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Smart gridlock? Challenging hegemonic framings of mitigation solutions and scalability

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Abstract

Urban energy transitions are key components of urgently requisite climate change mitigation. Promissory discourse accords smart grids pride of place within them. We employ a living lab to study smart grids as a solution geared towards upscaling and systematisation, investigate their limits as a climate change mitigation solution, and assess them rigorously as urban energy transitions. Our 18 month living lab simulates a household energy management platform in Bergen. Norway's mitigation focus promotes smart meter roll-out as reducing carbon emissions, by (i) unlocking efficiency gains, and (ii) increasing awareness for demand-side management. We problematise this discourse. Raising awareness encounters intractable challenges for smart grid scalability. Scattered efficiency gains constitute modest increments rather than the substantial change requisite for rapid mitigation. Whereas promissory smart grid discourse overlooks these ground-truthed limits, our findings caution against misplaced expectations concerning mitigation. We contest discursive enthusiasm on smart grids and argue for aligning local and systemic concerns before upscaling to avoid obscuring risks. Scaling up requires understanding and addressing interdependencies and trade-offs across scales. Focus group discussions and surveys with living lab participants who used sub-meter monitors to track real-time household electricity consumption data over an extended period show that technical issues and energy behaviour, as well as political economic and policy structures and factors, pose significant limits to smart grids. Urban strategies for climate change mitigation must be informed by this recognition. Our results indicate that upscaling relies on bottom-up popular acceptance of the salient technical, organisational and standardisation measures, but that measures to improve the democratic legitimacy of and participation in energy transitions remain weak. We highlight limits to smart grids as a standalone urban mitigation solution and call for a sharper focus on accompanying thrust areas for systematisation and scalability, such as renewable energy integration and grid coordination.

Introduction

Smart electricity agendas and imaginaries project an image of 'users' as prime beneficiaries. Part of this agenda, here termed the promissory discourse on smart grids, assumes and emphasises a need for 'behavioural change' by users to facilitate more efficient energy consumption. Emerging scholarship challenges such characterisation by problematising what motivates people to engage in energy efficiency measures. Our argument supports this challenge. Based on a multi-faceted empirical study, we show that expectations of and demands for behavioural change are not representative of current socio-technical developments. The discourse about the potential of smart grids for climate change mitigation promises too much; it must be corrected in order to examine and achieve their real potential.

A promissory discourse is constituted by influential agendas promoted by specific actors to set out shared collective horizons for action—in this case smart grids—in a given domain. The discursive construction and the gradual elision of facts and claims in the minds of the public and decision-makers imbue it with a performative element. This serves to inspire and attract various kinds of innovation actors into collaboration. A particular social imaginary of a smart grid mobilises policy developments that support and incentivise certain socio-technical futures while deleting alternatives that are at odds with the dominant discourse (Ballo 2015).

A mismatch between promissory discourse on smart grids (e.g. Amin 2015) and their capacity to deliver, motivates this intervention on a policy and academic concern that has pressing relevance for climate change mitigation. Drawing on academic and policy documents, we characterise the discourse on scaling up smart grids as a means for mitigation; and summarise a critique of 'Resource Man' (Strengers 2014), the image of 'an efficient and well-informed micro-resource manager who exercises control and choice over his consumption and energy options' (Strengers 2013, p 34). Our approach is grounded in a view of human behaviour as based on a complex set of factors (see Abrahamse *et al* 2005). We problematise the common understanding of 'scaling up' as dependent simply on the development of standards aimed at creating new infrastructure such as smart grids. Rather, scaling up involves many interdependencies and often features trade-offs between systemic gains and localised losses (see Frantzeskaki and Loorbach 2010, Silvast 2017), including to democratic participation. We argue that for infrastructural change to work towards objectives like climate change mitigation, the systemic must be aligned with the local across a whole range of applications and parameters before upscaling (see Bhatt *et al* 2014).

Alignment requires encountering and resolving problems and trade-offs, the premise for our living lab in the Norwegian city of Bergen in parallel with the roll-out of smart meters across Norway. By providing households with sub-meter monitors that simulated numerous potential smart grid functionalities, the living lab engaged with localised concerns to identify scope for such alignment under systemic upscaling of smart grids as an urban solution for climate change mitigation. Voytenko *et al* (2016, p 45) characterise living labs as featuring 'geographical embeddedness, experimentation and learning, participation and user involvement, leadership and ownership, and evaluation and refinement'. Ours featured innovations to empower interested citizens with information and incentives, and investigated the societal, ethical and environmental dimensions of smart electricity, mainly from users' perspectives.

The living lab design aimed to set up supportive conditions for behavioural changes geared towards efficiency gains, and enabled study of how this pans out in practice (Liedtke *et al* 2012). In keeping with behavioural economics views, we included gamification to target 'homo ludens' (see Rodriguez 2006), the play-driven ideal-type counterpart to rational choice-driven 'homo economicus'. We held focus group discussions to qualitatively study what actually motivates people to engage in energy efficiency measures (see also Gram-Hanssen 2010, Korsnes *et al* 2018). By virtue of a sub-meter monitor installed at no cost to households, participants gained real-time access to device-level consumption data via a smartphone application. They also received inputs to encourage energy-saving practices via monthly newsletters, complemented by an online scoring system and anonymised profile comparisons with participating households (details in 'Data and methods'). Hence, whereas the project centred on technical measures in line with main policy agendas, our inquiry into what actually motivates people crucially included questions of participation and democracy.

Participants evidently voiced more engagement with political economy issues than behavioural change aspects. Some functions associated with smart grids surface as being suited for automation, with a generally positive outlook on dynamic pricing by these tech-savvy, highly educated participants. Political economic roadblocks to more disruptive and exponential benefits from the advent of smart grids, however, indicate a need for deeper regulatory and institutional changes. These findings buttress arguments by Wolsink (2012) and Verbong *et al* (2013), and crucially also raise questions of energy democracy (see Burke and Stephens 2018, but see also Graham and Marvin 2002). Such changes are important for revolutionising the electricity sector, and electrifying other sectors like transport, to the far-reaching extent required to meet urgent climate change mitigation targets.

But scaling up a sociotechnical system as complex as the electric grid is known to entail a cost, and should thus be treated carefully and with some scepticism to ensure a strategy that is robustly informed by factors at multiple scales (Sareen and Haarstad 2018). It requires an approach to systematisation that is more attuned to localised social practices, and to how these may be aligned with interlinked developments elsewhere, than the current promissory discourse on smart grids affords. Change agendas are susceptible to path dependence and co-optation by private interests (Vesnic-Alujevic *et al* 2016), and risk yielding sub-optimal outcomes on climate change mitigation. Our living lab approach points to the need and possibility of including energy users and publics, not as add-ons to a technocratic process, but as participants in key decisions concerning our common energy future (see Hoffman and High-Pippert 2005). We argue that such ontological politics are key for climate change mitigation when upscaling smart grids in urban energy transitions.

This paper offers some pointers from our study towards aligning localised concerns and systemic ones for upscaling smart grids. Emphasising limits to smart grids as a standalone urban mitigation solution can sharpen focus on accompanying thrust areas for systematisation and scalability, such as renewables integration and grid coordination. Efforts to scale up must secure bottom-up popular acceptance of the salient technical, organisational and standardisation measures. Without such alignment, we caution that the promissory discourse around upscaling smart grids is in need of a reality check on the key registers we identify: technical, energy behavioural and political economic. Before presenting the study, the following sub-section elaborates the link between upscaling and promissory discourse.

Theorising promissory discourse on smart grids and upscaling

The discourse on smart grids resonates with other 'smart' discourses, especially 'smart cities', which are incredibly powerful, as promise and spectacle. Globally, smart city imaginaries have mobilised billions of dollars in diverse contexts over the past decade. Smart grids are imbricated within these discursive constructions, and interwoven with the urban fabric these imaginaries seek to 'smarten' by strategically redirecting urban development funds. Consequently, the promissory discourse of smart urban futures relies on a particular vision of the smart grid that it bankrolls and hopes to produce.

Promissory discourse on smart grids aligns this consequential vision with another desirable aspect of urban evolution, namely climate change mitigation. Cities emit 70% of global carbon emissions and host half the world population; thus, major initiatives and investments like smart grids gain traction through claims that align their growth prospects with urban mitigation solutions. Even lip service to mitigation targets helps depoliticise challenges and weaken resistance to particular new interventions (Blühdorn and Deflorian 2019). Earnest belief in upscaling smart grids as mitigation solutions can also play on a strong existing discourse on energy efficiency and shape the urban growth agenda (Janda and Topouzi 2015). At stake here is public discussion and decision-making on urban energy futures in line with urgent mitigation needs (Demski *et al* 2015), versus the financing of massive energy infrastructure commitments and codification of particular grid logics and path dependencies. These latter forces can freeze in place a social imaginary of smart grids based on ideal-type characterisations of this socio-technical intervention.

One ideal-type that the promissory smart grid discourse draws on is Resource Man, a masculine imaginary whose decisions are driven by economic rationality and a will to maximise efficiency (Strengers 2014). This assumption constitutes a main basis for ideas of behavioural change under smart grid roll-out that characterise humans as seeking to maximise utility under perfect information conditions. These ideas have been roundly critiqued in empirically-informed studies of energy use and human-infrastructure interactions within practice theory and energy anthropology scholarship (e.g. Abrahamse *et al* 2005, Gram-Hanssen 2010, Smith and High 2017). But within the dominant capitalist regime that characterises most energy market design, Resource Man retains a strong performative function and continued influence.

There is a need to balance out this supply-side discursive power with user perspectives and the kinds of dynamics evoked by channelling them (Delina and Janetos 2018). Scholars increasingly acknowledge that misrecognition at multiple scales drives injustice under energy transition (Bridge *et al* 2013). Calling for attention to the spatial scale in energy transitions, Späth and Rohracher (2014, p 118) argue that local efforts can impact 'local socio-technical configurations, but also influence public debates of national or even international reach', and 'establish and align supportive institutions, visions and actor networks and facilitate changes also beyond the locality'. This holds even if identified local phenomena challenge hegemonic discursive trends; hence we call for increased attention to political economic aspects overlooked in the promissory discourse on upscaling smart grids.

Subsequent sections describe our data and methods, present and discuss the results, and offer concluding reflections on the study's implications for smart grid upscaling for mitigation.

Data and methods

Testing for local and systemic alignment

The living lab that is our empirical focus here was part of a Joint Programming Initiative Urban Europe project called PARENT[2], featuring a mix of partners from academia and industry during 2016–2019. PARENT ran three living labs between late 2017 and early 2019. These comprised several dozen households in each of three cities—Amsterdam, Brussels, and Bergen. The project website states its aim 'to provide communities with the technology and support to help reduce energy consumption in their homes and to investigate ways in which communities can work towards more sustainable life styles[3]'.

Each living lab was run autonomously by relevant local partners; this piece focuses on the Bergen Living Lab (BLL). This comprised 46 households who self-selected as participants in response to a public city-wide call circulated through local networks. We expected this snowballing, word-of-mouth, network-based strategy to approximately proxy purposive selection, so that participants would tend to be environmentally-minded, well-educated, and largely tech-savvy. Such a group would in theory feature some of the likeliest citizens to enact behavioural change based on information generated during BLL.

Participants received a complimentary sub-meter monitor called Smappee, available online[4]. A technician

[2] PARticipatory platform for sustainable energy managemENT.

[3] See https://parent-project.eu/.

[4] See http://smappee.com.

facilitated free installation upon request. By downloading an application, participants accessed real-time household electricity consumption data disaggregated by individual devices via a smartphone or web browser. They could visualise consumption over time by device, both 'always on' consumption and live variable components, and were offered 'smart plugs' to help identify specific devices where Smappee's algorithm was insufficiently precise. The platform had a browser interface that gamified the experience for participants. It posed challenges that encouraged environmentally friendly practices with associated points and ranking—participants could also compare energy consumption with other households matched on parameters such as number of inhabitants and area. Participating households could be anonymous on this platform, but allowed the BLL project team to access data for analytical purposes. Participants received monthly newsletters with energy saving tips, activity updates, event invitations, and start-up and closing survey questionnaires.

A steering group of BLL participants with some domain-specific knowledge and interest, and a group of all interested BLL participants, were invited for focus group discussions at initial, midway and closing stages. Five such focus group discussions were audio recorded, transcribed and analysed for this paper. In October 2018, BLL participants interacted with the PARENT consortium, accompanied by a 'Smappee deconstruction workshop', where a BLL participant dismantled a Smappee and we discussed its inner workings together.

The living lab yielded two kinds of outputs. One is quantitative tracking of real-time consumption from late 2017 to early 2019, which showed scattered change and is not the focus of analysis here (but see table A1 in appendix A for overview comparisons of household consumption during January-February 2018 versus 2019 and tables B1–B10 in appendix B for some participant feedback after the living lab). The other output comprises qualitative insights from focus group discussions. These discussions and meetings followed a consistent format: each began with technical aspects (device installation, energy management platform roll-out), proceeded to everyday energy practices, and then took up political economy issues. 'Scaling up' was in this sense intrinsic to the ontology of our shared enquiry with living lab participants (see Hirschman and Holbrook 1986), pertaining to smart meter deployment towards a systemic smart grid in Norway. We mirror this sequence—from technical aspects to everyday practices to political economy issues—in our structure for reporting findings.

In the next section, we present and analyse insights into household energy practices concerning smart meter uptake and use. These have numerous implications for smart grid roll-out in urban Norway and more broadly. The conclusion returns to the promissory discourse on upscaling smart grids and mitigation. We discuss what key factors foregrounded by the BLL merit consideration for this promise to be borne out in practice, challenged or adjusted.

Results and discussion

Implications for smart grid roll-out

In this short piece, we focus on issues that surfaced during our focus group sessions and bear on the intersections of motivation, engagement, broader participation, and scaling (up). We deal with these on three distinct but nonetheless interconnected levels: technical, energy behaviour, and political economy, using select quotes interwoven with the narrative below. These results inform our subsequent reflections on whether and how smart grids can in fact be upscaled to be part of urban climate change mitigation strategies.

At the *technical* level we first note that a technical device like Smappee works well for triggering participants' curiosity and fascination. The latter pertains especially to the promise of 'plug and play', where the device will presumably reveal hitherto hidden patterns in the consumption of the household. Whereas this interest to some extent persisted throughout the project, a majority of participants reported troubles with the device: first, installation (into the household's fuse box) was more difficult than expected, and several needed assistance from an electrician. This settled, the device had problems recognising the household applications, and people had trouble 'teaching' it the differences between them. To quote a participant: 'I had detected the heating cables (floor heaters) in the hallway and the heating cables at the bathroom, and the stove in the kitchen … After a while I found out that it wasn't quite like that, it was … now it [the switch] was off on the wall, but then it was on in the app.' Another queried 'Are they separate circuits? Could it be reacting to one and not the other?' to which the first replied 'I don't know.'

These problems were reported as 'demotivating', and so worked to turn people away from participation. One said 'The new app looked promising. More user-friendly. But it's just not working … I thought it was silly, because I was quite keen on using it.' Another added that 'discovering the right things in the house has been difficult … I lost inspiration to really try again, if it doesn't improve. It seemed inaccurate.' Another quipped: 'You in a way hit a wall, then you lose inspiration[5]'. Among the technically proficient participants, few believed that this kind of free-standing device will be used in the future, but found it possible that it nevertheless points in relevant directions: several mentioned how houses and buildings are becoming smarter with more interactivity and

[5] Some frustration with Smappee is apparent from tables B3 and B4 of appendix B, where a majority of participants report decreased interest in Smappee over time and dissatisfaction with its identification of device-level energy consumption.

Table 1. Electricity consumption and production by household (January-February 2018 and 2019)[a].

S. No.	Household size	House type	Area (m^2)	1/18 con kWh	1/18 pro kWh	1/19 con kWh	1/19 pro kWh	2/18 con kWh	2/18 pro kWh	2/19 con kWh	2/19 pro kWh
1	1–2	*House*	>130	3203	23	2015	1	2674	80	1834	1
2	4	*House*	>130	2004	2	2333	—	1899	—	1527	—
3	1–2	*House*	>130	5862	63	3807	26	5819	115	2866	73
4	5	*House*	>130	—	—	3026	13	6093	108	2481	50

[a] con = Consumption, pro = Production.

information exchange built in, hence 'hidden in the walls'. But they did also express concern over the potential implications for privacy. To quote one participant on this emerging Internet of Things, 'Opening up this Pandora's box of them getting information that we don't formally consent to giving is a big issue'[6].

As concerns *energy behaviour*, several of the focus group participants reported that they already took an interest in energy consumption before joining the project, and that this may have been part of their reason for signing up in the first place. One mentioned that 'Actually getting info about all the power units, in my case, there would not be any changes for my power consumption, but now I am perhaps above average based on the energy consumption in the first place, so I plan everything according to how the energy flows in the house.' This complicates the possibility for assessing (or 'measuring') the impact of Smappee or the platform. Some participants reported that they could 'have done the same' without any technical measures.

Table 1 reports consumption and production data for four participants who were solar prosumers, for the months of January and February in both 2018 and 2019. Monthly temperature averages were the same for January 2018 and 2019 at 3 degrees Celsius, and lower for February 2018 compared with February 2019, 1 versus 5 degrees Celsius respectively[7]. Except for January 2018 versus 2019 for household 2, a trend of notable decreases in year-on-year monthly consumption is evident for both months. For this small sub-population of especially environmentally-minded and tech-savvy 'early adopters[8]', it is possible that more precise real-time monitoring via Smappee contributed to energy savings. One of these participants stated this explicitly: 'These are not things I was doing before the project, because I had no control or insight into what it really cost me before installing Smappee, and afterwards I could monitor and reduce consumption. So rather than the fact that I bought solar panels, it was because of the real-time monitoring of this project that I probably saved more money[9]'. For the other participants, who were not prosumers, appendix A shows more mixed results with no clear trend.

One participant argued for monitoring behaviour over time, and while Smappee can be of some help here, maintaining motivation and interest proved problematic. An interesting topic brought up by this BLL participant was whether people really want to change behaviour in this way (i.e. by having their consumption patterns continuously monitored and communicated to them), or whether this is a good example of tasks that should rather be automated. In their own words: 'I think if it is going to work for ordinary people, then it must be automated. Because you don't get the common person to keep track of what they are using at all times'. Another participant weighed in that 'It's a bit like taking a backup. If you have to do it yourself … you will remember every day for the first week, then you do it only once a week the first three weeks, and suddenly six weeks have passed and your computer breaks down … I think it's important that there is a central enabling of automation…it has to be the simplest form, but also enabling more advanced forms…'. This prompts us to ask: why indeed are 'smart electricity' technologies targeting energy behaviour, and not energy consumption directly? In countries such as Finland, Sweden, the UK and Portugal, we see similar developments: away from 'awareness raising' and towards automation, frequently in tandem with mechanisms of dynamic pricing (Silvast *et al* 2018). A quite general perception among our participants was that this is 'almost certain to come'.

The question of what motivates people came up in several contexts. The main interest (among Norwegians) for changing energy behaviour was generally reported as stemming from environmental concerns, the perception being that Norwegians are spoiled with cheap (and relatively clean) energy. Economic concerns may have some bearing on the issues but were not all that important. Norwegians were described as a bit pampered, and not really concerned much about their consumption. Some of the more highly motivated participants reported that they were not able to reduce their energy consumption more than they had

[6] Follow-up individual interview conducted on 07 May 2019.

[7] Based on publicly available temperature data accessed on 10 May 2019 at https://timeanddate.com/weather/norway/bergen/historic.

[8] While rooftop solar energy has recently begun to grow rapidly in Norway, it remains relatively expensive and households with installed solar capacity in 2017 were rare.

[9] Follow-up individual interview conducted on 09 May 2019.

done already, and that this would require further technical fixes or technological measures (e.g. improved energy efficiency). Some also reported decisive limits in terms of everyday routines that are not easy to change (picking up the children after school, going home to cook dinner, etc).

Some participants responded positively to gamification: especially highlighted here was the possibility to compare with other (similar) households in one's area. Relatedly, the visual impacts of the sub-meter device were pointed out as having some potential, since things are perceived to be more convincing when one can point to a screen displaying a graph and numbers. These visual aspects were also pointed to by people debating the social dimensions of the device: showing it to friends, colleagues and visitors, and the screen and the graphs, data and numbers.

Coming finally to the *political ecocomy* issues, discussions turned quite lively. A number of topics and issues were touched upon: in terms of motivation and participation, we saw strong interest in questions of where energy comes from, in terms of country of origin and energy source (i.e. through green certificates). In Norway, strong controversies persist over whether Norway should integrate its energy system, which is often portrayed as clean and green, with Europe or other neighbouring countries, since this seems to introduce a number of 'impure' energy sources, such as coal and nuclear, to the Norwegian system. Whereas some argue that Norway should retain its 'clean' energy for its own purposes, others argue that climate and energy issues are global, and that we should integrate and collaborate, with Europe and beyond. To quite an extent, the BLL participants questioned many of these assumptions, arguing that energy production, distribution and consumption have long been integrated with other countries, and that a main driving force has been Norway's desire to sell surplus energy abroad. Questions were also posed about the idea that Norwegian energy provisions, mainly based on hydroelectric power, are by default 'green'. Sweden abandoned this idea 15 years ago; in Sweden, it is mainly solar and wind that count as green and renewable, as hydroelectric power destroys rivers and water systems.

There seemed to be general agreement upon the Norwegian energy system thus being predicated on industrial and political interests. A participant opined that 'It is Norwegian industry and policy makers pushing for these developments, the spot market Nord Pool; not 'Europe'', a sentiment that does not necessarily penetrate public or political discussions. Whereas there was general agreement that the debate is therefore to some (or even a great) extent predicated on false moralism, this did not translate into agreement on action at political levels. An important issue here also pertains to trust in institutions: it may seem reasonable to have this kind of collaboration across borders, but trust in institutions was an overarching and oft-repeated problem: from the local energy company, to the grid operator, to multi-scalar institutions (regional, national and European). Speaking about cross-border energy exchange, one participant stated 'I am principally in favour of this, but I am not sure about the way it is done in just that way. And where the money goes, should be more transparent, to put it nicely.' Here, it seems that the broader conditions for effective collaboration were lacking. Yet, extant scholarship indicates that it is exactly such trust, and such institutions, that are required if smart energy production, distribution and consumption are to be scaled up (see Wolsink 2012, Savirimuthu 2013, Ballo 2015).

Trust also came up in relation to privacy issues. A smart meter, like a sub-meter monitor, generates huge amounts of person sensitive data (EDPS 2012). If the tendency towards automation noted above persists, the potential inclusion of new technologies such as Internet of Things and blockchain could drastically exacerbate such concerns. Our living lab was seen as trustworthy in this regard, since it was small-scale, not connected to commercial interests, and not connected to the public smart metering project. People were more concerned about the general, state mandated roll-out of smart meters, and their interactions with other devices or policies, such as in-house alarms and insurance schemes. As above, the main problem seems to be generally low trust in power companies and grid operators, but also national and European institutions.

In sum, our living lab surfaced technical, energy behavioural and political economic complexities linked with smart meter roll-out. The results briefly discussed above and the data shared in the appendices challenge the prommisory discourse. They highlight dimensions that merit serious consideration in relation to the climate change mitigation potential of upscaling smart grids. Participatory design and implementation emerge as crucial dimensions of smart grid roll-out, spanning technical, behavioural and political economic domains.

Conclusion

Situating smart grids in climate change mitigation strategies

Our study brings forward evidence of a mismatch between promissory discourse on smart grids and their capacity to deliver mitigation solutions. Beyond simply developing standards to create smart grids, scaling up requires understanding and addressing interdependencies and trade-offs across scales (Frantzeskaki and Loorbach 2010, Bhatt *et al* 2014, Silvast 2017), such as painstaking consideration of privacy concerns in democratic contexts. Intra-household technical issues and energy behaviour, as well as political economic and policy structures and factors, indicate significant limits to smart grids. We argue that explicit recognition of these limits must inform urban strategies for climate change mitigation in the energy transition.

Such recognition can resoundingly close public discourse and perception of smart grids as necessarily harbingers of sustainability (Ballo 2015), and problematise prevalent state narratives by inserting citizen concerns into the public debate (see Vesnic-Alujevic *et al* 2016). It can turn focus towards the potential for automation and dynamic tariffs to contribute to mitigation efforts by streamlining policies and political economic factors towards greater grid flexibility and renewables integration (see Sareen and Kale 2018). This is especially important given the current and future rapid electrification of other sectors, especially transport (both land-based and ferries) in Norwegian cities like Bergen, which present challenges that smart grids can help address. Yet, as we have seen, such measures can give rise to tensions around privacy and generalised distrust in energy companies, grid operators and institutions at various scales. There is thus a need to closely examine these factors and identify ways to resolve them.

The BLL results show that household smart meters in themselves are not the solution that needs to be scaled for smart grid-related mitigation gains. Attention is already shifting, also in public discourse, to the scope for automation and dynamic tariffs to support grid flexibility and increasing renewables integration. But deliberative, evidence-based decision-making for emphatically pro-public energy futures must inform automation (see Demski *et al* 2015). Careful public policy and planning can champion scales, sources, distribution and ownership models of future electricity generation that minimise carbon-intensive transmission infrastructure expansion and ecosystem service disruptions (Sareen and Haarstad 2018).

While our study did not focus on automation and dynamic tariffs, we hope future research will examine these to inform an enabling policy framework with diverse, cosmopolitan imaginaries (Delina and Janetos 2018). Accompanying cross-sectoral and political economic pushes can help translate smart grid functionalities into multi-scalar renewable energy integration and thus into gains for climate change mitigation. For instance, electric-vehicle-to-grid regulations for grid flexibility are being embedded within urban cross-sectoral decarbonisation strategies (Sørensen *et al* 2018), and political economic concerns are modulating the expansion of grid interconnections in the Nordic region which would increase flexibility in national renewable energy mixes (Sovacool *et al* 2018).

The role of households in mitigation efforts based on smart grids can indeed be scalable (see Späth and Rohracher 2014), but first smart grids have to be understood correctly and publicly acknowledged as having particular tendencies and limits. Where these limits are determined by political economy, the correction of public discourse and perception to be explicit about these actual drivers will create a more constructive environment for energy policies that maximise the mitigation potential of smart grids under energy transitions. How is this correction of public discourse to take place?

Existing scholarship suggests that awareness through engagement spurs social mobilisation (Hoffman and High-Pippert 2005, Burke and Stephens 2018); thus, proactive public deliberation can correct the sort of promissory discourse that the BLL results challenge. There is a need to shift from 'hero stories' to 'learning stories' in goal-setting for energy transitions (Janda and Topouzi 2015). To support energy transitions, sustained academic pushes can counteract hollow performances of sustainability and build a culture of substantively evidencing sustainability claims to support energy transitions (Blühdorn and Deflorian 2019). Hence, disrupting business-as-usual promissory discourses, such as around smart meters, with a publicly-engaged evidence base as with the PARENT project, represents a vital step towards unlocking deep and rapid climate mitigation solutions and identifying how to scale them.

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Appendix A. January-February household electricity consumption for 2018 and 2019

Of the 46 households that participated, 43 installed the Smappee and shared data with the project from late 2017 to early 2019. The earliest began in October 2017 while most joined by January 2018. The Bergen living lab formally concluded December 2018 but some households continued to share data till April 2019. Table A1 provides an overview of household electricity consumption figures for 39 households during January and February 2018 and 2019, as these enable comparison during the same months of the year. Corresponding data for both electricity consumption and production for four participating households during the same period which produced photovoltaic electricity as well is reported separately in the manuscript. Households for which figures are available for all four months are shown in italics. Overall, changes in electricy consumption are scattered and do not show a single clear trend.

Table A1. Electricity consumption by household (January-February 2018 and January-February 2019).

				January 2019 versus 2018			February 2019 versus 2018		
No.	Household size	House type	Area (m^2)	1/2018 (kWh)	1/2019 (kWh)	Change '19/'18 (%age)	2/2018 (kWh)	2/2019 (kWh)	Change '19/'18 (%age)
1	1–2	*Apartment*	<70	515	848	+65	428	598	+40
2	1–2	House	<70	—	628	NA	—	607	NA
3	1–2	Apartment	<70	—	—	NA	1154	—	NA
4	1–2	Apartment	<70	1309	—	NA	1395	—	NA
5	1–2	Apartment	<70	—	—	NA	—	906	NA
6	1–2	*House*	71–100	5517	3674	(−)33	5716	2792	(−)51
7	1–2	*Apartment*	71–100	1042	957	(−)8	931	698	(−)25
8	1–2	*Apartment*	71–100	612	1037	+69	513	794	+55
9	1–2	Apartment	71–100	—	844	NA	1321	816	(−)38
10	1–2	House	71–100	1468	—	NA	1341	—	NA
11	3	Apartment	71–100	497	—	NA	401	—	NA
12	1–2	Apartment	71–100	1408	—	NA		—	NA
13	4	*Apartment*	101–130	3696	2121	(−)43	3342	1612	(−)52
14	4	*House*	101–130	2732	2587	(−)5	2509	2018	(−)20
15	1–2	House	101–130	—	2818	NA	2646	2045	(−)23
16	1–2	Apartment	101–130	2039	—	NA	46	—	NA
17	1–2	House	101–130	3172	—	NA	2965	—	NA
18	1–2	House	101–130	—	3160	NA	—	2542	NA
19	4	*Apartment*	>130	2700	2775	+3	2540	2189	(−)14
20	1–2	*House*	>130	4576	4025	(−)12	3794	3399	(−)10
21	5	*House*	>130	4794	5014	+5	4943	3487	(−)29
22	5	*House*	> 130	3778	3788	0	3868	3133	(−)19
23	1–2	*House*	>130	3025	3476	+15	3047	2549	(−)16
24	5	*House*	>130	2955	3043	+3	2809	2433	(−)13
25	3	*House*	>130	1209	1261	+4	1151	972	(−)16
26	3	*House*	>130	1742	2218	+27	1644	1847	+12
27	5	*House*	>130	4391	4514	+3	3886	3418	(−)12
28	5	*House*	>130	2013	1729	(−)14	1758	1392	(−)21
29	1–2	House	>130	5604	3026	(−)46	5454	—	NA
30	1–2	House	>130	1557	1372	(−)12	1366	—	NA
31	3	House	>130	5114	2142	(−)58	—	1595	NA
32	5	House	>130	3964	—	NA	3754	—	NA
33	>5	Apartment	>130	1113	—	NA	986	—	NA
34	1–2	House	>130	3446	—	NA	2941	—	NA
35	4	House	>130	5229	—	NA	4807	—	NA
36	1–2	House	>130	2728	—	NA	2437	—	NA
37	1–2	House	>130	3908	—	NA	3210	—	NA
38	5	House	>130	—	3338	NA	—	2322	NA
39	3	House	>130	—	2515	NA	—	2236	NA

Appendix B. An overview of responses by participants on pertinent Bergen living lab concerns

Ten tables based on an online survey after participation in the Bergen living lab (12 respondents). Questions and responses have been translated from Norwegian into English.

Table B1. Selected activities during Bergen Living lab and responses ($n = 12$).

Activity/effect	Neutral	Some positive	Very positive	Irrelevant
Smappee	5	7		
Newsletter	2	9	1	
Gamification graphs	3	7		2
Gamification challenges	3	4	5	

Table B2. Feedback on engagement in Bergen living lab activities ($n = 12 \times 4$)[a].

Activity/effect	Neutral	Some positive	Very positive	Irrelevant
4 meetings and workshops	2	16	7	23

Note. NB: Most participants took part only in some events, so this question was asked separately for each of the 3 focus group discussions and the workshop, which were open to all participants.
[a] 7/12 liked in-person meetings most (separate question).

Table B3. Change in interest in Smappee over time.

	Yes, decreased over time	No, remained constant
Change in interest in Smappee	10	2

Table B4. Satisfaction with Smappee and device level energy use identification.

Activity/effect	Dissatisfied	Neutral	Mostly satisfied
Satisfaction with Smappee	3	3	6
Satisfaction with device level energy use identification	9	3	0

Table B5. Frequency of checking app.

Activity/frequency	Many times a week	Weekly	Once a month	Less than monthly
Checking app	4	4	1	3

Table B6. Self-assessment of learning from the project.

Activity/effect	Maybe a little	Yes, a bit	A lot
Learning from project	4	7	1

Table B7. Suggestions for potential improvements.

'I would have liked to go to some professional lectures/seminars that went a little more in depth on smappee/energy consumption etc'.
'Seemed to be too little clarity on what the goals of the project were'.
'The theme and discussions have always interested me. The technical solution with Smappee I think is straightforward and interesting in that you could extract data from my consumption. For my own part I eventually fell 'off the bandwagon' and have probably not checked my data in the past year'.
'More practical training in the app itself on how to identify each electric article in the house'
'Comparison with other users should have been linked to climate conditions and which energy sources are used for heating'.
'Could have been more information meetings'

Table B8. What participants liked best about Smappee.

'I see the whole scheme is well thought out, good app design and the theory is there: that one can control energy consumption with access from the app etc'.
'Best liked that I could pick up the consumption in real time'.
'Easy to use. Relatively informative interface'
'Provides a good overview, is more proven where consumption is'
'Design and potential'
'Seeing total consumption'
'Overview of daily consumption and management of 433 MHz switches'.
'That it provided detailed information on use in time and quantity'
'Contributes to awareness and being informed'
'That I can see accurate consumption at any time'
'Real-time display'
'The visual aspects'

Table B9. What participants liked least about Smappee.

'It was not user-friendly and I do not know if I trust the numbers I got from it when it comes to total energy consumption. Several times I was locked out of the app and it took time to get into it again. And then there was a new smappee app without the old one being deleted, so then I sat with 2 Smappee apps on my phone ... one should be able to rely on numbers and trust that the app you use is the right app'.
'They seemed to promise a little more than they actually did with regard to distinguishing different consumption items in the house'.
'The app was never good enough to distinguish between different appliances and equipment, so that it was not possible to save on some things'.
'Difficult/time consuming to name the sources well enough'
'It was unable to distinguish between the electrical appliances and most of the suggestions were wrong. Had to use a lot of time to define a single device'.
'It promised too much'
'Too simple. Too little detail in consumption statistics. Not possible to customise'.
'Had trouble naming different devices. The user interface became too complicated'
'Identifying electric articles'
'Device identification was flawed, to put it mildly'
'Identification of single devices did not work at all. It was therefore very difficult to assess how the energy consumption was distributed among different units.'
'Problems identifying the various household appliances'

Table B10. Self-assessment of any reduction in participant's home energy use during the project.

'From the electricity bill it looks like our energy consumption has gone down since last year'
'My energy consumption remained the same'
'My energy consumption remained the same'
'Yes, when I think through actions I did, I have a strong feeling that I reduced my energy consumption'
'I'm not sure, but I think I reduced my energy consumption'
'My energy consumption remained the same'
'I'm not sure, but I think I reduced my energy consumption'
'I'm not sure, but I think I reduced my energy consumption'
'I do not know'
'My energy consumption remained the same'
'Purchased electric car during the period, and that significantly changed consumption'.
'I'm not sure, but I think I reduced my energy consumption'

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