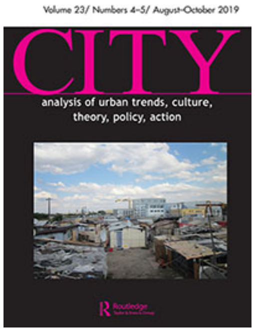

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Energy transitions and the alignment of urban and infrastructural temporalities

Ivonne Elsner, Jochen Monstadt and Rob Raven

Low carbon transitions of urban energy systems have been on urban research and policy agendas for several years now. While the spatialities of infrastructure transitions have been widely discussed, their temporalities have attracted much less attention. This is surprising, since the transition of urban infrastructures in the course of system integration and decarbonisation reveal strong temporal dynamics: new temporalities or temporal requirements not only emerge as a result of technological change (e.g. by integrating fluctuating renewables or storage technologies) but also of changing social practices (e.g. in urban load management or energy use). We argue that aligning urban and infrastructure temporalities involves negotiations between the various energy providers, regulators and users involved and is a highly political process. As we know little about such temporal dynamics so far, this study uses an explorative methodology to elaborate on a conceptual framework of urban and infrastructural temporalities. This framework has been developed in an iterative way by going back and forth between conceptual contributions and empirical findings drawn from expert interviews regarding low carbon transitions in Rotterdam. Our case study of Rotterdam indicates that unsolved challenges in aligning urban and infrastructural temporalities can be seen as a major restriction to realise low carbon energy solutions.

Key words: time, temporality, electricity, energy, infrastructure, low carbon transition, decarbonisation, renewable energies, smart cities, smart grids

Introduction

Low carbon transitions have been on urban research and policy agendas for several years now. The integration of renewable energy resources into existing energy infrastructures plays a key role in urban low carbon transitions. Due to the daily and seasonally fluctuating generation of electricity by renewable electricity generation plants, such as photovoltaics and wind turbines, their integration leads to socio-technical changes with strong temporal dynamics. It is one of the socio-technical specifics of the electricity system that generation and consumption need to be outbalanced at any time by systematic load management. However, the temporally fluctuating and spatially more decentralised power generation based on renewables is forcing traditional practices in balancing electricity loads to adapt. Electricity loads were traditionally almost exclusively balanced on the supply side through a system of centralised (fossil or nuclear) base-load and peak-load power

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plants that feed into transmission grids. Low carbon transitions, however, require system changes towards more decentralised and renewable electricity generation and a higher energy efficiency in energy supply and demand. In a system based on solar or wind energy, electricity loads increasingly depend on weather conditions and day-night cycles. This results in new temporalities of urban energy systems and considerable challenges in balancing generation and consumption. New challenges arise, e.g. how to balance fluctuating loads dependent on weather and seasonal conditions with the temporalities of urban peak demand hours (e.g. in the early evening).

We argue that the alignment of urban and infrastructure temporalities is neither politically neutral nor solely a matter of efficient techno-managerial effort. Instead, it is a highly contested process involving negotiations between various stakeholders. On the one hand, when faced with temporal alignment challenges, incumbent energy stakeholders often argue that fossil fuels continue to be essential for the near future in order to guarantee grid stability and a seamless energy supply. On the other hand, proponents of smart cities and energy innovators argue that technological solutions (e.g. smart electricity grids and metres or innovative storage technologies) are key to low carbon transitions and the better alignment of infrastructural and urban temporalities (e.g Brizzi et al. 2016). Many of them propose that smart grids allow for the integration of electricity with other infrastructure systems (mobility, heating, gas, wastewater, solid waste etc.) in order to gain synergy effects in energy demand, generation and storage. Cities, in this light, are seen as a complex 'system of systems' or 'web of systems'. Techno-managerial visions of smart cities and grids promote electricity together with information and communication (ICT) systems as urban super infrastructures. Electricity systems, in this view, not only shape the temporalities of other infrastructure systems, i.e. the times when they use, store or generate electricity. More broadly, they structure urban rhythms including the temporalities of electricity demand in urban households or businesses, production cycles, mobility patterns etc. (cf. Atasoy, Akinc, and Ercin 2015). As the discourse around smart cities and grids focuses mostly on technological feasibility and efficiency of such solutions, social and urban implications are often neglected.

The 'technocratic solutionism' and the social effects of smart city visions have been widely discussed (e.g. Hollands 2008; Luque-Ayala and Marvin 2015). While Kitchin (2017, 2018) investigated the changing temporalities of smart cities in order to identify social conflicts and challenges related to smart city concepts, the changing temporalities of system integration in the course of urban low carbon transitions and the resulting social implications have attracted less attention. Moreover, only limited research has been conducted on the alignment processes across urban infrastructure domains in general, or the urban interfaces between electricity systems and other infrastructures more specifically (e.g. Monstadt and Coutard 2019; Moss and Hüesker 2019). By focusing on these debates, we argue that temporal adjustments in the course of low carbon transitions are significantly shaped by: the temporalities of different infrastructure systems and, more broadly, the varied domains that use, generate and store energy. At the same time, electricity systems shape the temporalities of modern urban life and the rhythms of a city. We further argue that the dynamics of governing and aligning urban and infrastructure temporalities mirror power dynamics of various energy stakeholders.

In this paper, we first address urban and infrastructural temporalities by conceptualising how social, natural and technological temporalities play out at different temporal scales (short- and long-term) in urban energy systems. Building on that, we empirically investigate the alignment of urban and infrastructural temporalities in the case of the Dutch port city of Rotterdam. By analysing low carbon transitions through the lens of temporalities we reveal a messy and highly political process rifled with considerable uncertainties. Even though low carbon transitions in Rotterdam are still in an early phase, the empirical findings indicate that the implementation of socio-technical solutions strongly depends on the adjustment of existing urban and infrastructural temporal regimes. While many of the proposed technological solutions of smart cities and energy systems might prove efficient in sustaining low carbon transitions (e.g. temporal adjustments in electricity demand, generation and storage by multiple urban stakeholders), we show that centralised solutions in line with established temporal regimes and hence strongly conforming with existing power relations are favoured.

Based on a literature analysis of energy transitions, smart cities and electricity systems and on temporal dimensions of cities and technology, our empirical study on Rotterdam is based on qualitative fieldwork, including the analysis of policy documents, websites, newspapers and other grey literatures. Moreover, we conducted semi-structured interviews with 20 experts in urban and regional planning (5), grid operators (5) and other utility companies (2), academic and private research institutes (4), the port of Rotterdam (2) and private technology companies (2). The interviews were structured by an interview guide which included open explorative questions as well as specific questions on the temporalities of Rotterdam's urban energy systems.

Conceptualising urban and infrastructural temporalities

Time is always on our minds; whether being on time for a meeting, running out of time to hit a deadline, reflecting on the past or imagining the future. Yet defining what time actually is soon becomes delicate. This shows that time is not as absolute and unambiguous as it might seem at first glance. Instead, there are multiple, subjective types of (perceiving) time, hence revealing time as a social construct (Giddens 1987; Nowotny 1992; May and Thrift 2001). The term temporality stresses this socially constructed nature of time. McKeon defines temporalities as the '*[. . .] circumstances in which time is perceived as a problem or as a structure, [. . .] a formula which takes many forms and particularizations*' (McKeon 1974, 124). This shows that time (similar to space) does not exist independently from social processes, leading to a multiplicity and heterogeneity of co-existing temporalities (Harvey 1994). These multiple temporalities are both interrelated and place-specific (Ogle 2013; Massey 2005). In urban spaces—shaped by specifically dense and heterogeneous conglomerates of people, infrastructures, commodities and knowledge but also of different temporalities—a vast multiplicity and heterogeneity of space-specific temporalities exists (Crang 2001). The multiplicity of temporalities leads to a multitude of conceptual approaches to temporalities across various disciplines. However, conceptualisations of social and technological temporalities of urban infrastructure systems have yet to be articulated.

Just as the elements of the socio-technical systems of a city are interconnected and together build an urban 'system of systems', their specific temporalities are highly interdependent. Similar to the understanding of time as infrastructure (Besedovsky et al. 2019), the temporalities embedded in heterogeneous infrastructure systems form temporal regimes. These temporal regimes greatly matter to urban residents' lives, urban commuter patterns and business practices in different urban places. Not only do these regimes enable, constrain or stimulate social activities of urban residents or economies, they also define a constraining, enabling or stimulating structure for other technologies or technological practices. To replace, for example, one technology with one that features different temporal characteristics, the temporality of the new technology needs to align with incumbent infrastructural and urban time regimes. In our case of low carbon transitions, established urban regimes of temporal alignment between supply and demand loads can become unstable under the influence of renewable technologies. Their temporality is shaped by natural rhythms of day-night cycles or fluctuating weather conditions and thus challenge existing time regimes in balancing electricity loads. In order to overcome such temporal mismatches, different options are possible. In our case, such options include the adaptation of urban demands to the rhythms of renewable power supply or the development of storage technologies or backup capacities for periods of low power generation. However, each of those options come with additional costs or changes in the business routines of established service providers or user and regulatory practices. Therefore, the negotiation of how to align temporalities can be seen as a highly political process which mirrors the negotiation of different interests and power relations (Wajcman and Dodd 2017).

In the following sections, we refer to time regimes as being frozen or materialised in technical infrastructures. Following a science and technology studies understanding, we understand infrastructures as constituted by a seamless web of technology, society and nature. These three spheres constantly interact and shape each other and form stable temporal regimes, e.g. as manifested by the incumbent energy system's independence from natural rhythms through fossil power plants and established practices of load balancing. Technological change, e.g. the replacement of a gas-fired power plant by wind turbines, thus not only results in changing relations between these individual spheres but can also require changes of established temporal regimes. Attempts at reconfiguring the existing relations between technological, social and natural elements may thus run into an inertia of temporal regimes. Furthermore, the following sections refer to different scales at which temporalities play out (long-term and short-term). Looking at the short-term scale involves operational challenges of real-time temporal alignment which is especially crucial in the time-sensitive electricity sector. Whereas in a long-term scale we focus on the planning of infrastructures and on path-dependencies of the built environment. We argue that analysing the two dimensions of temporalities (spheres and scales) and their interdependency sharpens our understanding of the dynamics of change and thus temporal mismatches and frictions in urban transitions.

The spheres of natural, social and technological temporalities

Referring to distinctions between natural and social time in debates on smart cities (Kitchin 2017), natural time includes cycles such as diurnal rhythms of day and night or annual rhythms like earth seasons. For the conceptualisation of social time, Kitchin draws on a set of literature (e.g. May and Thrift 2001; Lefebvre 2010) as well as empirical findings to explain that human behaviour, user practices and social relations are mediated through time. The interconnection of natural and social time may play out in socio-natural rhythms, for example as day and night cycles impact body clocks which yet again impact social behaviour (Kitchin 2017). The interplay of social and natural temporalities is very important within urban energy systems. On the one hand, the constant supply of energy in many modern cities enables an independence of social rhythms from natural cycles (e.g. electric light allowing activities after sunset, heating in cold seasons) and has thereby considerably been impacting urban rhythms since the 19th century. On the other hand, social rhythms highly impact urban energy demand patterns, e.g. peak energy loads in the late afternoon and early evening. With the integration of renewable energy generation plants, this independence from natural rhythms is challenged, as technologies like wind energy plants and solar panels are highly dependent on natural cycles and weather conditions. This is in line with Wajcman and Dodd's (2017) observation that the physical characteristics of technologies imply specific temporalities (temporal flexibility, reaction times, life-times etc.). These temporalities become obvious in processes of technological change. Whether they are scripted in the material design or in the regulatory, user and operation practices of a new technology (e.g. solar technology), they need to be aligned with the temporal regimes of existing configurations of technical artefacts, institutions and social practices that have stabilised over time.

The scales of short-term and more long-term temporalities

With regards to their operation, the short-term alignment of temporalities has always been key to electricity systems as the process of balancing electricity supply and demand at any given time is important to guarantee grid stability and to avoid power interruptions. Therefore, even traditional electricity grids without an extensive ICT layer are highly reliant on real-time operation—making the electricity sector very time sensitive. The relevance of aligning supply and demand in real time increases even more through current ambitions to shift toward smarter energy systems. Here, scenarios of future energy systems based on virtual power plants (cloud-based distributed power plants that aggregate the capacities of heterogeneous distributed energy resources), smart metres (two-way information gateways allowing for monitoring and managing electricity use in line with shifting electricity loads) and storage technologies indicate considerable shifts of established temporal regimes through a variety of ICT applications. Gaining more insights into the temporalities of electricity systems (and other connected infrastructure systems) is thus a key requirement for managing these systems (Kitchin 2018).

Material components of infrastructure systems such as power plants, electricity grids and boilers are built for long time spans. Infrastructure systems are characterised by path dependency and inertia so that abrupt and path-deviant changes of their material components or established regulatory structures and user practices are rather rare. Thus, they project into the future the socially constructed characteristics acquired in the past when they were designed (Hughes 1983). Managing change is subject to urban and infrastructure planning which therefore need to combine knowledge of the past when infrastructures were developed and built with anticipatory long-term visions and strategies providing ideas of an improved future (Abram 2014; Konrad et al. 2017). This is also clearly the case for urban low carbon transitions which shall anticipate risks of climate change e.g. by integrating more renewable energy sources into existing infrastructure systems. Looking closer into planning processes reveals that they usually consist of a mixture of not only long-term but also of near- and medium-term plans. Therefore, different future horizons are subject to urban and infrastructure planning—at times leading to conflicting temporalities (Abram 2014). Such plans (be it near-, medium- or long-term) act as a '*vehicle for present action*' (Abram 2014, 131). Therefore, the short-term temporalities of operating infrastructure systems and the more long-term scale of planning these systems are highly interdependent.

Aligning urban and infrastructural temporalities in Rotterdam

Rotterdam, the second biggest city in the Netherlands, has organically grown around its harbour. Hosting Europe's largest seaport, the city's economy is strongly shaped by trading and logistics and other energy-intensive industries benefiting from locational advantages of the global transport node. Rotterdam is therefore an emblematic case where specifically high impediments to low carbon transitions coincide with their high necessity. Indeed, the interviews stressed the ambiguous relationship between the city government and its harbour: On the one hand, the port of Rotterdam is a very important economic factor for the city, but on the other, it is responsible for the city's enormous carbon footprint which is the highest in the Netherlands.

The current domestic energy infrastructure in the Netherlands mostly relies on fossil fuels. The Dutch heating and electricity sectors are strongly based on the natural gas resources in the North of the country. This dominance of fossil fuels coincides with the Netherlands having Europe's second lowest share of renewables in gross final energy consumption in 2017 (eurostat 2019). According to the interview partners, the two most pressing urban energy challenges are the integration of renewables in Rotterdam's carbon intensive industries and the phasing out of natural gas.

In this section we discuss the interplay of the different conceptual dimensions (sphere and scale) of temporalities that we presented above. We explain the interplay of natural, social and technological temporalities of low carbon transitions by first focusing on the short-term load balancing in urban electricity grids and secondly by analysing long-term path-dependencies and anticipatory planning practices in urban energy systems.

Short-term scale: temporal alignment challenges in balancing urban electricity loads

Since the share of intermittent renewable energy generation plants is still relatively low in Rotterdam, the operation of electricity grids is not yet facing temporal alignment problems (Interviews, transmission grid operator and distribution grid operator in Rotterdam 2017). However, for the Rotterdam-the Hague area, 8 million photovoltaic panels, 117 onshore and 450 offshore wind energy plants are planned for installation by the year 2050 (Interview, municipality of Rotterdam 2017). Therefore, the grid operators agree that the real-time alignment of these intermittent sources will be an important task for the future especially on the low and medium voltage level. Different socio-technical solutions are envisioned to effectively integrate renewable energy generation plants by aligning with the social and technological temporalities of the existing energy system: these include a combination of more buffers (like storage systems), flexibilisation of loads (by demand side management) and more real-time knowledge on electricity loads (like in smart grids). However, these solutions have quite different impacts on the incumbent system and the social temporalities of urban users.

Storage systems may allow more independence to the incumbent system from the fluctuating technological temporalities of renewable energy generation plants. As the integration of storage requires little adaptation of the social and technological temporalities of the incumbent system, it is one of the preferred solutions of experts. Even though stakeholders in Rotterdam all agree that storages are very important (may it be on a household, district or city level), interestingly, they usually do not see themselves as the responsible party to actually implement them. Reasons for this are related to the current regulation schemes of the Dutch electricity sector as well as current tariff schemes. Due to unbundling, grid operators are not allowed to own generation plants or storages—even though they might be a beneficial option for grid operators to balance electricity loads. Similarly, grid operators are not allowed to convert electricity into other energy carriers or products (power-2-X; Interview, grid operator Rotterdam 2017). Current tariff schemes do not provide sufficient financial incentives for private users to install storage systems—even though private households with a solar panel could integrate their own storage system in order to increase on-site consumption and reduce pressure on the grid.

Although the balance of generation and consumption has so far been mainly managed by alterations on the generation side, the management of demand offers further options to increase flexibility within the electricity system. The potential for demand side management is assessed to be high for the industrial sector in Rotterdam, especially for the big industrial facilities within the port area. These industries are hotspots of electricity demand, therefore, a more flexible demand response may be achieved with a small number of stakeholders and therefore relatively little coordination involved. However, this requires the adjustment of technological and social temporalities of the industry sector. Hence, production cycles, maintenance schedules and working shifts have to be aligned to new temporalities of electricity generation. But as production cycles are usually already highly optimised, sufficient financial incentives such as flexible tariffs are needed in order to make industrial demand side management beneficial for the industry. Furthermore, some production schemes are more time-sensitive than others, hence, not all industries can flexibly contribute to reducing peak loads through shifting/postponing their demand. Nevertheless, a variety of big industrial facilities in the port area may allow a high potential for shifting demands to off-peak hours.

In contrast to that, the interview partners assessed the potential for demand side management within private households in Rotterdam as relatively low. Just like for the industrial sector, the lack of financial incentives makes it unattractive for private households to participate in demand side management at this moment. But more importantly, reducing or shifting demands to off-peak hours would imply that users would be obligated to change their social rhythms and practices, e.g. when to use electricity, when to charge e-vehicles etc. Therefore, even if financial incentives via flexible tariffs were given, interview partners assessed the interests of users to trade comfort (hence maintaining social temporalities) over financial benefits as very low. Additionally, managing demands at the household level requires the temporal alignment of a relatively high number of involved parties who have only relatively low flexibility potentials due to their relatively low individual energy consumption compared to large industries. In order to still make use of the flexibility options in private households, the role of intermediaries between electricity producers, users and grid operators—so called 'aggregators'—is discussed. Such aggregators could trade flexibility options on the energy market and could therefore align and manage the heterogeneity of distributed generation plants, storages and users. Thereby, such intermediaries could become central actors to align technological temporalities of renewable energy generation plants with social and technological temporalities of existing systems of grid operation and energy users. This would also enable users to participate in demand side management programmes. However, the interviewed experts had differing opinions on what exactly such an aggregator role could or should look like and to what degree incumbent utility companies already fulfil this role now in Rotterdam.

Proponents of smart grids often argue that an extensive ICT layer within the electricity system is indispensable for the integration of renewable energy generation by providing real-time insights into the system. Smart grids could allow for a real-time management of different flexibility options (such as storages and demand side management). So far, Rotterdam's

> '[. . .] low voltage networks are designed in the way to "fit and forget". So, we design the network with sufficient capacity [. . .] and then it can last for at least 40–50 years without any problem and that is going to change. So, that means that for most of our low voltage networks we don't know really how they are used, where is the peak, what is the size of the peak [. . .]' (Interview, grid operator Rotterdam 2017)

Despite smart grids' potential of real-time management of social temporalities of energy users, interview partners were uncertain to what degree they are indeed needed for the future temporal alignment of an increasing share of renewable energy within existing infrastructure systems. While private companies who offer such solutions argue that smart grids are indispensable, incumbent grid operators are more reluctant to path-deviant changes of existing grid topologies and management practices when considering their high transaction and investment costs.

Long-term scale: temporal alignment challenges of urban low carbon transitions with incumbent infrastructure systems

The multiplicity of potential socio-technical solutions for the integration of renewable energies into incumbent systems shows that low carbon transitions in Rotterdam are still in the early phase of the transition process. Stakeholders tinkering with a variety of socio-technical solutions face too much uncertainty about future developments. As urban and infrastructure planning involves a multitude of demand sectors as well as various energy stakeholders (such as utilities, municipalities, private service providers etc.) it has to address a multiplicity of (conflicting) interests and varying long-term visions. The interviews revealed that even experts within the same organisation have diverging ideas of what future energy systems could or should look like. Besides the differences in interests and priorities, the different organisations involved in low carbon transitions in Rotterdam also plan around quite different temporalities and time horizons. Faced with market pressures and regulatory uncertainties, private companies usually address rather mid-term horizons and pursue investments with short payback periods. While municipalities also address more long-term developments, their decision making strongly depends on temporalities of election cycles. The planning priorities in Rotterdam are highly dependent on the political agendas of the city council, as the specific policy priorities and approaches to climate mitigation have considerably changed over election cycles: '*[...] On a city level we have elections next year [2018] [...] I don't know who is going to be on our board. So that depends on whether we go forward, go fast forward or slow.*' (Interview, municipality of Rotterdam 2017).

The challenge of diverging temporal horizons of planning and investment decisions not only exists with regards to stakeholders within the electricity sector but also across different other infrastructure domains such as heating, water, wastewater, transportation or ICTs which increasingly interface and overlap with electricity. This applies to the decarbonisation of transportation by promoting electric vehicles but also different long-term visions to decarbonise heating systems in Rotterdam and to phase out natural gas. Examples here are the electrification of heating (via heat pumps), district heating (from residual heat of industrial facilities in the port area or from waste incineration) or the replacement of natural gas by hydrogen or synthetic natural gas (Interviews, grid operator and municipality of Rotterdam 2017). Such system integration usually implies an increasing use of ICTs to align a variety of decentralised demand and supply options within smart grids. Another example is the district approach by the RUGGEDISED project in Rotterdam's district 'Heart of South'. It pursues low carbon transitions through explicit system integration and establishes new infrastructural interfaces between energy, wastewater, water and transportation systems: by generating thermal energy from waste water, by extracting heat/cold from surface water and by installing pavement heat/cold collectors.

The electrification of heating or mobility and the generation of hydrogen or synthetic natural gas in power-2-gas facilities both imply additional electricity demands or supplies and impact the temporalities of electricity systems quite differently. The electrification via heat pumps leads to electricity demands mostly at periods of heating demand peaks (e.g. evenings during winter) while the electrification of mobility shifts peak electricity demands to off-peak hours of commuter flows when users are loading their cars. Hydrogen or wastewater-2-energy projects, in contrast, facilitate energy storage. Therefore, hydrogen could be generated and stored at peak hours of renewable generation and be used during peaks of electricity or heating demand.

However, these different infrastructure systems are typically characterised by different planning horizons, payback periods and sector-specific planning logics which are not necessarily in line with the temporalities of electricity systems. For example, the life and investment cycles of the hard- and software of information and communication technologies or that of electric cars are considerably shorter than those of electricity systems—challenging to align planning horizons and investment cycles in both the electricity system and other infrastructure domains. Since the temporalities of different infrastructure domains are becoming more intertwined, temporal alignment is required—both with regards to their present or short-term operation and their long-term planning.

Aside from such temporal dimensions, socio-technical change driven by the phasing out of natural gas has strong socio-spatial implications. As the switching to alternative heating sources usually involves investments by users (appliances such as new boilers or cooking stoves), it is likely that high-income neighbourhoods are better positioned to switch to sustainable alternatives. Ultimately, low-income neighbourhoods may lag behind with switching to other heating sources. Hence, the fixed costs of gas grids need to be borne by a decreasing number of people leading to higher individual costs. According to the interview partners, this may lead to energy poverty. In general, the question of who is paying for the transitions or respectively how these costs should be allocated among different stakeholders and users is one of the major concerns of most interview partners.

The temporal synchronisation of increasingly intertwined infrastructures requires more collaborative effort between different energy stakeholders as the strategic decisions of one company (e.g. the gas grid operator) highly impacts other stakeholders (e.g. the private district heating operator or users). The typically anticipatory role of urban and infrastructure planning has considerably changed over the last years due to the privatisation and liberalisation of infrastructure systems. Means of municipal authorities to directly shape future infrastructural developments has decreased over the time. Even though the municipality of Rotterdam is still an important shareholder in major energy companies in the region (including utilities like Eneco, the local gas and electricity grid operator Stedin and the Port Authority as the owner of the land of the port of Rotterdam), the city cannot directly influence the strategic decision-making processes of these companies (Interview, municipality of Rotterdam 2017). Therefore, the role of the municipality of Rotterdam has increasingly become that of a mediator who is '*[...] orchestrating the transition [...]*'. (Interview, municipality of Rotterdam 2017).

> 'Now the challenge is that we don't own the buildings, we don't own the grids. So, we don't have any say in what needs to be done. While at the same time the national government says the coordination of the transition is in the hands of the local government, which is a bit of an odd situation.' (Interview, municipality of Rotterdam 2017)

Because of this lack of direct regulatory resources, the city of Rotterdam is trying to align their low carbon agendas with existing infrastructure providers on the one hand by supporting innovation through local bottom-up initiatives. On the other hand,

> '[...] in areas where we know that there is a big area that has renovations, new buildings, new sewage systems planning, [...] combined we try to work towards a district top-down, or more top-down to a district-oriented agreement and to try to transform the whole area as much as possible in one time.' (Interview, municipality of Rotterdam 2017)

The following table gives an overview of the most relevant urban and infrastructural temporalities that were identified to shape urban low carbon transitions in Rotterdam (Table 1).

Table 1 Temporalities of low carbon transitions in Rotterdam

Sphere	*Social temporalities*	*Natural temporalities*	*Technological temporalities*
	• Demand side management requires alignment of urban rhythms like user behaviour (e.g. rhythms of energy use); • Flexible tariffs as incentives for users to change their social temporalities • Political rhythms of election cycles strongly shape (changing) visions and planning strategies • Regulations can lead to constraints of temporal alignment as they are often lacking behind socio-technical innovations	• Natural cycles like seasons and day/night rhythms determine technological temporalities of solar and wind generation plants; • Seasons shape energy demand patterns (e.g. for heating and cooling)	• Technological temporalities of renewable energy generation depend on natural temporalities • Specific time regimes of each energy carrier (e.g. heating with electricity vs. synthetic gas to phase out natural gas) • Technological temporalities like production cycles need to be aligned in industrial demand side management
Scale	*Long-term temporalities*	*Short-term temporalities*	
	• Existing path dependencies constraining change due to the durability of tangible infrastructure artefacts as well as norms and values inscribed and investments sunk into technical artefacts and associated regulation schemes and users' behaviour • Interdependence of planning decisions and visions in different infrastructure domains: e.g. electrification of mobility and heating impacting future electricity demand and supply patterns • Planning cycles, visions but also contracting schemes in different infrastructure domains need alignment in case of system integration • Planning as anticipatory approach to the transformation of urban infrastructure systems as a highly political process	• Operation of electricity grids requires real-time alignment of social, natural and technological temporalities • New role of aggregators to manage intermittent generation by trading flexibility on a short-term scale • Provision of (real-time) flexibility by storages, power-2-gas, demand side management possible, with different social and technological temporalities	

Conclusion

In this paper, we have investigated the co-evolution of urban and infrastructural temporalities and how they shape low carbon transitions. The analysis of this case study has shown that urban energy transitions require the alignment of social, natural and technological temporalities on short-term and long-term scales. The governance of temporal alignment can be seen as a highly political process. As low carbon transitions in Rotterdam's energy sector are still in the early phase of a socio-technical transition, the solutions discussed are strongly shaped by existing practices and come with controversial political and economic interests. Decisions on specific socio-technical solutions and on future pathways to pursue on a large scale are still unclear and beset by uncertainty. At this point, solutions with the least temporal alignment challenges and highest conformity to incumbent infrastructure pathways seem most likely to be implemented. Centralised solutions allowing for the use of existing grid structures and perpetuating existing power relations seem to be favoured. This enables not only the continuity of most technical arrangements (especially the grid infrastructures) and their temporalities but also the least disruption of urban temporalities shaped by rhythms of energy use. As temporalities are embedded in existing and co-evolving social, technological and natural spheres, through their path-dependencies they privilege some solutions over others. For this reason, in Rotterdam, storage implementation is much more likely to be implemented than demand side management in private households, which invokes considerable alignment challenges of natural, technological and social temporalities and therefore a more disruptive socio-technical transition.

This stresses the highly political character of temporal alignment processes within urban transitions. The way many stakeholders promote temporal alignment of renewable energy generation plants with the help of system integration seem like 'technological solutionism'. The focus on technological solutions for temporal alignment processes shifts away the attention from underlying structural causes (Kitchin 2018, 32) like high energy consumption and social implications of urban low carbon transitions. In the case of the city of Rotterdam, agendas on low carbon transitions are mostly fostered at a district level. However, such district-oriented approaches and pilot projects suggest an increasing heterogeneity of urban infrastructure systems. This means that there is not a single low carbon transition happening in Rotterdam but rather a range of social interests driving a multiplicity of transitions (see also Rutherford and Coutard 2014). Urban energy transitions are taking place in different domains, at different scales, with different scopes and different actors, each with potentially different implications for future urban and infrastructural temporalities.

The analysis of the alignment of urban and infrastructure temporalities in the course of low carbon transitions in Rotterdam with the help of our conceptual framework has shown that temporalities are deeply embedded in infrastructure systems and resistant to abrupt change. Temporalities therefore constitute an important perspective of urban and infrastructure transitions in order to reveal power relations of multiple stakeholders involved.

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References

Abram, Simone. 2014. "The Time it Takes: Temporalities of Planning." *Journal of the Royal Anthropological Institute* 20: 129–147.

Atasoy, Tugrul, Hulya E. Akinc, and Ozden Ercin. 2015. "An Analysis on Smart Grid Applications and Grid Integration of Renewable Energy Systems in Smart Cities." In 4th International Conference on Renewable Energy Research and Applications (ICRERA), 547–550.

Besedovsky, Natalia, Fritz-Julius Grafe, Hanna Hilbrandt, and Hannes Langguth. 2019. "Time as Infrastructure: For an Analysis of Contemporary Urbanization." *City* 23 (4–5): 580–588. doi:10.1080/13604813.2019.1689726.

Brizzi, Paolo, Dario Bonino, Alberto Musetti, Alexandr Krylovskiy, Edoardo Patti, and Mathias Axling. 2016. "Towards an Ontology Driven Approach for Systems Interoperability and Energy Management in the Smart City." In International Multidisciplinary Conference on Computer and Energy Science (SpliTech), 1–7.

Crang, Mike. 2001. "Temporalised Space and Motion." In *TimeSpace: Geographies of Temporality*, edited by Jon May, and N. J. Thrift, 187–207. Critical geographies 13. London: Routledge.

eurostat. 2019. "Renewable Energy Statistics." Accessed July 6, 2019. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics.

Giddens, Anthony. 1987. *Social Theory and Modern Sociology.* Stanford, CA: Stanford University Press.

Harvey, David. 1994. "The Social Construct of Space and Time." *Geographical Review of Japan* 67 (Ser. B) (2): 126–135.

Hollands, Robert G. 2008. "Will the Real Smart City Please Stand up?" *City* 12 (3): 303–320. doi:10.1080/13604810802479126.

Hughes, Thomas P. 1983. *Networks of Power: Electrification in Western Society 1880–1930.* Baltimore: Johns Hopkins University Press.

Kitchin, Rob. 2017. "The Timescape of Smart Cities." doi:10.17605/OSF.IO/Y4E8P.

Kitchin, Rob. 2018. "The Realtimeness of Smart Cities." *TECNOSCIENZA: Italian Journal of Science & Technology Studies* 8 (2): 19–42. http://www.tecnoscienza.net/index.php/tsj/article/download/316/197.

Konrad, Kornelia, Harro van Lente, Christopher Groves, and Cynthia Selin. 2017. "Performing and Governing the Future in Science and Technology." In *The Handbook of Science and Technology Studies*, edited by Ulrike Felt, Rayvon Fouché, and Clark A. Miller, 4th ed., 465–494. Cambridge, MA: The MIT Press.

Lefebvre, Henri. 2010. *Rhythmanalysis: Space, Time and Everyday Life. Reprint.* London: Continuum.

Luque-Ayala, Andrés, and Simon Marvin. 2015. "Developing a Critical Understanding of Smart Urbanism?" *Urban Studies* 52 (12): 2105–2116. doi:10.1177/0042098015577319.

Massey, Doreen B. 2005. *For Space.* 1st ed. Los Alamitos, CA: SAGE.

May, Jon, and N. J. Thrift, eds. 2001. *TimeSpace: Geographies of Temporality.* Critical geographies 13. London: Routledge.

McKeon, Richard. 1974. "Time and Temporality." *Philosophy East and West* 24 (2): 123–128.

Monstadt, Jochen, and Olivier Coutard. 2019. "Cities in an Era of Interfacing Infrastructures: Politics and Spatialities of the Urban Nexus." *Urban Studies* 56 (11): 2191–2206. doi:10.1177/0042098019833907.

Moss, Timothy, and Frank Hüesker. 2019. "Politicised Nexus Thinking in Practice: Integrating Urban Wastewater Utilities into Regional Energy Markets." *Urban Studies* 56 (11): 2225–2241. doi:10.1177/0042098017735229.

Nowotny, Helga. 1992. "Time and Social Theory." *Time & Society* 1 (3): 421–454.

Ogle, Vanessa. 2013. "Whose Time is it? The Pluralization of Time and the Global Condition, 1870s–1940s." *The American Historical Review* 118 (5): 1376–1402. doi:10.1093/ahr/118.5.1376.

Rutherford, Jonathan, and Olivier Coutard. 2014. "Urban Energy Transitions: Places, Processes and Politics of Socio-technical Change." *Urban Studies* 51 (7): 1353–1377. doi:10.1177/0042098013500090.

Wajcman, Judy, and Nigel Dodd. 2017. "Introduction: The Powerful are Fast, the Powerless are Slow." In *The Sociology of Speed: Digital, Organizational, and Social Temporalities*, edited by Judy Wajcman, and Nigel Dodd, 1st ed., 1–12. Oxford: Oxford University Press.

Ivonne Elsner is Research Associate in the Department of Architecture & Associate at Research Training Group KRITIS at TU Darmstadt, Germany. Email: elsner@kritis.tu-darmstadt.de

Jochen Monstadt is Professor of Governance of Urban Transitions in the Department of Human Geography and Spatial Planning at Utrecht University, the Netherlands. Email: j.monstadt@uu.nl

Rob Raven is Professor of Institutions and Societal Transitions, Copernicus Institute of Sustainable Development at Utrecht University, the Netherlands & Professor and Research Director at Monash Sustainable Development Institute, Melbourne, Australia. Email: r.p.j.m.raven@uu.nl