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Damsø, Tue Noa Jacques; Kjær, Tyge; Christensen, Thomas Budde

Published in:
Journal of Cleaner Production

DOI:
10.1016/j.jclepro.2017.08.156

Publication date:
2017

Document Version
Peer reviewed version

Citation for published version (APA):
Damsø, T. N. J., Kjær, T., & Christensen, T. B. (2017). Implementation of local climate action plans: Copenhagen - towards a carbon-neutral capital. *Journal of Cleaner Production*, *167*, 406-415. https://doi.org/10.1016/j.jclepro.2017.08.156

Implementation of local climate action plans: Copenhagen – towards a carbon-neutral capital

Tue Damsø*,[a], Tyge Kjær[a] & Thomas Budde Christensen[a]
[a] Department of People & Technology (DPT), Roskilde University (RUC)
P.O.-box 260, DK-4000 Roskilde, Denmark.
*Corresponding author: tnjd@ruc.dk; +45 2022-1373

Highlights:

- Assessment of implementation and monitoring in local climate action planning.
- A case study: the plans and activities of the Copenhagen municipality.
- High implementation performance in terms of system changes and emission reductions.
- GHG indicator useful for benchmarking but challenged in terms of specificity.
- Neutrality target results in inconsistent scope, challenging long-term transition.

Abstract:
The purpose of this article is to improve understanding of local climate action plans and their implementation and evaluation. It explores how goal definition and the choice of assessment metrics frame goal attainment and influence implementation behaviour. Using the Danish capital of Copenhagen for an in-depth case study, we map activities undertaken and assess implementation performance in terms of infrastructure changes and GHG emission reductions during the period from adoption of the first climate action plan in 2002 to the present day (2017). The study shows that while Copenhagen exhibits a high overall implementation performance, both in terms of changes in energy supply and emission reductions, these metrics are only partially linked. It also shows that inconsistencies between the system scope of the base year emissions and goal attainment, due to the use of offsetting, may lead to system developments that inhibit further changes beyond the initial target period. The article concludes with a list of lessons learned for other cities that are in earlier stages of climate planning. Most importantly, the study points to the need for activity-related evaluation metrics, scope consistency, and targets that can provide a robust incentive through changing energy systems.

Keywords:
Implementation, Assessment, Indicators, Monitoring, Energy transition, Mitigation

1. Introduction

Mitigating global climate change will be one of the defining challenges facing current generations (Scrase et al., 2009). While the problem is global in nature, the human activities driving climate change are indisputably local. The greenhouse gases (GHG)[1] accumulating in the atmosphere are the result of emissions from the use of fossil fuels and from agriculture, forestry, industry and waste taking place in a local context (Wilbanks & Kates, 1999; Bai, 2007; Bulkeley, 2013). In mitigating the problem, we should focus our attention on reducing these emissions, and in doing so local governments may play a crucial role (Rayner, 2010; Fudge & Peters, 2009; Musco, 2010). In this paper, we aim to expand the knowledge of climate change mitigation activities by local governments by studying the implementation and assessment of local action after the adoption of a local climate action plan (CAP). Reviewing the field of local climate action, we can observe that a large number of local governments are joining international networks, adopting local CAPs and pledging ambitious mitigation action (Bulkeley, 2010; Corfee-Morlot et al., 2009; Damsø et al., 2016). This emergence of local climate action planning and the adoption of local CAPs have been studied extensively. To name a few such studies, Wheeler (2008) assessed the first generation of CAPs adopted by US states and local governments, Bedsworth and Hanak (2013) surveyed the adoption of policy tools and programs in California, Dixon and Wilson (2013) examined the attitudes of climate change officers in UK cities, and Damsø et al. (2016) studied the extent of local climate action planning in Denmark. Far less research, however, has been conducted on what happens after the adoption of a CAP, i.e. on its implementation and subsequent evaluation, with several authors highlighting the lack of impact studies as an urgent issue to be addressed (Bulkeley, 2010, 248; Salon et al., 2014; Wheeler, 2008). Turning first to *implementation*, the studies that have been completed point to significant difficulties with the execution of these action plans, indicating that they are seldom implemented fully and are characterised by grabbing

[1] Abbreviations: AMW: Amager CHP, AVV: Avedøre CHP, CAP: Climate Action Plan, CHP: Combined Heat & Power, CCS: Carbon Capture and Storage, CPH: Copenhagen, DH: District Heating, EV: Electric Vehicle, GHG: Greenhouse Gas, GPC: Global Protocol for Community Scale Greenhouse Gas Emission Inventories, HOFOR: Hovedstadens Forsyning [the capital's utility company], LG: Local Government, PV: Solar Photovoltaic, W-t-E: Waste-to-Energy plant.

the ‘low-hanging fruit’ while not addressing the more challenging long-range aspects (Musco, 2010; Bulkeley, 2013; Rice, 2013; Sperling et al., 2011; Milliard-Ball, 2012). Implementation is usually evaluated through performance *assessments*, which determine whether the effects of plan implementation are indeed the desired effects (Crossley & Sørensen, 1983). The indicators that are used while monitoring performance influence the perception of goal attainment.

This article intends to fill the knowledge gap on CAP implementation through an extensive case study of Copenhagen, the capital city of Denmark, and to discuss the inter-relationship between implementation and performance assessments. The aim is to improve the validity and utility of monitoring systems in ensuring the contribution of local CAPs to climate change mitigation. Copenhagen was chosen for several reasons: it was one of the first cities to set ambitious climate change mitigation targets; it is a large capital city and a member of the C40 group; and it is renowned as a leading environmentally friendly and green city (EU, 2013; Floater et al., 2014, Morlet & Keirstad, 2013). The city has a goal to be climate neutral by 2025 (we will discuss later what that implies). The fact that the city has been actively involved in climate action planning for nearly two decades makes it possible to study the relation between the planning and implementation stages, and further to study how CAPs are developed over time, and from this to flesh out important lessons for other cities that are at earlier stages of climate action planning.

2. Methodology

A **case study approach** is applied in studying implementation and assessment, to allow an in-depth review (EC, 2004; Bryman, 2004). The Copenhagen municipality has been selected as the case. The key methodological approach is **document analysis**, utilizing both quantitative and qualitative content analysis techniques (Robson, 2011). The documents used in the analysis were collected from websites, supplemented by online search engines and email enquiries.

The document analysis included the following documents:

- Greenhouse gas accounts 2005 and 2008–2015
- Environmental accounts 2007–2014
- CPH Climate Project reports 2014 and 2015

- Midterm evaluations 2012–2015
- Municipal budgets for 2004–2016 and annual financial reports from the local utility company, HOFOR, and subsidiary companies for the same period
- Municipal Climate Action Plans 2002, 2007, 2009 and 2015
- Municipal spatial plans 2005, 2009, 2011 and 2015
- Municipal waste plans for 2008, 2012 and 2018 (target year)
- Waste water plans for 2008
- Strategies from local utility companies Biofos and Københavns Energi (Copenhagen Energy, now HOFOR).
- In addition, a screening of all reporting to LG networks in which Copenhagen participates, and information on specific initiatives at all relevant websites have been conducted, and results added.

The collected data were sorted and key information extracted with content analysis techniques, through which the targets and initiatives of the various CAPs were identified and sorted following a specified coding manual. Implementation was then assessed by reviewing the aforementioned documents thematically, following a categorization established by the CAP content. Subsequently we conducted an analysis of implementation, performance and assessment tools using the method and approach described in the next section.

In addition, **interviews** were subsequently conducted with key actors, with the aim of qualifying our observations on implementation performance and providing additional information on the implementation process and methods of monitoring performance. Two interview techniques were employed: 1) a semi-structured technique in which an interview was conducted, condensed, and a transcript submitted to the interviewees for verification, and; 2) a structured interview in which a list of questions was submitted to the interviewee and answers were returned by email (Bryman, 2004; Connolly et al., 2010). The choice of technique for each interview was based on interviewee availability, with the former being the preferred method and the latter applied in cases of unavailability.

2.1. Local planning efforts

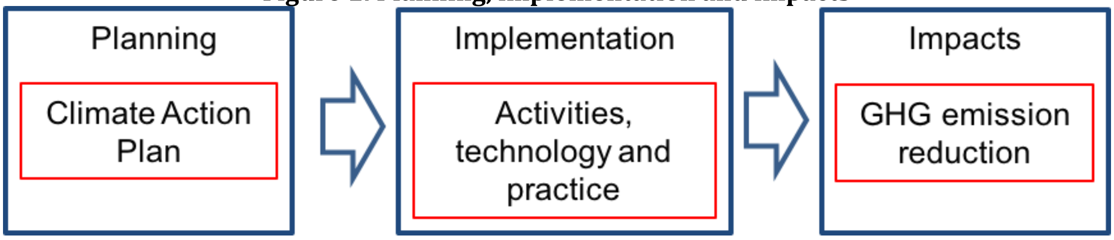
In categorising and using the extensive data, we distinguish between the stages of planning, implementation and assessment following Crossley and Sørensen (1983). We study the implementation work of Copenhagen municipality and its continuing performance assessments, in order to assess the long-term relevance of implementation activities and the utility of assessment measures in informing local planning efforts.

Planning: Several aspects of CAP content are of key relevance for implementation and performance assessment, in particular the scope, the target, and the strategies and activities to be undertaken in reaching it. The *scope* defines the boundaries of the emission system, which includes defining and delimiting the spatial boundaries, sectors, and activities included (Kramers et al., 2013; Levin et al., 2014). The *target* determines the temporal scope, the unit, range and type of objective at hand (Kramers et al., 2013; Levin et al., 2014; Damsø et al., 2016). Finally, *mitigation strategies*, or activities and initiatives, are formulated to be undertaken in reaching the target (Boswell et al., 2012).

Implementation: Implementation is the stepwise process of executing a plan and translating goals into action (Ryan, 2015). Each individual project must both stand alone in the present-day system, and contribute towards the overall strategic target of the CAP. In this study we use a logical framework approach (EC 2004) in distinguishing between the plan's implementation and its effect (measured as changes in GHG emissions).

Assessment: Most approaches in local climate action planning employ a traditional goal-attainment evaluation model, in which assessments are primarily used to determine goal attainment (Hansen, 2011). Furthermore, assessments have the operational purpose of contributing to the design and modification of interventions, as well as the accountability aspect of reporting on achievements (EC, 2004; Crossley and Sørensen, 1983). Following this approach, assessments can be conducted for output, outcome and impact respectively, usually by the formulation of indicators, i.e. metrics providing information on performance (Boswell et al., 2012; Hammond et al., 1995; Rich et al., 2014). To simplify the analysis we distinguish between planning, implementation (actions) and effects (changes in GHG emissions). The relationship between the key concepts of the different planning stages is illustrated in figure 1.

Figure 1: Planning, implementation and impacts



Source: Own elaboration. The blue boxes show the planning stages and the red boxes the key aspects reviewed for each stage in this study.

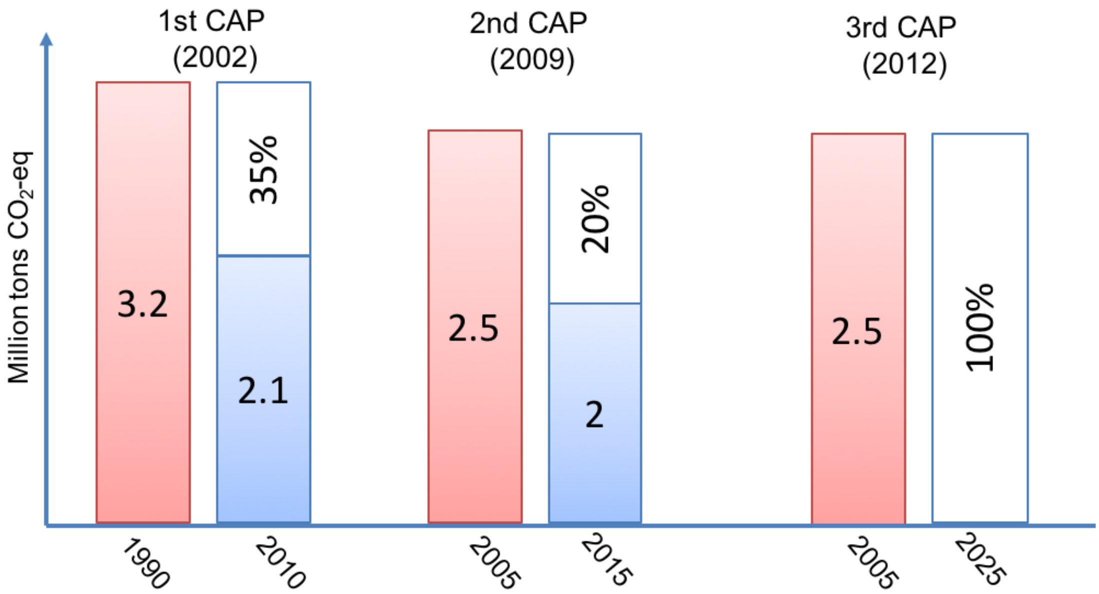
3. Results

Copenhagen is the capital of Denmark. The city is situated on the eastern coast of Zealand, along the Øresund strait. It is joined to Sweden by the Øresund Bridge and has a total area of 74.4 km^2, covering less than 1% of the country (EU, 2013: 15; DST, 2016a). The population of the municipality is 602,448 (2017), in addition to which there is a large adjacent population relying to some extent on the city as well, with 1.2 million inhabitants of the greater Copenhagen area and 2.6 million in the Copenhagen-Malmö metropolitan region (EU, 2013; DST, 2016b, 2016c). Denmark has undergone a significant energy transition since the mid-1970s, moving towards a decentralized, efficient and sustainable energy system (Damsø et al., 2016; Sperling et al., 2011). As a result, Denmark has a high proportion of distributed energy generation and the lowest energy intensity in the European Union (Morlet & Keirstad, 2013; Damsø et al., 2016). In Copenhagen, 98% of households are connected to the district heating system, for which the energy is primarily supplied from combined heat and power (CHP) plants and waste-to-energy facilities (EU, 2013; Floater et al., 2014). The city also has a long history of effective spatial planning in support of its environmental performance, with high accessibility to public transport and a large proportion of its inhabitants using bicycles as their primary means of transport (Gössling, 2013; EU, 2013; Floater et al., 2014). It follows that the energy and transport systems in Copenhagen have undergone a transition and that further improvements will require significant effort, as most of the low-hanging fruit has been harvested. The municipality is an active participant in a range of municipal networks, including the Covenant of Mayors, the Compact of Mayors, C40, and the Carbon Neutral Cities Alliance (C40, 2016; Compact, 2016; Covenant, 2016; USDN, 2016).

3.1. Copenhagen's Climate Action Plans

The municipality has adopted three CAPs in the past two decades. In 2002 it adopted a CAP with a target of reducing emissions by 35% by 2010, compared to 1990 (CPH, 2002). This target was supplemented in 2007, when the municipality published an eco-metropolis vision (CHP 2007) containing a number of sustainability targets, including a target to reduce emissions by 20% by 2015, compared to 2005. A 2009 CAP outlined the initiatives intended in order to reach this target, and established an additional carbon neutrality target for 2025, which was subsequently expanded on in the most recent 2012 CAP (CPH, 2009a). The target levels are illustrated in figure 2.

Figure 2: Target levels



Source: Own adaptation based on CPH 2002, 2009a, 2012a. The red columns represent base year emissions for the different targets, the white boxes (lined in blue) the emission reduction in percentage and the blue boxes the remaining emissions in the target year.

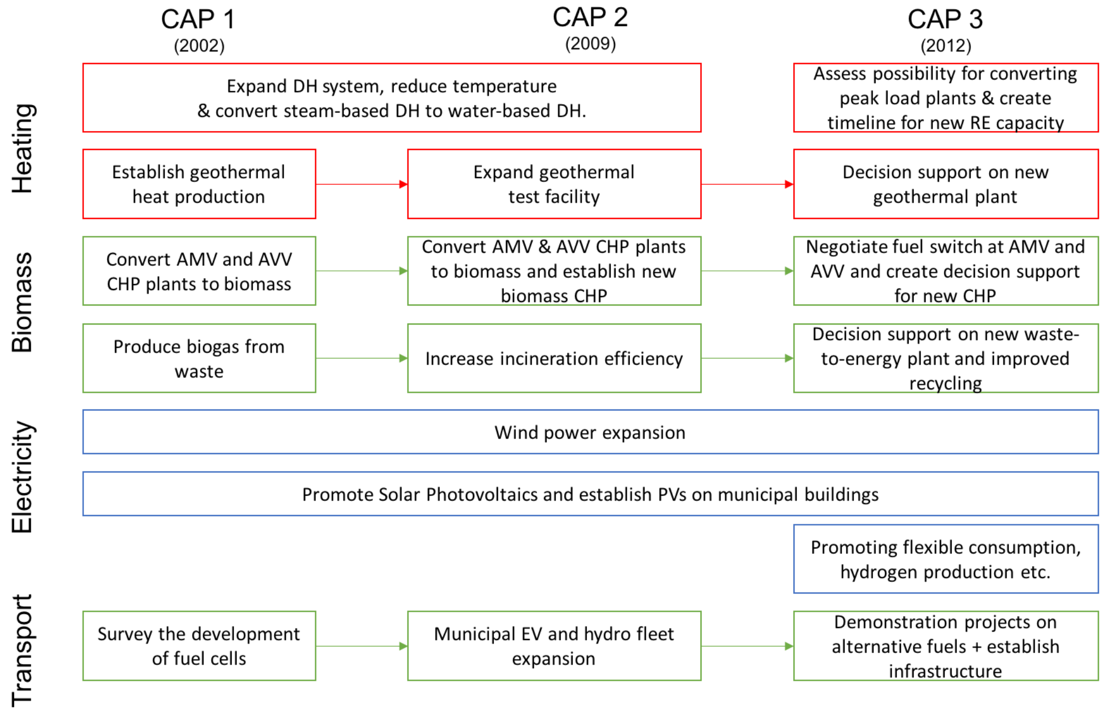
With regards to *target* typology, the municipality used base-year emission goals in the first two targets, switching to a fixed-level target with the carbon neutrality goal in the second and third CAPs (Levin et al., 2014). The *scope* is somewhat consistent throughout the CAPs, using the geopolitical jurisdiction as the spatial boundary and including emissions occurring in the municipality and emissions related to grid-supplied energy consumed in the municipality, generally referred to as scope 1 and 2 emissions (Kramers et al., 2013; Fong et al., 2014; CPH, 2015a). The carbon neutrality goal, adopted in the 2009 CAP, declares that the municipality should reach a zero net emission by 2025, which may be achieved by a combination of emission reductions in Copenhagen and by crediting transferable emission reduction units from the reduction of emissions outside its geographical boundary (CPH, 2009a). Net emissions are determined by accounting for renewable electricity production inside the municipal boundary as well as outside it, if the municipality has had a significant influence on the establishment of it. These GHG reductions are then subtracted from the municipal emissions, to arrive at net CO_{2e} emissions (CPH, 2015a). With regards to the *mitigation strategies*, the CAPs vary somewhat in their quantification and specificity of initiatives. The third CAP makes distinctions between three implementation periods, the first in 2013–2016, the second in 2017–2020 and the third in 2021–2025 (CPH, 2012a). Each stage concludes with an evaluation of the progress made and a roadmap for the subsequent phase that specifies the initiatives for the given implementation period (CPH, 2012a). The evaluation of the first period (CPH, 2016b) and the roadmap for the second (CPH, 2016e, 2016f) were completed and reviewed by the municipality’s Environment Committee in June 2016 (CPH, 2016d).

Unsurprisingly, the energy sector contributed the largest share of emissions throughout the 2000–2010 period. This energy sector in the CAPs therefore also comprises the largest share of initiatives, and the initiatives with the largest impact (CPH, 2002; 2009a; 2012a). As a result, this study will focus on the energy sector, in particular energy supply. The study should ideally include all mitigation activities; however, the total of 165 initiatives in the three CAPs makes a comprehensive assessment of them all an insurmountable task, whereas focusing the analysis on key initiatives allows us to conduct an in-depth review and discussion. For this purpose, the energy supply initiatives have been selected. They contain the largest expected reduction by far, as well as a high degree of written documentation, allowing an analysis based on document study.

3.2. Implementation

A total of 51 mitigation initiatives in the energy supply sector can be identified in the three CAPs. From the first CAP (2002), 12 initiatives with an expected emission reduction of 475,800 tons CO_2-eq have been included, comprising 83% of the total quantified reduction (CPH, 2002). From the second CAP (2009), nine initiatives with an expected reduction of 617,000 tons have been included, covering 72% of the total reduction in the CAP. The 30 supply initiatives from the third CAP (2012) amount to 885,000 tons, or 82% of the expected total reduction resulting from the CAP (CPH, 2009a; 2012a). The initiatives were selected based on the criterion that they relate to the energy supply sector, which alongside electricity production and district heating initiatives include fuel switching in the transport sector and refurbishment of the existing (soon to be former) waste incineration plant. The initiatives with the largest expected mitigation effects relate to changes in the district heating system, fuel switching from coal to biomass at CHP plants, wind power expansion, and waste incineration (CPH, 2002; 2009a; 2012a). The key energy supply initiatives from the CAPs are illustrated in figure 3.

Figure 3: Energy supply initiatives in Copenhagen CAPs



Abbreviations: AMV: Amager CHP, AVV: Avedøre CHP, DH: District Heating, EV: Electric Vehicles, PV: Solar Phtovoltaic. Source: CPH, 2002, 2009a, 2012a. The red boxes contain initiatives aimed at reducing emissions from heating, the blue boxes initiatives aimed at reducing emissions from electricity consumption and the green boxes contain initiatives on switching to biomass based fuels in energy production and transportation.

While there is a significant recurrence of initiatives in some thematic areas, there are also noticeable differences in the focus of the CAPs. Only the first CAP contains a significant share of initiatives aimed at improving the district heating system. Conversely, the third CAP has a significantly larger share of initiatives aimed at promoting a fuel switch in transport and on the incorporation of wind power in the electricity system. Looking at wind power, for example, the first two CAPs contain initiatives on wind power expansion, while the third includes several initiatives on identifying potential sites, negotiating with landowners, and promoting a new billing model. The change is likely due to an increased focus on the modes of governance available to the municipality, and to the fact that several initiatives take the form of studies or demonstration projects with the purpose of clarifying the applicability of initiatives for future implementation periods, in addition to reducing emissions in the current target period (Kristensen, 2016; CPH, 2016f).

Comparing the implemented activities and the planned activities from the CAPs, the municipality has largely achieved its targets, although some areas are significantly off target (a full thematic account of implementation activities is included in Appendix A). In 2012, in a mid-way evaluation of the second CAP (CHP 2012b), the municipality concludes that of its 50 initiatives, four had been completed, 37 had been started, and only five had been abandoned. Conversely, in the most recent evaluation report (CHP 2016), of 19 of the milestones in the 2012 CAP, six were on target, six were underway but slightly behind schedule, and seven had significant shortfalls; most of the 66 initiatives had been started.

Focusing on the energy supply initiatives reviewed in this study, it was reported that the district heating system development was on track and appeared to have progressed without major delays. Significant steps had been taken in waste utilization, with the establishment of a new waste-to-energy facility and biogas plants for wastewater treatment. However, the collection of plastics and biogas production on organic waste fractions were not completely on track. With regards to wind power expansion, the municipality was behind its expansion target (64 MW of 140MW target for 2015), but had taken steps to improve it, amongst other things by assigning responsibility to the utility company. Similarly, for biomass utilization, difficulties in ensuring the targeted transition of the Amager CHP facility led the utility company (HOFOR) to acquire the plant, finalizing the plans for a conversion in 2014 and expecting the converted plant to be in operation by 2020 (CPH, 2015b). With regards to fuel switching in the transport sector, the municipality was on track with expanding infrastructure and converting the municipal fleet, but significantly behind target on the diffusion of alternative fuels outside its own fleet.

As of 2017 only a few projects have been initiated on improving the flexibility of the electricity system, which could be intended as the second roadmap greatly enhances efforts in this area (Edström, 2016; Kristensen, 2016; CPH, 2016f). No activity has been taken on promoting CCS, and the municipality has faced some difficulties in achieving the target on geothermal heat, due to challenges with the test facility.

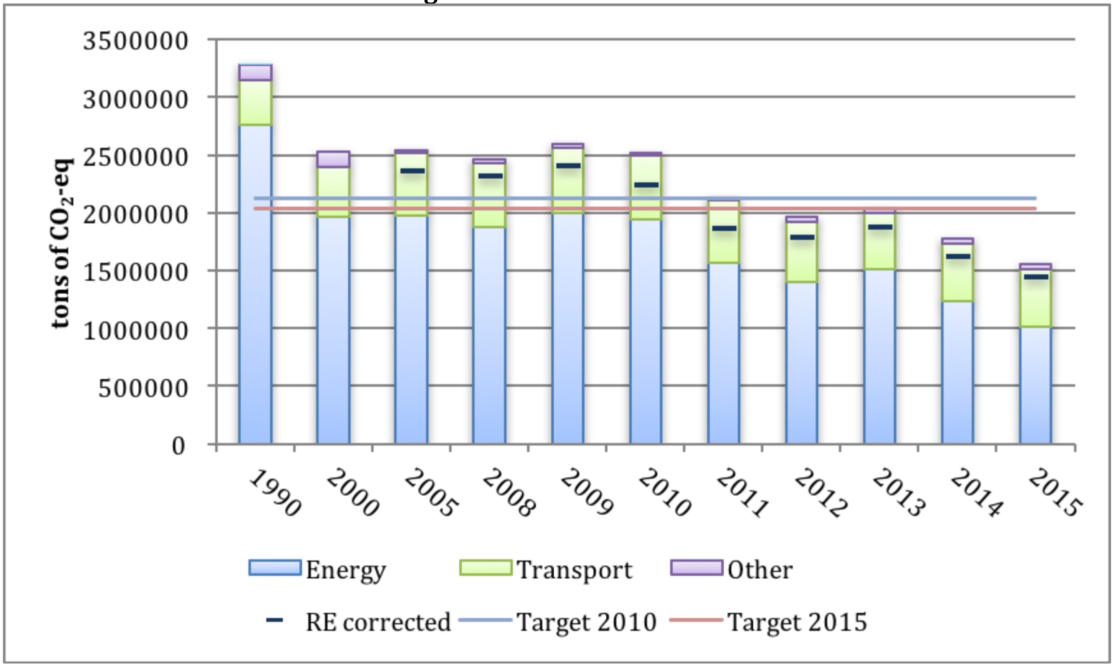
In June 2016 a roadmap for the 2017–2020 implementation period was introduced, containing 46 new initiatives and 15 initiatives carried over from the 2013–2016 roadmap (CPH, 2016d). The report concludes that if all initiatives were halted the

2025 emissions would be 900,000 tons of CO_2-eq, and even if the planned initiatives were completed, there would be a shortfall of 286,000 tons (CPH, 2015b; 2016d; 2016f). Several new initiatives were introduced to address this shortfall, including an additional 100 MW of wind power to be added to the existing target of 360 MW by 2025, initiatives to increase the collection and separation of plastics in waste incineration, increased PV expansion, as well as studies and initiatives on alternative fuels for transport and flexible consumption and production of electricity (CPH, 2016d, 2016e, 2016f). Combined, the new initiatives were expected to deliver a reduction of 367,000 tons, thereby covering the shortfall (CPH, 2016e).

3.3 Impact (reduction in GHG emissions)

In addition to investigating the implementation (understood as meaning the activities, installation of technology, processes, etc.) of the CAP, we can assess the impact of CAP implementation in terms of GHG emission reductions. Most municipalities, including Copenhagen, use emission reduction targets as 'the bottom line' in climate action planning and we are therefore able to assess their goal attainment by evaluating the *impact* of the *implementation* in terms of the reduction of GHG emissions. Figure 4 sets out the municipal emissions for the 1990, 2000 and 2005 base years as well as for the period 2008–2015, for which GHG accounts have been completed and published (CPH, 2008, 2009b, 2013a, 2015a, 2016a). These emissions are compared to the 2010 and 2015 target levels respectively.

Figure 4: Goal attainment



Source: CPH, 2002: 10, 2008: 6, 2009a: 7, 2009b: 6, 2013a: 11, 2015a: 9f; 2016a: 9f. The columns show emissions subdivided into emission categoriers. The solid lines indicate emission levels corresponding to the 2010 and 2015 targets respectively. Renewable Energy (RE) adjustment is calculated by subtracting the municipalities production of RE electricity (inside and outside the municipality) from their total electricity consumption before calculating emissions for the remaining consumption, indicated by the dark blue bar.

The municipality calculates total emissions both with and without adjustments for local renewable energy production, i.e. with and without the inclusion of transferable emission units in calculating goal attainment. This adjustment is completed by mapping the municipality's RE electricity production and subtracting it from the total electricity consumption before calculating emissions associated with the remaining electricity consumption, indicated in figure 4 by the dark blue bar (CPH, 2015a; Nielsen et al., 2009). From the figure, we can conclude that the 2010 target was not reached, with emission levels exceeding the target by between 383,704 and 113,111 tons of CO_2-eq, depending on the calculation procedure for local RE production. The 2015 target, conversely, was significantly overachieved, with 2015 emissions below the target level by 582,442 or 480,902 tons of CO_2-eq. With a decade's worth of mitigation action before the third target year, it is too early to assess whether this target will be reached, but we can discuss current progress towards it. If the target is to be reached, emissions must on average be reduced by

152,404 tonnes of CO_2-eq annually (7.14% of base year emissions) throughout the period 2011–2025. Looking at the achieved reductions according to the GHG accounts, the annual reduction in the period 2011–2015 was 145,440 tonnes, or 6.8%, or about 5.6% if RE adjustment is included (CPH, 2015a). While this is a fairly impressive reduction rate, it does not put the municipality on course to achieving the 2025 target.

3.4 Monitoring progress and effects

Alongside the quantitative metrics on energy consumption and RE expansion, the municipality conducts two types of evaluations: the annual monitoring reports and the periodic evaluation reports (EC, 2004). Looking first at the annual reports, they have a thematic structure, highlighting particular projects instead of conducting a full account on the progress of CAP implementation (CPH, 2014a; 2015b). This is consistent with their purpose of disseminating completed initiatives and sharing best practice examples, and as such their applicability for evaluation is of less concern (CPH, 2014a; Kristensen, 2016). The midway evaluation of the second CAP and the first evaluation of the third CAP, conversely, included full accountings of CAP progress, reviewing all initiatives and characterising implementation performance using a three-level classification system (CPH, 2012b; 2016b). A discussion on difficulties in implementing initiatives and an evaluation of whether initiatives can be continued in the subsequent CAP are included as well (CPH, 2012b; 2016b). In addition to the formal evaluations, a one-page description specifying the purpose, success criteria and timeline for implementation is completed for each initiative annually (Kristensen, 2016). These descriptions act as a basis for regular coordination meetings between the municipality, the utility company (HOFOR) and other relevant parties (Edström, 2016; Kristensen, 2016). Two or three times a year they assess and report progress to management, to ensure that challenges are addressed (Kristensen, 2016). These project descriptions and coordination meetings clearly act as the primary means of operational monitoring, while the evaluation reports are used to assess whether progress is on track, taking new technology and changes to framework conditions into account, and creating the basis for the subsequent implementation period (CPH, 2016c). In combination, they appear to be a highly useful way of assessing implementation performance.

3.4.1. Impact assessments

The key assessment metric with regards to CAP impact is GHG emission monitoring. While some of the GHG emission reduction can be ascribed to local activities, a substantial part of it is achieved outside the scope of the municipality. Looking at the electricity sector, which provides by far the largest reduction, electricity consumption fell 4% in the period 2005–2015, local RE production increased 13%, whereas the emission factor for the national Danish electricity grid was reduced by 55% in the same period (CPH, 2008; 2016a). While changes to consumption and local RE production can arguably be tied to the local CAP, the emission factor is for the national grid and includes changes at the national level, which inherently limits the validity of the measure in monitoring local action. This affects the changes in other sectors as well; for example, several of the trains operating in Copenhagen run on electricity (CPH, 2008; 2016a). In the district heating sector, which provides the second-largest contribution, the primary means of reduction is again changes to the emission factor, with a 32% reduction over the period 2005–2015 (CPH, 2008; 2016a). However, while the district heating system covers several municipalities, Copenhagen holds a significant influence, and it could be argued that the changes in emissions in this sector were due largely to local activity, such as converting the Amager CHP. GHG accounting is the key metric used in monitoring progress on local action, and while it provides an easily understandable and reportable metric useful for benchmarking performance, our study indicates that there are challenges as changes in GHG performance may originate from other sources (e.g. changes in the emission factor of the national grid) than the local activities it is intended to measure.

4. Discussion

4.1. Implementation performance

With regards to the ***framework conditions***, the Copenhagen case indicates that the frameworks provided by national governments significantly influence how GHG reductions are pursued. In Copenhagen, this can be seen in the changes to the PV expansion strategy following changes in national support schemes, the abandonment of plans for a toll ring around Copenhagen due to a lack of government support, and most recently the government's plans to cancel the erection of coastal wind turbines following HOFOR's prequalification for tender (HOFOR, 2014; CPH, 2015b, 2016f; Altinget, 2016; DEA, 2016). Through establishing the framework conditions, the central government can attempt to maintain the dominant strategic line, which is often considered necessary in ensuring a long-term perspective and coordinating the many local initiatives (Smith, 2009; Giddens, 2009). The importance of these strategic guideposts is particularly evident if we review the mitigation effort of Copenhagen in a ***long-term perspective***. The Danish energy system is currently in a transitional stage, between a system based fully on fossil fuels and a system based exclusively on renewable energy (Sperling et al., 2011). In the course of a system transition this is a natural developmental step, and in the coming years further transitions will lead to continuous system changes, which necessitates an intertemporal system optimization. Specific projects and technologies should be evaluated not only on their 'fit' in the current system but on their robustness in adapting to future system developments. In a transition from a fossil fuel based system to one based on renewable sources of energy, increasing RE penetration will create different demands for system integration and increased decentralisation (Sauter & Bauknecht, 2009). Targets and projects should ideally be able to accommodate this change. A key example is the increased use of biomass for heat and electricity production, which arguably should be used as a transitional fuel in the heating sector and subsequently be employed in sectors with fewer alternatives, for example the transport sector (Edström, 2016; Klimarådet, 2015; Floater et al., 2014; Kristensen, 2016). Following this argument, the current expansion of biomass-based heat capacity could arguably lock the city into a development pathway that may be difficult to reconcile with those ambitions, as well as being costly and challenging to reverse (Floater et al., 2014). The municipality is aiming to address this challenge and avoid suboptimization by developing a plan for the long-term transition to becoming a fossil fuel free city in 2050 (CPH, 2016f; Kristensen, 2016). In addition to the municipality adapting its targets and initiatives to fit long-term objectives, ensuring robustness in system development will require a high degree of coordination and cooperation between various local actors and across various levels of government on transboundary issues such as biomass utilization.

4.2. Assessment measures

Monitoring and evaluating impacts is the key to ensuring accountability as well as enhancing learning and implementation effectiveness in local climate action (Lehtonen & Kern, 2009). The case study of Copenhagen municipality indicates that the GHG emission metric, used as the bottom line in most local climate action planning, is only partially linked to local mitigation effort. In the final section of this paper we explore the relation between the targets and associated indicators applied by Copenhagen municipality.

As argued by Lehtonen and Kern (2009), using GHG emissions as an indicator is valuable in giving a sense of direction and acting as a political signpost. It is simple to measure and is principally related to the key impact – the reduction of GHG emissions. However, as shown in the analysis, the indicator is only partially linked to local action and the results obtained are therefore only partially linked to the activities undertaken. ***Indicators*** used in assessing progress towards climate targets should be measurable and should be analytically sound and valid as well as having policy relevance and utility for users (Schepelmann et al., 2010). These aspects are intrinsically linked, as policy relevance and utility require that feedback is specific to the activities undertaken. Copenhagen municipality primarily employ GHG accounts to monitor and report on progress towards the overall goal, while the continuing operational planning and monitoring employ activity-based indicators related to the specific initiatives (Edström, 2016; Kristensen, 2016). While this application of parallel monitoring systems is likely quite common, it does create some challenges, when arguing the need for increased effort in situations where emission reductions are on schedule.

The challenge is related to how a ***target*** is defined, as the definition also frames the strategies used to pursue it and the indicators employed in measuring performance. The temporal scope of the target, i.e. whether it is a long-term or short-term goal and whether it requires annual reductions or reductions in a single future target year, self-evidently shape the way municipalities will work to achieve it. It follows that the widespread reframing of mitigation action in terms of local job creation and green growth has implications as to what activities are undertaken as well, shaping the focus of the plan towards the areas relevant for this issue bundling (Bulkeley, 2010; Sperling et al., 2011). Similarly, using emission reductions as the main objective and emission accounting as the bottom line may lead to a different conceptualisation of the energy system than if an overall system transition was the main goal (Sperling et al., 2011: 1344). Kramers et al. (2013) argue that targeting only GHG emissions may be too narrow an approach, as local emissions may be reduced by using a larger share of biomass-based energy than is globally available, causing other cities to have access to fewer biomass resources and resulting in higher emissions. While the planners in Copenhagen clearly work towards avoiding this suboptimization, a target related to a broader set of indicators might support that effort.

Finally, the ***scope*** of the system for which a target is defined may also influence the carbon management strategy. In Copenhagen, this system scope is affected by the carbon neutrality target. Whether a zero carbon or a carbon neutral target is adopted affects the strategy for managing municipal emissions. If a zero carbon target is used, emissions will have to be eliminated, which in turn can inspire significant innovation in technology and operational strategies. Conversely, a carbon neutrality target allows for balancing or offsetting emissions, which inherently reduces the need for system changes (Kennedy & Sgouridis, 2011). There is a different incentive associated with balancing as opposed to eliminating emissions, which will likely influence the selection of activities. Looking to Copenhagen, this is evident in the focus on wind power expansion outside the municipality instead of on activities aimed at mitigating emissions inside its geographical boundaries, for example in the transport sector. Conversely, one could argue that the availability of the offsetting mechanism allows the municipality to set a more ambitious target than would otherwise be possible. The principal task of climate action targets and plans are to create a mandate for mitigation action, which the carbon neutrality target has achieved.

We would however like to highlight a few challenges associated with this procedure: *firstly*, that the application of a target dependent upon the offsetting effect of particular projects is associated with some risks. Recent reports from the municipality argue that the displacement effect of the municipal windmills was less than expected, as emissions from electricity in Denmark have been greatly reduced (CPH, 2016c; 2016f). As a result, they propose further efforts including an additional 100 MW of wind power to increase the carbon displacement effect (CPH, 2016f). Naturally, the new roadmap is faced with the same challenges as the previous one in that regard. *Secondly*, that the inconsistency between the system scope of the municipality and the scope of the target promotes a focus on abatement cost instead of on the necessary initiatives in a system transition. While a transition should naturally be completed at the lowest possible price, offsetting creates a cap on abatement cost corresponding to the price of setting up wind turbines elsewhere, as initiatives exceeding that abatement cost are financially inefficient. To avoid short-term suboptimization as a result, the municipality proposed a 2050 fossil-free target and plan, which may counteract the offsetting incentive to some degree (Kristensen, 2016). Whether or not it will be able to guide a long-term system transition for the Danish capital could be a highly relevant topic for further enquiry following the 2025 target year.

5. Conclusion and Policy Implications

The study shows that Copenhagen exhibits a high overall implementation performance, both in terms of changes in energy supply and emission reductions. Copenhagen significantly overachieved its 2015 target and is moving at an impressive pace towards its climate neutrality target for 2025 (within the logic of its chosen GHG accounting framework). The study demonstrates how a city can function as an important facilitator for climate change mitigation – in the case of Copenhagen, primarily through close collaboration between the municipal administration and the local utility owned by Copenhagen and a group of neighbouring municipalities.

However, the case study also shows inconsistencies between the system scope of the base year emissions and the scope of goal attainment due to the use of offsetting (in this case, switching from coal to imported biomass at two power stations and installing wind turbines outside the geographical boundaries of the city). The paper argues that these may lead to system developments that inhibit further changes beyond the initial target period.

An important lesson is therefore that the choice of GHG accounting procedure is crucial to goal attainment, but also that while offsetting GHG emissions may seem attractive to municipalities, the long-term implications may prove to be less appealing. With respect to GHG accounting procedures, the study points to the need for activity-related indicators, consistency of scope, and targets that can provide a robust incentive to change energy systems. These are core learning outputs from the case study.

A final lesson from the Copenhagen case study is that while the emission neutrality target (in the case of Copenhagen, the production of enough renewable energy to offset local fossil fuel consumption) may provide an easily understandable goal and is in many ways an ideal basis for a policy mandate, it is as yet uncertain whether it may also function as a successful guide to key strategic choices on energy system development, towards a sustainable energy supply for the Danish capital in the long-term.

Acknowledgements

The authors are grateful to Copenhagen municipality and HOFOR for providing data for this study, to Jörgen Edström for taking part in an interview, to Niels Kristensen for responding to our e-mail survey, and to Roskilde University for funding the research. The usual disclaimers apply.

Appendix A: Thematic account of implementation activities

Theme	Activities
District heating system	Several small initiatives to reduce the temperature in the district heating (DH) grid have been completed, but the key activities in the DH system are composed by three major projects, as follows.

	• A project to convert steam-based DH to water. Commenced in 2008, and expected to run for 17 years to completion in 2025. Implementation is on track. The target date was advanced to 2021 in the spring of 2014. • A project on establishing and then expanding district cooling in the city centre. Initiated in 2008, with the first plant in operation by March 2010, and additional plants subsequently being constructed and the grid expanded. • A major new development in the northern harbour combining low energy consumption and innovative energy production techniques. Sources: CPH, 2005, 2009d, 2012b; Edstrøm, 2016; HOFOR, 2014, 2015; KE, 2009, 2012.
Electricity system	Very few projects with the particular purpose of improving system flexibility have been implemented, which may be due to the fact that this theme appeared only in the most recent CAP, and that these initiatives are concentrated in the later part of the implementation period of the third CAP. While flexible consumption is discussed and the district cooling project is highlighted as a tool in integrating flexible demand, the only major project is the installation of two 5MW heat pumps as a pilot project by the municipal utility company HOFOR, plus the development in the northern harbour, which will include new solutions for system flexibility and the promotion of flexible consumption by the municipality. The usefulness of local hydrogen production has been assessed and deemed too expensive to scale up at this time, and the price for using onshore power for cruise ships was too high as well. Finally, this area received significantly more attention in the roadmap for the second implementation period than it has up until 2016. Source: Edstrøm 2016; HOFOR, 2015; KE, 2009; Kristensen, 2016.
Transport system (fuel switch)	The municipality has completed two key initiatives on fuel switching in the city: 1) setting up electric chargers and establishing a natural gas and a hydrogen gas station (infrastructure), and; 2) commencing a switch of the entire municipal fleet to alternative fuels, starting with small vehicles and moving on to pilot programs for waste collection trucks and buses that then form the basis for a city-wide tender. While the infrastructure expansion and switch of municipal vehicles are well underway, the spread of vehicles among citizens and businesses is still lacking and further complicated by recent changes to the framework conditions. Source: CPH, 2009c, 2010a, 2012b, 2012c, 2012d, 2012e, 2013b, 2014a, 2015b.
Geothermal	A geothermal facility was put in operation at Margretheholm in 2005. The expansion of the test facility was delayed and an assessment of the possibilities for establishing geothermal energy in the northern harbour development has also delayed establishing a second large-scale facility elsewhere. The utility company highlights significant issues with the operation of the current plant as a key aspect in delaying further expansion of geothermal capacity. They are currently working towards reducing the cost of the investment and improving the operation of the current test facility, which is why the 2009 target has been postponed until such time as a new facility can be constructed that is financially sound. It is however argued that geothermal production will be a key systemic solution in the future in need of further development. Source: CPH, 2005, 2012a, 2012b, 2014a; CTR et al., 2011; Edstrøm, 2016; HOFOR, 2014; Kristensen, 2016
Biomass	Within the area of biomass utilization, the key initiative throughout the CAPs was a conversion of the AMV CHP plant from coal to biomass. While the operator of the plant converted one of the units to biomass in 2010, there has subsequently been a long discussion on converting the remaining units, in which the operator does not comply with the municipality's requests. As a result, the

	municipal utility company (HOFOR) procured the plant, taking over operation in January 2014 with the purpose of converting it completely from coal to biomass. In doing so they intend to retire the old coal-based unit and construct a new biomass-based unit instead, expected to be ready in 2020, combining the initiatives on converting AMW and establishing a new biomass-based plant. Furthermore, conversion of the other major CHP pant in the Copenhagen district heating system, the AVV plant, was completed in 2016, so that it is now able to use only biomass energy. Source: CPH, 2010a, 2011a, 2012b, 2012c, 2013b, 2014b, 2015b; DE, 2017; DONG Energy, 2017; Edstrøm, 2016; HOFOR, 2014, 2015; KE, 2009.
Wind power	In 2010, the municipal utility company received a directive on establishing a municipal wind power company, with the goal of erecting 140 MW in 2015 and 360 MW by 2025. Available areas inside CPH municipality were identified and assessed for setting up wind turbines in 2009. While regulation and protests have halted two of the projects, the third (on Prøvestenen) went into operation in January 2014. The wind power company has established a total of 24 windmills, with 64 MW inside and outside CPH. Source: CPH, 2010a, 2011a, 2012b, 2012c, 2014b, 2015c; Edstrøm, 2016; HOFOR, 2013, 2015; KE, 2012; Kristensen, 2016.
Waste	In the area of waste, the key energy-related initiatives can be subdivided into four categories: the waste-to-energy (W-t-E) plant being replaced, utilizing wastewater in producing biogas, removing fossil fuel based waste (plastics) from incineration, and assessing technologies for treating organic waste. • While the decision on constructing a new W-t-E facility is not in itself a part of the CAP, it has resulted in delays on the flue gas condensation project as it is unfeasible to complete that project until the new facility has been completed. The plant was put in operation in the spring of 2017. • The city of Copenhagen has two major wastewater treatment plants, one of which began producing biogas in 2012 and the other in 2013. • Several activities aimed at removing plastics from waste are described throughout the reports. The key initiative is a pilot program from 2004 that was expanded in 2008, giving all households the opportunity of sorting out hard plastics from household waste. While the program has been implemented for all apartment buildings and 18,000 villas, the amount of plastic collected is still quite low (10%). • The REnescience facility, combining technologies in separating waste fractions and subsequently producing biogas on the organic fraction, has been tested. The residual fraction is currently too polluted to be spread on agricultural soils as intended, necessitating further development. Source: CPH 2012b, 2012c, 2012d, 2012e, 2013a, 2014a, 2014c, 2015a, 2015b; Energy Supply DK, 2017; Kristensen, 2016.
PV	The earliest available information on PV expansion is the formation of a PV guild in CPH where citizens were given the choice of buying solar power. Subsequently the municipal wind power company was given permission to expand its activities into setting up PV facilities, dedicating DKK 2 million to assisting housing associations with PV projects. Although deemed a large success, the project was refocused due to changes in national legislation, towards setting up PVs only on their own facilities, beginning with wastewater facilities from 2014. At the time of writing there are 4MW PVs out of the targeted 40MW for 2025, necessitating a considerable increase in the rate of expansion. Source: CPH, 2004, 2005, 2006; HOFOR, 2013, 2014, 2015.
Other	No CCS initiatives are mentioned, but a number of initiatives on the city gas system can be discussed in this section, as they do not pertain directly to any of

	the other categories. This system has undergone a significant transition in which emissions were reduced by a new production process (natural gas based instead of coal based) in 2007, necessitating new production plants and changes for several end users. Subsequently a switch towards using biogas from the wastewater treatment facilities has been completed, achieving a 10% biogas content in 2014 and 20% by 2015. Source: CPH, 2005, 2006; Edstrøm, 2016; HOFOR, 2013, 2014, 2015; KE, 2009, 2012.

Abbreviations: AMW: Amagerværket (Amager CHP), AVV: Avedøreværket (Avedøre CHP), CAP: Climate Action Plan, DH: District heating, PV: solar Photovoltaic, W-t-E: Waste-to-Energy plant.

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