the EU operators and users). Furthermore, the operation aspects following the best practices recommended in the CoC for Energy Efficiency in DCs bringing improvement of energy efficiency and climate neutrality are in the spotlight.

Possible EU interventions regarding the energy efficiency in DCs was already described in D4.1 (Kochanski et al., 2021) and further qualified in D4.3 (Kochanski et al., 2022) as a policy instrument not formally considered in the model, but as a potentially influential factor. Accordingly, the mentioned soft instruments in the categories of Voluntary approaches and Public Voluntary Schemes were used as a case in this report.

The policy background was investigated in task T4.1 and it was recognized that assistance for policy making can be mainly developed regarding the Digitalization targets (**E**urope's Decade: digital targets for 2030**)** and the investment sector in new digital services. Furthermore, the parameters resulting from energy demand models that could be useful for the policy making process were indicated:

- Energy use by ICT equipment across the sector:
    - Energy use of the DC infrastructure such as cooling, ventilation, uninterruptible power supplies;

    - Energy efficiency measures to reduce the PUE of DCs (and as free cooling, separation of warm and cold aisle, adjusting set-points and other operational measures);
- Energy use and emissions related to ICT equipment production.

The case focuses on the EU MSs and the actual, planned and previous locations of the DCs and their connection to the infrastructure enabling the supply of energy, heat and data sharing. The outcome supports energy-demand modeling in recommending solutions favorable for energy efficient and climate neutral data centers. The scope is also narrowed down by the operation parameters included in the FORECAST-Tertiary. The case focuses on:

- internal and external drivers of locating DCs in Europe (described in section 6.2 of this chapter),
- policy gaps that are interesting for policymakers, stakeholders and citizens, namely aspects of digitalization targets and investment in new digital services.

The abovementioned topics are also considered in CoC, which was created for DCs' operators and owners and it responds to the increasing energy consumption in DCs. It addresses the urgency to reduce environmental, economic and energy supply security impacts. The CoC aims to achieve this by improving the understanding of energy demand within the DC, raising awareness, and recommending energy efficient best practices and targets. The European CoC for DCs was launched in 2008 and it remains a voluntary initiative, managed by the JRC, which sets ambitious voluntary standards for companies willing to participate. The CoC identifies and focuses on key issues and agreed solutions, described in the Best Practices document.

There are also other initiatives connected to the European Green Deal. For example, Self-Regulatory Initiative - Climate Neutral Data Center Pact, within which the DC operators and trade associations committed to the European Green Deal, to ensure climate neutrality of DCs by 2030 will take actions in areas of (Climate Neutral Data Center Pact):

- Energy Efficiency – both DCs and server rooms shall meet a high standard for energy efficiency, which will be demonstrated through aggressive PUE targets;
- Clean Energy – DCs will purchase clean energy;
- Water - DCs will meet a high standard for water conservation by the application of a location and source sensitive water usage effectiveness (WUE) target;
- Circular Economy – prioritization of the reuse, repair and recycling of servers and other electrical equipment;
- Governance – on 1st January 2021 the initiative was signed and the European Commission will meet twice a year to review the status of the initiative.

6.2 Summary of information regarding energy efficiency in DCs' location

6.2.1 Energy efficiency

According to the online survey presented by Jakob et al. (2021) performed in Switzerland, the key parameters for the electricity consumption assessment (understood as installed capacity, PUE, utilization) and energy efficiency measures (e.g. system temperatures, airflow, type of storage and back-up systems) are collected from three different segments:

- data center service providers,
- in-house data centers and server rooms in large companies, public companies and administrations (with estimated electricity consumption for 1.85 TWh in 2019)
- server rooms in small and medium-sized companies (SMEs; with estimated electricity consumption for server rooms of 2.37 TWh in 2019).

DCs have already accomplished some of their efficiency gains connected to lower energy use and IT efficiency improvements. Some of the advantages are linked to technology improvements, such as increased server efficiencies. Others are due to structural changes like shifting to hyperscale DCs (DCs exceeding 5000 servers and 10,000 square feet, operating with high efficiency). The trend to shift to a large scale is growing, in 2015 there were 260 hyperscale DCs in the world and 5 years later there were already 650 of them. Moreover, their operators in particular are leaders in corporate renewables procurement, particularly through power purchase agreements (Brocklehurst 2022; Masanet et al., 2020). Hyperscale DCs are not only big companies like Google, Amazon, Facebook, IBM, and Microsoft, but also public clouds and networks used by public administration.

19% of all global hyperscale DCs are located in Western Europe, the majority of DCs are located in deep-rooted FLAP (Frankfurt with 398 DCs, London with 702 DCs, Amsterdam with 363 DCs, and Paris with 204 DCs; Brocklehurst 2022; Statista 2022). Recently, Ireland (107 DCs in Dublin), Sweden (80 DCs in 2021), Norway (35 DCs in 2021), Finland (34 DCs in 2021), Denmark (37 DCs in 2021), and Iceland have taken their place in the market (Statista 2022). Currently, those countries are fiercely competing for customers by offering them preferential legal and authorization regimes, taxation, lower costs of land, operational incentives and political stability beneficial for the DC's establishment and operation (Kamiya and Kvarnström 2019; Brocklehurst 2022).

As all of FLAP are large urban and/or business and/or government centers, those could also be the enablers for DC facilities and the reason for the construction of DCs (Brocklehurst et al., 2022). However, the cost of land in FLAP will increase and combined with the consequences of Brexit these factors could be barriers to build more DCs in these parts of Europe.

The growing Dutch DC industry, especially in the Amsterdam area, was badly affected by its own success and international attractiveness. Amsterdam has connectivity options and a skilled workforce. Moreover, it is close to other key European markets and a business environment ready for foreign direct investments. However, it also had energy supply and environmental issues and the authorities decided to change it. As shown by the example of the moratorium from the Amsterdam and Haarlemmermeer municipality[8] announced on 12 July 2019, FLAP cities can make a sudden change in their approach. The new regulations want to bring sustainable growth to the sector. Therefore, new projects are expected to meet strict criteria in terms of efficiency and sustainability (like a PUE of 1.2 for new builds), they are allowed only in designated areas and (if possible) to use multiple floors. What might have been a crushing experience for the Dutch DC industry, became a new opportunity to be a leader in the market. This time in terms of DCs' sustainability and meeting the new regulations and targets set by the European Green Deal and the Climate Neutral Data Center Pact. More governments including Frankfurt, Ireland. Singapore and even some regions in China have been forced to follow similar path (Data centers dynamics 2021). In the meantime, the Netherlands remain the attractive location for DCs also owing to the efficient design and operation leading to a PUE between 1.15-1.3 (Brocklehurst 2022).

6.2.2 Code of conduct

"The European Code of Conduct for Energy Efficiency in Data centers" recognized the importance of location for DCs in the best practices published in the years 2020-2022 for DC Building in two areas: "Physical Layout" and "Geographic Location". All criteria within the sections have remained the same over the years (Acton et al., 2022).

The physical layout of the building can present fundamental constraints on the applicable technologies and achievable efficiencies in sections like security, location and maintenance (Table in section 8.1 Building Physical Layout). However, the importance to locate the DC where residual heat can be reused was reassessed this year. The assigned value in the range from 1 to 5 (maximum) corresponds to the level of benefit to be expected from a listed action and the relative priorities that should be applied to them. The Value of Practices raised from 2 to 3 in 2022. Even though, all the practices regarding the Building Geographic Location (section 8.2 in CoC) are still optional for participants of CoC (Acton et al., 2022).

As stated in CoC's section "8.2 Building Geographic Location", some operators may have no choice regarding the geographic location for a DC, nevertheless it impacts achievable efficiency, primarily through the impact of external climate. The practices listed in the document in this area are reasonable and rather general. The document advice to (Acton et al., 2022):

[8] https://www.datacenterdynamics.com/en/news/amsterdam-pauses-data-center-building/

- locate the DC where residual heat can be reused (in CoC each recommended practice has the assigned qualitative value (1-5) to show the benefit expected from an action; the value of this practices lately was increased (2 in 2020 and 2021, 3 in 2022));
- locate the DC in an area of low ambient temperature;
- avoid locating the DC in high ambient humidity areas;
- locate near a source of free cooling;
- co-locate with a power source.

The CoC also sees the 'Cooling of the Data Center' as an area for improvement, as the cooling is often connected to the largest energy loss in the facility. It includes (Acton et al., 2022):

- Air flow management and design to circulate only the necessary volume of air via DC required to remove the heat actually created by the IT equipment;
- Cooling management to adjust the cooling systems following changes in the facility thermal load or external ambient conditions;
- Temperature and humidity settings to achieve increase in chilled water temperature set points delivering enhanced efficiency for free cooling and a lower compressor energy consumption;
- Cooling plant (free cooling/ economized cooling and high efficiency cooling plant) representing the majority of energy used in the cooling system;
- Computer air conditioners/air handlers is another energy-consuming element, which unfortunately was often badly designed and optimized in older facilities;
- Direct liquid cooling, which in some situations like extremely high power density deployments, can have advantages over air cooling;
- Reuse of DC waste heat having high potential in providing cheap energy.

What is important, the CoC advocates to use trending rather than hard targets for PUE, which can be proposed in the Climate Neutral Data Center Pact or the Sustainable Digital Infrastructure Alliance (SDIA). The foundation for the variable recommended in CoC would be kWh consumption and a consistent IT Load (Acton et al., 2022). PUE is not an optimal measure for comparing energy efficiency among DCs as it does not show the overall energy, productivity or resource efficiency of a DC. DCs with the same equipment and IT and infrastructure design still use various amount of energy depending on the applications that they are running resulting in different PUEs (Brocklehurst 2022). CoC best practices implementation is oriented more towards reducing overall carbon footprint and sustainability improvement instead of direct energy efficiency advancement. However, the document recommends including the energy efficiency performance of the IT device in DCs as a high priority decision factor in the tender process. Also, IT equipment utilization is important in optimizing the DC energy efficiency (Acton et al., 2022).

The very comprehensive international review of energy efficiency in DCs for IEA EBC Building Energy Codes Working Group both for European and non-European DCs was published in 2022 (Brocklehurst 2022). Detailed information on DCs location and the factors influencing the choice of location are in Appendix 7.

Data on current locations and factors affecting choice of location in the Brocklehurst's report (2022). Below is a short overview of the mentioned factors based on the information presented by Dutch Data Center Association in 2020 included in the Brocklehurst's (2022) report.

Table 1 Factors affecting choice of location (based on Brocklehurst 2022)

Area	Factor
Geographic conditions	Temperature Natural disaster risk Transportation and access Social, economic and political stability Proximity to HQ/business locations
Energy sources characteristics	Quality of energy supply Electricity costs Access to and share of renewables
Presence of major markets, customers	Population within 500 km Population within 1000 km
Telecommunication infrastructure	Submarine cables Broadband internet subscriptions (per 100 inhabitants) Internet network
Additional costs	Construction price Property tax rates
DC redundancy	Overabundance of DCs
Other factors	Labor costs and availability Quality of life Tax and regulatory climate

6.3 Overview of current DC's location modeling

Currently, the location is not in the focus of modeling regarding the energy efficiency in DCs, although some aspects regarding the ambient temperature and the geographical location were considered in the literature. For example, Berezovskaya et al. (2020) consider location of the area where temperature is calculated in their tool for Improving DC's Energy Efficiency.

Ounifi et al. (2018) used cases of Consortium Laval-UQAM-McGill and Eastern Quebec (CLUMEQ) data centers to introduce the DC meta model (DCMM) covering the DCs heterogeneous structure, main characteristics and diverse constraints including location considering input power (and others like various IT and non-IT sub-systems dependencies and relations, environmental e.g., humidity and temperature, and system function as well as availability, security, and efficiency). The authors also suggested the method to generate a Power Flow Model (PFM) from an input DC model used to compute the PUE.

There is also a dedicated methodology for selecting the DCs' sustainable location in Iran created by Kheybari et al. (2020) with criteria (that could be adapted for Europe):

- Economic
  - Operational costs,
  - Investment costs
    - Local incentives,
    - Network communications connection costs,
    - Electric grid connection cost,
    - Land acquisition and construction,
    - Synchronization costs;
- Environmental
  - Local pollution,
  - Interference with protected areas,
  - Energy saving
    - RES (solar and wind),
    - Areas where waste heat data center can be reused,
    - Potential for free cooling;
- Social
  - Information security,
  - Life quality
    - Life security,
    - Availability of public transportation and accessibilities;
  - Political risk
    - Change in the general policies and laws of the country,
    - The existence of restrictive laws,
    - Government failure to comply with obligation;
- Economic risk
  - Earthquake (for Europe it could be included in risk of natural disasters),
  - Electromagnetic radiation,
  - Other natural disasters (storms, floods and landslides, which can become more common in Europe due to climate changes).

For Nordic countries Christensen et al. (2018) listed eight factors that are important for site selection:

- Reliable power supply,
- International data connectivity,
- Low energy prices,
- Political stability,
- Time-to-market,
- Abundance of energy and other resources,
- Competent workforce,
- Natural disaster-free climate.

Only one model, which considers the DCs' location, was found during the literature review. Depoorter et al. (2014) built a dynamic energy model integrating a free cooling strategy and the development of photovoltaic energy to develop a holistic approach. The model considers the differences among regions including the electricity attributes from the grid and assesses these differences using energy indicators and the behavior of a DCs in various European locations. This study shows that DC's geographical location can significantly affect its operation and environmental impact. The authors also considered the environmental aspects connected to the energy, the grid characteristics and linked emission factors. As an example, they showed how electricity consumed by a DC in Stockholm (Sweden; 133 tCO2; electricity mainly from hydro and nuclear energy) would be 11 times greener than the same DC operated in London (UK; 4188 tCO2; electricity from coal). Sweden also offers lower electricity prices for industrial consumers. To give an example a DC located in Stockholm that is operated in the same manner as a DC in Frankfurt, could reduce their energy bill by 42.5% (Depoorter et al. 2014). Based on these results the authors suggest that future DCs could consider site selection as a new strategy to limit the environmental impact attributable to this sector.

The aim of the study of Depoorter et al. (2014) was to limit the environmental impact of DCs. An energy model of a reference DC was developed in TRNSYS, in which potential DCs in different European locations with direct air free cooling strategy and integrated PV system integration were investigated. It is important to place the right reference case for the DC due to the fact that the vapor compression system is used as the cooling system, the overall energy consumption is not affected by the location. It can also be overcome, by using a variable to describe the heat rejection temperature instead of fixed value. Still, there were significant differences between regions connected with the electricity attributes from the grid.

In TRNSYS, the Economizer scenario includes water consumption costs. This resource should be considered as it is used by some cooling systems and high consumption could have an impact on local resources and utilities. Cold air is very dry and needs additional moisture to achieve the minimum inlet humidity. Nevertheless, cold Northern Europe can still be a good location for DCs, as Nordic countries are abundant in water while warmer Mediterranean areas are not (Depoorter et al. 2014).

Petrovic et al. (2020) investigated the DCs' role in the future Danish energy system and found that the geographical location has an influence on their character, mainly regarding the exploitation of excess heat (EH) for district heating (DH). Denmark is a relatively good location for DCs, as it has a cold climate, developed DH grids and a large share of renewables in their energy mix. Locating DCs within DH areas is optimal for the energy system as it can minimize the costs of EH utilization for DH and the infrastructure, such as the transformers already being placed in the area plus the energy prices are lower. Even though, the DCs can value other locations more (due to other factors presented in the table in section 6.2 of this chapter). Denmark also facilitates investments in DCs by the gradual abolition of the Public Service Obligation tax on electricity consumption to encourage investments. On the other hand, it can be a burden for the Danish energy system and influence transition towards carbon neutrality (Petrovic et al., 2020).

The geographical distribution of the participation of DCs in the EU CoC together with Geographical zoning with average temperature and relative humidity are presented in Bertoldi et al. (2017). As there are several supercomputing centers across Europe to ease high-performance computing, their distribution is coordinated by European initiatives like HPC Europa and EuroHPC JU[9]. They collaborate with the Distributed European Infrastructure for Supercomputing Applications[10] (DEISA) and within the CORDIS[11] framework. HPC Europa wants to provide access to supercomputers across Europe and it brings together Austria, Belgium, Bulgaria, Croatia, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, Netherlands, Norway, Poland, Russia, Slovenia, Spain, Sweden, Switzerland, and the UK.

6.4 Recommendations for the modeling of DC's location

The scope of the case was focused on the location of the DCs in Europe and trends in relocating them as well as mapping plans for EuroHPC projects and supercomputers in Europe regarding demand and communication with DCs in MSs, and the factors influencing DC's location in the EU that can serve as an input to the FORECAST-Tertiary, and policy gaps mentioned in section 6.1. of this chapter. However, there is also the aspect of energy consumption linked to the DCs and their emissions depending on their location. Which can be important not only for modeling in the digitalization area, but also prosumagers, circular economy and shared economy, as for example DCs can enable other sectors including industry and transport. The literature review for this case resulted in one model by Depoorter et al. (2014) that could be of interest for future improvements of DCs' location modeling. The conclusions can be summarized as:

- Most valid and up to date information on DCs locations and factors influencing them has been summed up and released in the review by Brocklehurst (2022). This data can be a valid input for the FORECAST-Tertiary modeling of the DC's location aspects.
- Locations of planned EuroHPC supercomputers should be included in the future modeling and energy demand scenarios.

Furthermore, recommendations regarding the modeling and policy regulations can be condensed to:

- need for improved capacity to represent trends, as DCs are continously developed and upgrade with larger yet more efficient machine and systems;
- DCs geographical location was somehow neglected in modeling regarding the energy efficiency in DCs, as shown in sections 6.2 and 6.3 in this chapter. Still, it should be evaluate under which circumstances it makes sense to include this aspect in the energy-demand modeling.

[9] https://eurohpc-ju.europa.eu/index_en

[10] https://en.wikipedia.org/wiki/Distributed_European_Infrastructure_for_Supercomputing_Applications

[11] https://en.wikipedia.org/wiki/CORDIS

- Considering using the reference DC to enable objective comparison for various EU locations and cooling technologies in the model as with some types of cooling systems the overall energy consumption will not be affected by the location or make sure to include the heat rejection temperature as the variable.
- Exploitation of EH for DH in a particular location should be considered as an effective way for energy savings.
- Account for expected climatic changes in temperature and humidity and other extremes associated with rising global temperatures in defining new DC location. It would be advised to incorporate the rising climate risk in planning and locating DCs.
- Although water resources and air humidity are not directly connected with the energy use in DC, they can change the cost of cooling system operation in a particular location. It is advised to consider this factor in the DC’s location. It can be also developed using the WUE from Climate Neutral Data Center Pact.
- There are not many models concerning the geographical location of DCs, therefore it would be advised to conduct a meta-analysis of the previous studies and include this parameter to see to what extent it can help lower energy demand.

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