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Citizen Participation and Knowledge Support in Urban Public Energy Transition—A Quadruple Helix Perspective

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Abstract: Climate change, energy transition needs and the current energy crisis have prompted cities to implement far-reaching changes in public energy supply. The present paper seeks to map out the conditions for sustainable energy provision and use, with a particular view to the role of citizens in a quadruple helix context. Citizen participation is often seen as a sine qua non for a successful local or district energy policy in an urban area but needs due scientific and digital support based on evidence-based knowledge (using proper user-oriented techniques such as Q-analysis). The paper sets out to explore the citizen engagement and knowledge base for drastic energy transitions in the city based on the newly developed "diabolo" model, in which in particular digital tools (e.g., dashboards, digital twins) are proposed as useful tools for the interface between citizens and municipal policy. The approach adopted in this paper is empirically illustrated for local energy policy in the city of Rotterdam.

Keywords: urban energy transition; citizen participation; knowledge filters; quadruple helix; Q-analysis; diabolo model; digital tools

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1. Introduction

Emerging and pressing societal issues, for instance, social and civic security, quality of life and liveability, or energy poverty and sustainable resource use are not the exclusive concern of policy circles or the academic community, but also belong to the competence of civic society ranging from the "man in the street" to professionals. The involvement and voluntary engagement of citizens concern in particular the identification of social—often local—well-being and quality-of-life problems and commonly accepted ways out.

The search for solution trajectories in complex societal problems has led to a rising popularity of the quadruple helix concept, in which the mix of scientific knowledge, policy competence, industrial stakeholders' interests and citizens' engagement may provide a balanced actionable arena for enhancing societal wellbeing in a broad sustainability context (see, e.g., [1–10]). This awareness has also prompted the rise of a new methodological perspective on handling complex and multifaceted problems in a democratic society, coined citizen science ([11–19]). This is a cocreational and co-productive mode of organising and implementing a community project or scientific activity (e.g., a local energy initiative) in which the research community, stakeholders and citizens share insights and expertise on pressing actual issues (see, e.g., [20–22]). Not only can an involvement of local stakeholders lead to a better identification of real problems, but it may also lead to more support for necessary policy actions [23]. The engagement of large groups of citizens at low cost has been tremendously facilitated by modern digital internet opportunities [24], e.g., through apps, citizen portals, and social media channels (see Figure 1). This allows also an appropriate combination of quantitative data and qualitative information, while the transfer of scientific findings to a broad civic constituency is clearly encouraged by open access information.

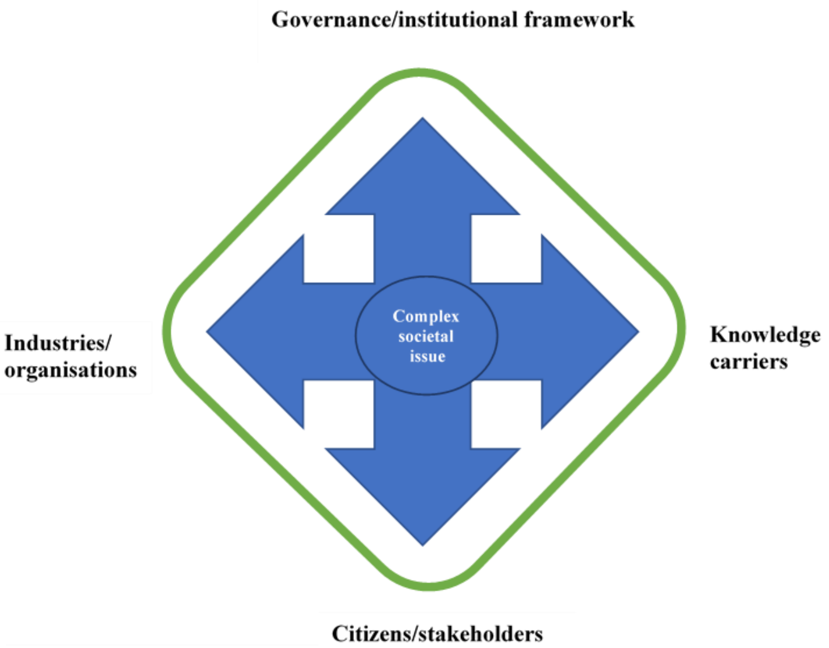

Figure 1. A quadruple helix.

A field that nowadays enjoys growing scientific and public interest is climate change. Notwithstanding the fact that climate change is recognised by most people as a pressing environmental issue, with great threats for a sustainable future and socioeconomic wellbeing [25], there is still fundamental uncertainty about many aspects of climate change [26], which has an impact on citizens' responses to this challenge as well as on the research roadmaps to be followed. It is noteworthy that climate change prompts immediately more interest, if local events (e.g., floods, storms) are involved. Even though climate may be seen as a global public good, the responsiveness of citizens is much higher if climate change manifests itself in a tangible manner at local or regional scale. An interesting overview of local climate dimensions (e.g., climate adaptation) that frame subnational sustainability initiatives can be found in [27].

In recent years we have witnessed rapidly rising interest in local climate adjustment initiatives from the perspective of a carbon-free or decarbonised economy. Nowadays, many cities all over the world are considering and developing new energy transition strategies and measures to cope with global climate change at local or regional scale, an effort that has been intensified by the energy crisis as a result of the war in Ukraine. In a recent study by [28], the authors used a cocreation process—through the use of a Delphi study—to identify and articulate the urban stakeholders' climate change awareness. Various participation and communication tools were employed in this study, such as: development of norms and sustainable procurements, sensitisation actions, corporate responsibility actions, adoption of new value systems, development of new technologies, information campaigns, communication workshops, etc. The authors conclude that in a pluriform urban society a specific target group approach is to be preferred. In another recent study, authors of [29] sought to sketch out new renewable energy business models for supporting a prosumers' integration by identifying enablers and barriers in a consumer-centric framework. Regulatory obstacles in the public energy domain are often seen as a major impediment to energy transition initiatives.

It is increasingly recognised that the energy sector will gradually have to make a change from a traditional centralised energy supply model to a distributed energy system, such as peer-to-peer sharing for locally or regionally connected user groups (see [30]). The operation of energy systems seems to move to a decentralised energy supply system, with a great variety of stakeholders involved. This rising complexity—from an often centralised public energy space to a spatially distributed energy space—prompts two important conceptual challenges: (i) the shift in the energy supply as a centralised public competence to a locally distributed public energy system; (ii) the greater involvement of citizens in the organisation of the local supply of energy resources (the citizen as a "prosumer"; see, e.g., [31]). The management of the increasingly complex organisation of a decarbonised local economy prompts various questions on the range and competence of the public domain at the local level of sustainable energy provision as well as on the active role of citizens in meeting the sustainability demands in the era of energy transition, in particular through the use of digital technology (e.g., smart meters, individualised sensors, energy dashboards, interactive digital twins). In the light of the above observations on trends and challenges in the recent spatially differentiated local energy market, the present paper seeks to offer a stakeholder-based and citizen-oriented approach to multi-actor local energy transition issues, by identifying the state-of-art of scientific knowledge on such issues and by articulating the insights and preferences of local experts/stakeholders—as a representative communication platform (or citizen engagement)—on the same energy transition issues.

Our study uses the energy transition challenges in the city of Rotterdam as a frame of reference. This city has an ambitious sustainability policy programme also comprising energy and climate goals, which have to be supported by digital support tools. It is worth noting that Rotterdam is aspiring to become one of the leading cities in Europe in setting up an advanced digital twin infrastructure.

The study is organised as follows. After this introductory section, we provide the knowledge frame needed in the context of local energy transition policy in Section 2. This is followed by an overview in Section 3 of the scientific state-of-the art on local energy transition as documented in many energy studies on Rotterdam. Next, Section 4 describes the way in which (directly and indirectly) citizens' communication and engagement can be organized. Next, Section 5 describes the quadruple helix approach using a cascade framework, leading to a new public participation tool, viz. a "diabolo" framework through the use of intermediate "shadow" support groups. Section 6 provides empirical results in the actual context of our energy case study, viz. the Prinsenland/Het Lage Land district in Rotterdam, which is based on Q-analysis. Section 7 provides some conclusions and lessons.

2. Setting the Scene

In the "urban century" (as advocated by the UN), cities and urban agglomerations play a pivotal role in steering economic and technological development of regions and countries (the "New Urban World"; [32]). Cities are usually seedbeds of negative externalities (e.g., mass pollution, heat islands), but may also act as innovative actors in coping with such externalities. The current popularity of "smart cities" symbolises the positive role of technologically advanced cities in paving new roads for sustainable urban futures. This is clearly witnessed in contemporaneous energy transformation initiatives, which mostly find their origin in urban areas. Clearly, any urban system is extremely complex and any intervention in the energy system has an effect on the citizens' interest, in terms of energy certainty, energy pricing or indoor heating systems and so forth, with often significant financial implications.

The complex force field of local energy transition calls for a data-rich policy environment, as is illustrated in Figure 2. It is clear form this figure that a modern urban energy policy operating at the edge of urban public competences and individual households' interests can only effectively be implemented in case of reliable and up-to-date energy information [33]. Examples of such basic decentralised energy data needs are the presence of solar panels, the degree of energy isolation of individual dwellings (e.g., double-glazed windows), the efficiency of central heating installations, and so on. Additionally, therefore, a detailed energy map of the city concerned is needed, in which, preferably at the level of individual buildings (houses, shops, amenities, etc.) or neighbourhoods, a range of relevant energy data is available. The main challenge is then to construct a data warehouse that provides a systematic architecture of all relevant data in the urban energy domain (see for an illustration Figure 3). This figure depicts the contours and elements of a comprehensive data warehouse that is geared towards an actionable (local) energy policy. Figure 3 contains the cornerstones of digital twin energy that forms the information framing of interactive citizen participation at local, neighbourhood and individual levels in the city of Rotterdam.

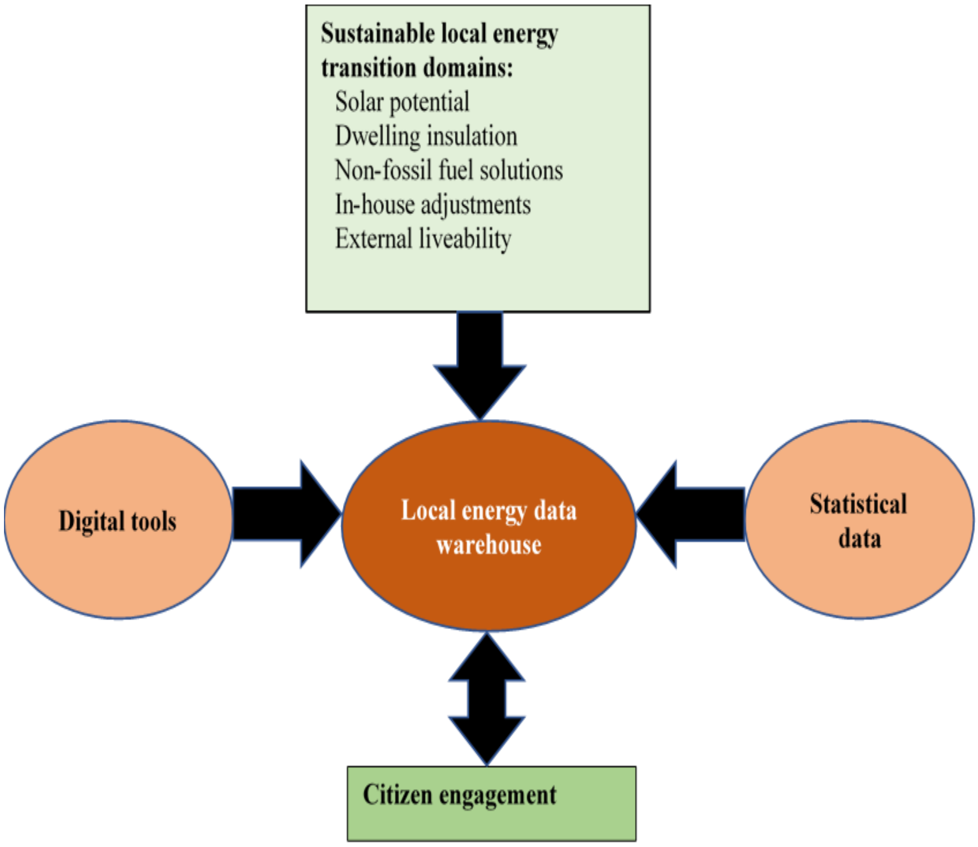

Figure 2. Data support framework for local energy transition.

The systematic collection and representation of individualised or localised energy data can next be visualised by means of GIS methods in a dedicated 3D urban energy image, called digital twin (see, e.g., [34–41]). Thus, a digital twin is a GIS-inspired 3D visualisation of the built environment (including infrastructure) of a given city and its material constituents or objects, with the aim to show patterns, interactions and future options in a complex urban space. It should be noted that the current challenges imposed by energy transition policies in cities are very suitable for 3D-mapping in urban territory. Clearly, a digital twin is not crafted in stone; it is an interactive dynamic tool that can be used for, e.g., urban sustainability scenarios, vulnerability and resilience analysis, and challenges to energy supply (ranging from a micro to a macro scale).

The user-friendliness of visualisation tools such as digital twins also makes these tools suitable for democratic consultation experiments in the context of citizen participation, including preference elicitation of desirable future choice options in the urban energy domain. Such information is not only useful in a situation of stable energy supply. The recent energy crisis caused by the war in Ukraine has led to sharp energy price increases, with the consequence that citizens tend to become sensitive to any public energy intervention, especially in case of uncertain outcomes. Therefore, full-scale, objective and transparent information on implications of public interventions in the urban energy sector is a sine qua non for any effective energy policy nowadays. Ideally, this might take the form of a citizen-oriented energy cost–benefit analysis, which would provide all necessary information on the financial and technical implications (costs and benefits) of any change (or a portfolio of changes) in the supply of energy to individual dwellings or buildings. In this context, the use of digital twins as a visual communication tool may be very helpful, not only to policymakers but also to the citizen. Clearly, quantitative data on energy efficiency alternatives (at individual, street or district level) may also provide evidence-based information for effective and adaptive urban energy planning (e.g., in the form of KPIs systematically included in an urban energy dashboard).

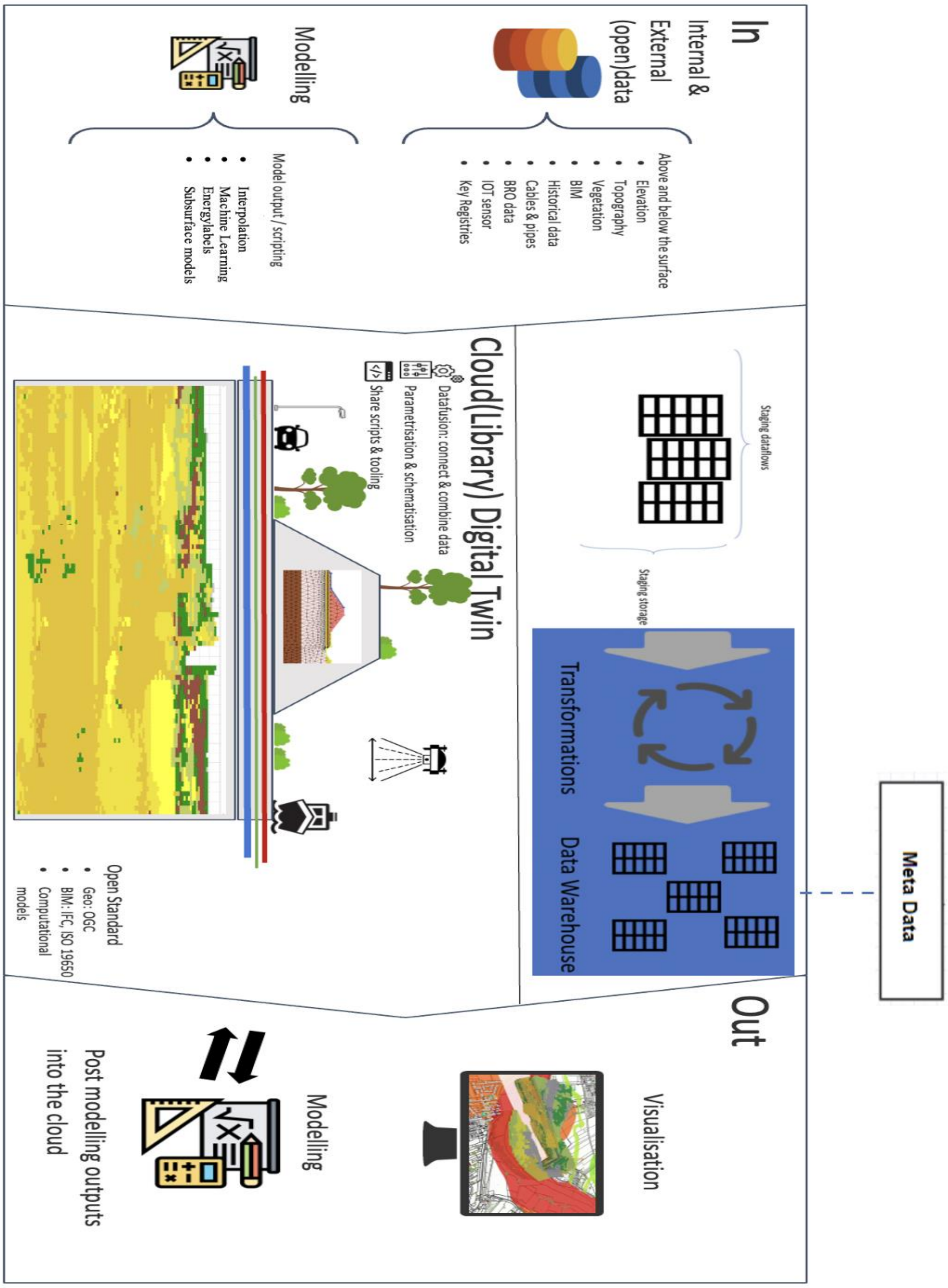

Figure 3. Sketch of an urban data warehouse. Source: authors' own production.

An important remark is in order here. The city shows great heterogeneity among its inhabitants, e.g., in terms of income, wealth, family size, age, cultural background etc.; "the citizen" does not exist. And therefore, a target group approach related, e.g., to income groups or cultural groups seems to be appropriate. However, in all cases the question arises, how do we combine heterogeneous opinions into a common citizen "platform" or "forum".

In this context, the use of multiple criteria decision-making tools (MCA) is rather promising and common (see, e.g., [42]). In our case, the use of the so-called MAMCA model—which is able to handle large groups of citizens characterised by a high degree of heterogeneity (see, e.g., [43,44])—seems to be a very promising approach.

The abovementioned observations can be mapped out in a systematic summary visualisation presented in Figure 4, which forms the backbone of the present study. This scheme provides the methodological logic of our approach to local sustainable energy transition and forms the backbone of our stepwise cascade approach in our study focussing on the city of Rotterdam.

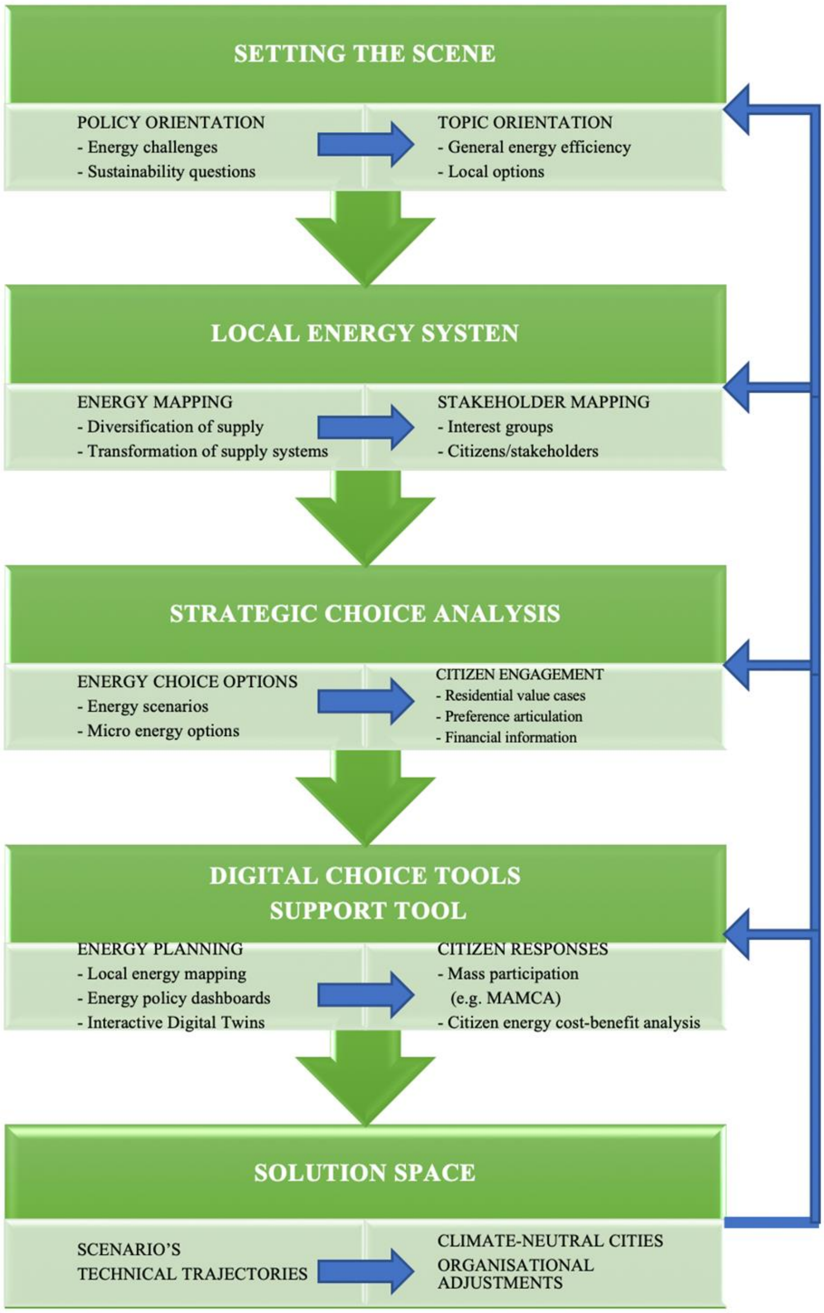

Figure 4. The energy transition framework.

3. Mapping Energy Knowledge on Rotterdam

The city of Rotterdam has taken the decision to play a prominent role in contemporaneous energy transitions from the perspective of an urban sustainability programme (see, e.g., [45]), to be supported by advanced digital tools, in particular interactive digital twins and related advanced digital tools such as user-oriented energy dashboards. It goes without saying that such an ambitious policy presupposes a wealth of knowledge on the energy situation in the city, such as: property conditions of houses, synchronisation of urban energy savings projects, presence and sharing of solar panels revenues, combination of energy restructuring projects with general real estate maintenance, multifunctional use of roofs of houses and buildings, energy return delivery conditions to the public energy network, development of citizen-inspired micro- and meso-energy scenarios, experimentation with bonus systems (e.g., vouchers, nudges) for energy-conscious citizens, development of citizen-inspired KPIs for decentralised energy efficiency actions, design of quantitative participation tools in a multicultural urban society and so forth. To some extent, the city of Rotterdam may be seen as a modern "living lab" for energy transition, with the aim to learn from various experiments with this experimental showcase.

To pave the road towards a successful energy strategy, several scientific studies—often in cooperation with digital and energy experts of the city—have been carried out. Such studies were, in the past years, often undertaken in cooperation with students and researchers from the Erasmus University in Rotterdam. These studies covered a wide range of energy topics, such as governance of climate-neutral cities, energy for liveable urban districts, relevance of the Paris Agreement for Rotterdam, urban cocreation initiatives, digital citizen engagement, etc. Some of these studies were not exclusively focused on Rotterdam but also covered other regions or cities. After a long digital search process a total of 21 documented studies could be identified that had a relevance for the topic of digital support tools for sustainable energy in Rotterdam (see list of internet sources in the Appendix A).

Several studies considered in our overview have paid explicit attention to the governance of smart and sustainable energy cities, with a focus on Rotterdam. The general findings from these studies—based on a general meta-overview— largely came to similar conclusions: the city of Rotterdam has not yet developed a systematic, consistent, evidence-based and testable digital strategy as a support tool for sustainable energy policy. The implementation of digital energy measures is clearly the Achilles heel of urban energy policy. Furthermore, cocreation and citizen participation initiatives appear to be very popular in administrative documents, but there is still a wide gap to the harsh reality in which citizens are at a considerable distance from energy and climate policy in the city. An important lesson from citizen engagement initiatives is that clear feedback on conclusions or decisions from sustainable energy proposals to the citizen is a sine qua non. In general, consistency in policy, transparency in choices and interaction with citizens/stakeholders are seen as a major critical success conditions.

Despite the heterogeneity in these studies, there are—as shown above—also quite a few generic findings: openness to the local community by the city administration, accessibility of public officials involved with the execution of energy policy in the city and focus on "down-to-earth" information and concrete actions were highly recommended. To map out the commonalities between the great variety of the 21 Rotterdam studies under consideration, we carried out a content cloud analysis. A content cloud is a visual representation of the most striking similarities in keywords used in a set of heterogeneous studies or documents. The content word cloud based on the above mentioned 21 Rotterdam studies is presented in Figure 5 (using word clouds in Python).

Figure 5 is based on background studies on Rotterdam energy issues written in the Dutch language. This content cloud is difficult to translate into English. Therefore, we provide only a few interesting concepts that are prominent in this cloud. Keywords that often show up in all these Rotterdam studies are (in English): district, neighbourhood, participation trajectories, community, people, working groups, talking, residents' meetings, co-design, engagement, etc. The concepts with the highest frequency in these studies are clearly related to "people" and "trust". These findings highlight once more that a resident-based local energy transition is highly desirable, while a transparent government policy is also a necessity.

Figure 5. A content cloud of key words in 21 Rotterdam energy studies.

4. Citizen Participation in Urban Energy Transition

In recent years, we have witnessed a gradual shift from the concept of "government"—often seen as an omnipotent decision-making body—to "governance", where leadership competence in complex multi-agent organisations is critical. Stakeholder interaction under uncertain external conditions (e.g., an energy crisis) has become an important strategic pathway (see, e.g., [46]). This holds true for multi-scalar energy transformation initiatives and actionable approaches in the urban domain in particular. There is apparently no fixed action arena; problems and preferences, for instance, in relation to climate issues, often change as a result of external shocks or contextual changes (e.g., the war in Ukraine). This is often referred to as context-specific governance in the management literature [47]. It is clear that citizen participation is often confronted with unforeseen contextual shifts in external conditions [48]. This means that citizen engagement is also subjected to unanticipated disruptions in the policy arena, so that traditional views on citizen participation need to be amended. Here, we present a standard approach developed by [49] as an example (see Table 1).

Table 1. Citizen participation goals and methods.

Participation Goal	Participation Description	Participation Method
Informing	The local government informs the citizens of decisions and policies. Citizens do not provide input.	Information evening, debate, campaign.
Consulting	Politics decide the policy direction. Citizens take part in conversations about policy.	Citizen panel, survey, focus group.
Advising	Politics let the citizen formulate problems and solutions. The ideas of citizens have a full role in policymaking.	Citizen jury, advisory board, neighbourhood platform.
Co-producing	Politics and citizens together discuss problems and solutions.	Consultation group, project group, work atelier.
Co-deciding	Citizens decide about policymaking. Politics take over the results with specific adaptations.	Binding referendum

Source: [49] (p. 242).

This table follows conventional linear logic, from participation goals via participation description to participation methods, and this shapes and maps out the form of the dialogue with citizens and stakeholders. However, advanced interactive consultation procedures induced and supported inter alia by digital technology are left out of consideration, while they may play a pivotal role in modern urban planning, including energy planning. Modern citizen science approaches in an e-society are based on a more direct and cocreational role of citizens (see, e.g., [1,50,51]).

The city in the "New Urban World" [32] is definitely also the arena of energy dynamics and social tensions on sustainability initiatives. All citizens are dependent for their needs on energy, most of the time in various forms. Energy is often delivered to citizens through public energy networks, but decentralised—sometimes private—forms of energy production (e.g., solar panels) are also increasingly coming to the fore. A forced government intervention by public agencies in energy supply systems—with deep consequences for in-house energy systems and use—is normally not highly appreciated by inhabitants. Consequently, the notion of citizen participation/engagement in energy transition has in the recent past gained much popularity and support. There is indeed a wealth of literature on citizen participation (see, e.g., [49,52]). The most prominent advantages of citizen participation are generally thought to be:

- Citizen involvement in local changes in energy supply conditions is in agreement with democratic principles at local level.
- More citizen involvement may lead to more support for drastic interventions.
- Citizens are a rich source of information, so that listening to directly involved inhabitants may avoid mistakes in the preparation and implementation of energy plans.
- Creation of an "acceptance" attitude among citizens may avoid long-lasting juridical appeal procedures, and hence increase an effective implementation of new energy plans.

The digital revolution has indeed meant a radical change in the operation of public decisionmakers. The way public services are nowadays provided or decided upon in a smart city (e.g., procurement procedures) is completely different from a few decades ago. The various challenges involved with the territorial and urban aspects of the digital technology transition of public services has been extensively described in a [53] study. One of the strategic policy recommendations in the ESPON study is the following: "Support the digital transition of towns and smaller cities. Findings indicate that larger cities are leading the way in the digital transition. Policy action is needed to ensure that public service provision in towns and smaller cities is not left behind. Services that require critical mass to be developed and/or maintained can be provided at national or regional level, depending on relevant competencies, capacities and demands. Support should be provided for capacity building through networking and collaborations to facilitate the uptake of digital solutions by local authorities." (p. 16).

Local capacity-building based on intermediate support systems is one of the promising policy constellations in the case of professional and well-organised citizen engagement, in which ICT can play a critical role. The field of energy transition—with a broad array of new energy initiatives—is increasingly shaped by digital advances (e.g., smart meters, distance sensors), while in the supply sector of energy, producer and distributor digital tools such as blockchain systems and artificial intelligence are increasingly coming to the fore. The energy supply system is gradually moving towards an industry 4.0 (see, e.g., [54–57]. We may thus conclude that ideally the functionality of modern digital systems would allow for a significant upgrading of the urban energy system. However, we also note that the full-scale exploitation of digital services in the energy sector is hampered by two bottlenecks, viz. the lack of familiarity with digital technology on the side of citizens and the general lack of trust in government measures that are seen as an intrusion on someone's private domain. This means that ultimately citizen participation has to find its origin in a scientific underpinning of the issues at hand in order to be useful for rational and consistent urban energy planning initiatives. This will be further highlighted in Section 5.

5. A Quadruple Helix Framework for Energy Transition Policy

The Rotterdam energy case is a good illustration of the governance complexity of energy transition at an urban scale. Public administration is responsible for shaping the overall contours of new urban energy policy, while at micro- and meso-urban level it needs sufficient support of actors involved (citizens, business). A significant part of the energy system (e.g., energy suppliers) is also the competence of private actors in energy production and distribution, while evidence-based knowledge and scientific analysis regarding sustainable energy supply and use (e.g., using advanced digital tools) is also a necessary condition for a successful local energy policy. Consequently, a quadruple helix constellation—incorporating all relevant energy actors—offers a logically organised and scientifically oriented framework for a better governance of multi-actor urban energy issues in a transition phase.

The stepwise structure of our analysis of quadruple helix activities can be represented by a cascade approach (see Figure 6).

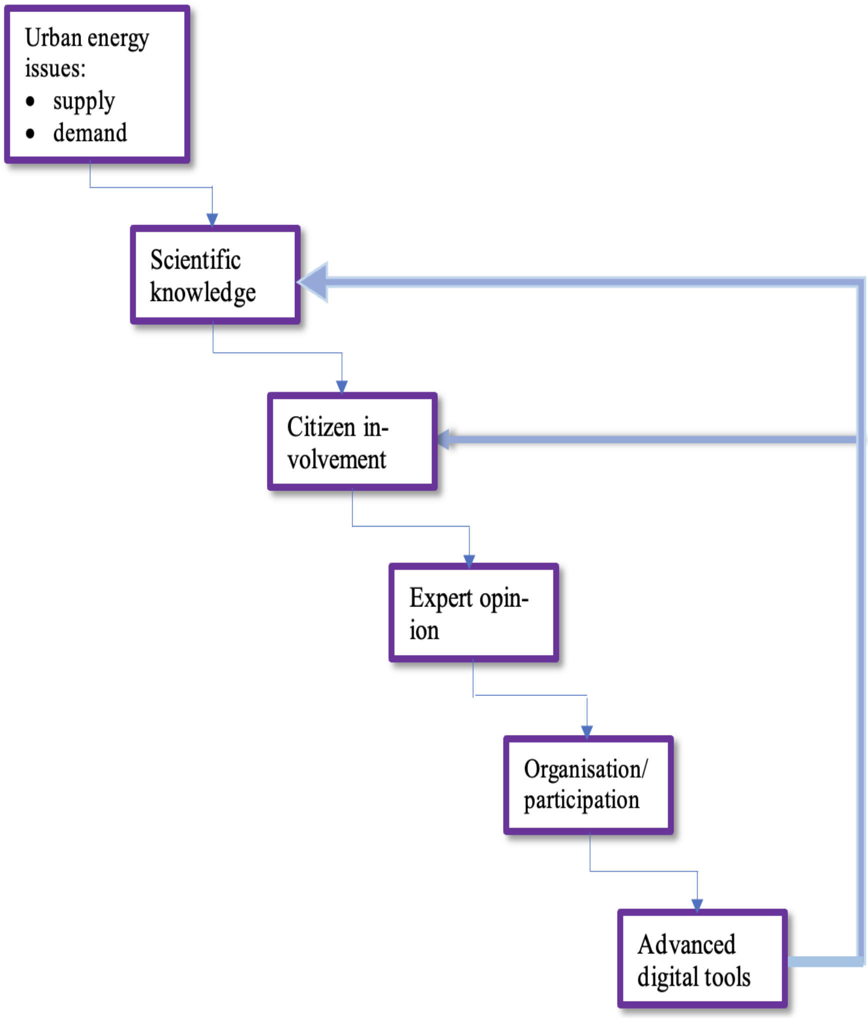

Figure 6. Participatory digital energy transition support systems.

The cascade system mapped out in Figure 6 will—after the previous general description of the first three steps, viz. urban energy transition (Section 2), scientific knowledge (Section 3) and citizen participation (Section 4)—now be further operationalised by addressing expert opinions on urban energy transition. In the cascade system of Figure 6, citizen participation is included as a pivotal element in local energy transition. However, as mentioned above, the involvement of all residents—or even the engagement of a representative group of citizens—is an almost impossible task and has failed in most democratic consultation rounds, due to inappropriate participation methods, lack of interest, lack of trust in public bodies or a lack of digital knowledge. Numerous attempts have been made on many occasions, but without any great success. The interface between local government bodies and citizens clearly needs an intermediate link (a filter or a "broker") that can communicate with both sides of the spectrum (citizens versus governmental bodies). This has led to the current popularity of intermediate agents in the form of energy coaches, sustainability ambassadors, liveability experts and the like, with the task of forming a liaison between local government bodies and citizens. They are nowadays seen as the real energy knowledge brokers. This has led us to the construction of a so-called diabolo model for citizen participation, in which these energy knowledge brokers play a central role in citizen-oriented energy transition (see Figure 7).

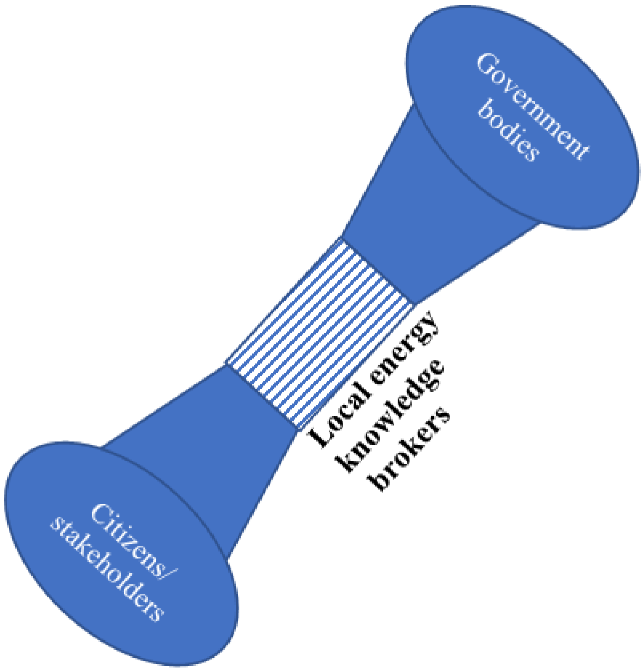

Figure 7. The "diabolo model" for citizen participation in local energy transition planning.

In Section 6, we use the expert insights of the local energy knowledge brokers as a source of information for identifying potentials and bottlenecks in local energy transition initiatives.

6. Expert Opinion of Local Energy Brokers on Energy Transition: A Q-Analysis

There is clearly a wide array of citizen involvement methods, each having their own advantages and limitations [58]. A critical success factor for citizen participation is the question: what information is needed from the side of public officials and what information is expected from the side of citizens? To ensure a clear mapping of the information in the multistakeholder process, a set of semi-structured interviews was organised with local energy experts ("brokers") in Rotterdam operating at the interface of public energy policy and local citizen involvement.

The approach adopted in our study is thus based on energy knowledge experts at city or district level who have qualified and broad information knowledge on the energy situation in the city and its districts and are familiar with the opportunities and bottlenecks of the local and district level (including policy resistance by residents). After careful screening and consultation, we were able to select nine qualified energy coaches and experts who were able and prepared to participate in a semi-structured interview exercise aiming at distilling their knowledge on the sustainability and energy challenges in the city of Rotterdam, with a particular focus on the potential of the use of advanced digital tools for facilitating necessary energy transition in the city.

The interviews were consistently organised and administered according to a structural schematic format, viz. (i) a general orientation and specific expert knowledge on energy transition in a participatory setting, and (ii) an opinion/preference elicitation score method on their views and experiences in the city. The general topics discussed were inter alia: arguments for sustainable energy transition, reasons for citizen engagement, bottlenecks in actual citizen participation, representativeness of citizen participation, instruments used for citizen involvement (and in appropriate phases of the energy programme), interaction/cooperation with public energy authorities/officials, and success (conditions) of public democracy on energy transition. These questions were related to the observations made in Sections 1–5 of the present study and confirmed largely the propositions put forward above.

The second stage concerned the numerical scores provided by these nine interviewees to a limited set of core questions raised in the first half of the year 2022, in order to obtain a quantitative representation of their expert views that could be used as a test frame for the development of our digital participation tools. Several questions were—in the form of contestable statements—presented to the interviewees, with the request to respond to them in terms of intensity of agreement (ranging 1–5) on a five-point Likert scale. These statements are:

S1: Participating citizens should form a good representation of the city or district.
S2: Citizens have confidence in the municipality.
S3: The organisation of citizen participation is difficult.
S4: Citizens need feedback after their input in a participation process.
S5: A complex issue like energy transition needs solid prior knowledge.
S6: The *average* citizen is hard to engage in a participation project.
S7: Citizens wish a complete transparency during a participation project.
S8: Citizens do not only wish to advice, but also to co-decide.
S9: A strong district/neighbourhood community sense is beneficial for citizen participation.

The score results of this interview exercise are presented in Figure 8.

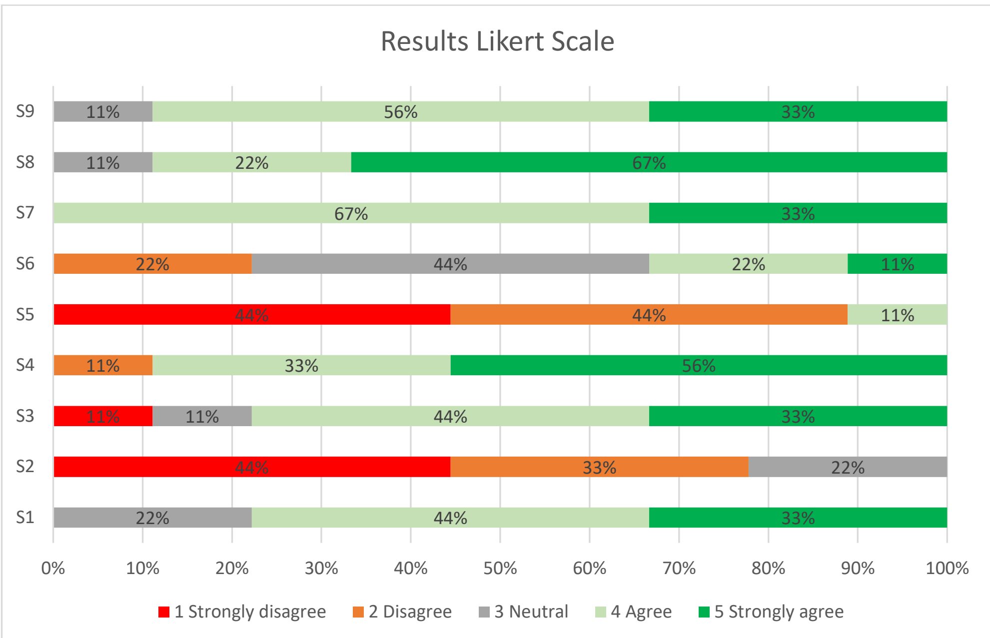

Figure 8. Score results of nine energy knowledge brokers on nine critical items on energy transition in Rotterdam.

The scores in Figure 8 lead to the following tentative findings. This seems to be a "communis opinio" among energy knowledge brokers that in general citizens have a low degree of confidence in local governments (including energy planning) (S2), while also the need of scientific knowledge on energy issues is contested (S5). Another striking fact is that citizens do not only want to be heard, but also want to have a say (S8), while citizens also wish for a transparent energy transition process (S7) and regard a strong community sense as a major asset (S9).

It should be noted that the information in Figure 8 is not based on the usual statistical properties of representative sampling. The main goal of this expert opinion elicitation is to identify core issues and bottlenecks. In the social sciences, it has become customary to use then an appropriate multidimensional method, Q-analysis.

The scores in Figure 8 were next analysed in more detail by using a Q-analysis. A Q-methodology is a method that is used to examine expressed subjective views, allowing stakeholders to define their opinions on a set of prespecified issues. The method allows for the identification of relatively homogeneous groups (clusters) of stakeholders that either share opinions or have common differing opinions ([59–64]). In a Q-study, stakeholders (respondents) are asked to order a set of statements regarding the topic of the study based on their individual preferences. A Q-methodology is suitable when researching opinions, experiences and interpersonal relations. The method is focused on capturing systematically the prevalent opinions and stances regarding a certain predefined topic. The goal of a Q-study is to extract, in a coherent way, different trains of thought, not necessarily the prevalence of them in a population. A Q-analysis uses multivariate factor analysis as a basic tool; in contrast to standard factor analysis, clusters (factors) are identified that represent groups of individuals with similar opinions and feelings regarding the topic of the study. When multiple stakeholder groups are involved, the composition of the factors provide critical insight into which stakeholder groups agree or disagree [65]. It should be noted that a Q-methodology has no interest in estimating population statistics; the aim is rather to sample the range and diversity of views expressed, not to make claims about the percentage of people expressing them ([66] p. 208). An example of Q-analysis in the energy domain can be found in [67], in a study where 43 stakeholders ordered statements regarding policy measures for the electric energy system. This Q-method is now applied to the expert opinions on energy transition in Rotterdam (see Table 2).

Table 2. Q-analysis results of nine energy "brokers" on nine distinct critical energy items.

	Componente	Value for Individual Responses	1	2	3	4	5	6	7	8	9
	1	Statement 1	5	4	5	5	4	4	3	3	4
Respondent1	0.979	Statement 2	3	1	1	1	3	2	1	2	2
Respondent2	0.950	Statement 3	4	1	4	4	5	5	5	4	3
Respondent3	0.976	Statement 4	4	5	5	4	5	4	5	5	2
Respondent4	0.991	Statement 5	2	1	1	2	1	2	1	2	4
Respondent5	0.986	Statement 6	3	2	5	3	3	4	3	2	4
Respondent6	0.990	Statement 7	5	4	5	4	4	4	4	4	5
Respondent7	0.981	Statement 8	3	4	5	5	5	4	5	5	5
Respondent8	0.986	Statement 9	4	5	3	5	4	4	5	4	4
Respondent9	0.951										

The left-hand column of Table 2 represents the multivariate component scores for each individual respondent, while the right-hand matrix (with nine respondents in the vertical column and nine statements in the horizontal rows) provide insight into the importance attached by the interviews to each of the nine statements.

The results presented in Table 2 are—as mentioned above—based on the standard ingredients of a Q-method, using a principal component analysis. The overall patterns of the perceived energy opinions of citizens in Rotterdam—on the right hand side of Table 2—provide interesting insights on the heterogeneity in citizen's pattern images. The results in Table 2 show that all nine statements have an effect on the opinion profile, but that statement 8 ("Citizens want not only to advise, but also to have a say") seems to be the most important factor shared by many "brokers", while there is also reasonable consensus on item 4 (the necessity of a feedback to citizens). The Q-analysis also demonstrates that statements 2 and 5 do not enjoy much support, a result in agreement with our previous findings. We may thus conclude that the views of these nine knowledge brokers provide important guidelines for the operation and understanding of citizen involvement in local energy matters.

7. Retrospect and Prospect

The present study sought to develop a new framing for sustainable energy planning at local level, against the background of an interactive quadruple helix fabric, based especially on the need of citizen engagement and participation in the complex public arena of current drastic energy conversion initiatives. We have articulated the need for intermediate knowledge filters ("brokers") as effective liaisons between the public energy domain and the individual citizens' interests. The conceptual diabolo model for citizen participation turned out to be a useful operational concept, while its outcomes were tested through the use of Q-analysis on the brokers' expressions of concerns, opinions and recommendations.

From a data-analytic perspective the use of modern advanced statistical and digital research and visualisation tools seems to be indispensable for successful urban energy transition. For operational purposes, the following data-driven tools may be helpful for an actionable citizen-based transition planning in future participation trajectories:

- Energy scoreboards on the local, district, street or individual dwelling stocks, in terms of relevant and available energy performance data (e.g., energy labels).
- Energy dashboards (e-compasses) on critical KPIs on energy use and expenditures, in terms of critical parameters (e.g., solar energy, housing insulation, inhouse adjustments).
- Digital twin tools, with a double function:
    - Decision-support visualisation tool for local or district sustainable, public energy policy (macro);
    - Three-dimensional information tool for familiarising citizens or business with possible options (images) for energy saving.
- Digital preference elicitation tool, for expressing and collecting the citizens' views on energy issues in a systematic manner (e.g., MAMCA), with a view to:
    - Accountable citizen participation;
    - Underpinning of meso/macro energy policy at municipal level.
- A citizen-oriented financial cost–benefit analysis tool, for assisting citizens in solving complex choices on costly indoor energy adjustments.
- An operational transformation of spatial data infrastructure towards a digital twin energy infrastructure.
- Metaversal energy scenario experiments [68] on innovative initiatives among stakeholders in the energy domain, using existing information as the basis for a verisimilitude in future energy planning.

In conclusion, the field of local energy transition planning is a rich field of research, not only from a technical and digital perspective, but also from an organisational and citizen science perspective, while making use of modern citizen participation tools. Sustainable local energy transition forms a great challenge to smart urban governance.

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Appendix A

List of 21 studies on energy policy, Erasmus University Rotterdam

1. Erasmus University Thesis Repository: Sturen naar de klimaatneutrale stad (eur.nl)
2. Erasmus University Thesis Repository: Energie voor leefbare wijken: Onderzoek naar de koppelkansen tussen de warmtetransitie en het verbeteren van de leefbaarheid in kwetsbare wijken (eur.nl)
3. Buurttransformator | Topsector Energie
4. SNAP Neighbourhood Projects—Toronto and Region Conservation Authority (TRCA)
5. Erasmus University Thesis Repository: Een Omgevingsagenda voor Zuid-Holland (eur.nl)
6. Erasmus University Thesis Repository: Meerwaarde van co-creatie voor de Zeeuwse omgevingsvisie (eur.nl)
7. https://thesis.eur.nl/pub/43817 (accessed on 1 March 2022).
8. Erasmus University Thesis Repository: De energietransitie als kans; Hoe Kopenhagen partnerships toepast om het innovatievermogen te vergroten (eur.nl)
9. Erasmus University Thesis Repository: Van klimaatdoelstelling in Parijs tot 'achter de voordeur' in Purmerend
10. Erasmus University Thesis Repository: De Druk van het Klimaatakkoord: Hoe de Rotterdamse haven zich kan aanpassen om haar concurrentiepositie te behouden (eur.nl)
11. Erasmus University Thesis Repository: De Rotterdamse haven: een koploper in de energietransitie (eur.nl)
12. https://thesis.eur.nl/pub/32055, (accessed on 1 March 2022).
13. Erasmus University Thesis Repository: Burgerparticipatie bij stedelijke vernieuwing in de gemeente Rotterdam (eur.nl)
14. Erasmus University Thesis Repository: Burgerparticipatie binnen de pijlerprojecten binnen het Pact op Zuid (eur.nl)
15. Linda-Schut-Burgerparticipatie-wat-doet-het-voor-de-woonomgeving.pdf
16. Erasmus University Thesis Repository: Van Participatie naar Maximalisatie (eur.nl)
17. Hiba-Amina.pdf
18. Butt-Saqib.pdf
19. Gao-Kun-Man.pdf
20. Bastiaans-Marleen.pdf
21. Dijkstra,_Aan-Age_1.docx (live.com, (accessed on 16 December 2022))

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