Resources **2015**, *4*, 548-565; doi:10.3390/resources4030548

OPEN ACCESS

resources

ISSN 2079-9276

www.mdpi.com/journal/resources

Article

From Goals to Action: The Efforts for Increasing Energy Efficiency and Integration of Renewable Sources in Eskilstuna, Sweden

Iana Vassileva *, Richard Thygesen, Javier Campillo and Sebastian Schwede

School of Sustainable Development of Society and Technology, Mälardalen University, P.O. Box 883, Västerås SE-721 23, Sweden; E-Mails: richard.thygesen@mdh.se (R.T.); javier.campillo@mdh.se (J.C.); sebastian.schwede@mdh.se (S.S.)

* Author to whom correspondence should be addressed; E-Mail: iana.vassileva@gmail.com; Tel.: +46-732708840.

Academic Editor: Witold-Roger Poganietz

Received: 30 April 2015 / Accepted: 8 July 2015 / Published: 15 July 2015

Abstract: Cities' energy usage accounts for two thirds of global primary energy consumption. Energy efficiency in urban areas is, therefore, one of the most important topics to consider when dealing with urban sustainability. This paper evaluates the goals for increasing energy efficiency and use of renewable energy sources in the areas of transportation, buildings and consumers' awareness, as stated in the Climate action plan, for the municipality of Eskilstuna, Sweden. The efforts of the municipality to successfully reach their energy efficiency goals, are described in this paper including future perspectives. The results show that although the municipality counts with the advantage of owning and working together with the local housing company and energy provider, in order to reach the established goals, additional strategies need to be considered. For an increased use of renewable energy sources, analysis of rooftops suitable for photovoltaic (PV) installation should be carried out as well as the integration of goals for self-consumption. In the transport field, the city needs to prepare for large-scale electric vehicle (EV) market penetration and to consider different bike or car sharing options. Finally, more specific awareness campaigns are needed to engage the citizens in reducing their energy consumption and living a more sustainable life.

Keywords: smart city; sustainable development; energy efficient city; transportation; renewable energy; smart citizens; biogas; self-consumption

1. Introduction

With half of the world's population living in cities, they are responsible for approximately two thirds of the global primary energy consumption with 86% of the energy demand being supplied by fossil fuels [1]. In the developed world, household energy use is becoming one of the most significant contributors to the countries' energy balances with different forecasts showing that in the near future, over 40% of the total yearly consumption will come from this sector in most western countries [2]. As a consequence of the constantly increasing population, and to mitigate the effects of the increasing urbanization levels, several initiatives have been carried out promoting the adoption of measures and goals on sustainable development, by countries worldwide. As an example, one of the most relevant initiatives targeting sustainability is the World Summit on Sustainable Development, the first of which took place in Rio de Janeiro as early as in 1992. The "Agenda 21" was one of the main outcomes of the summit, encouraging all countries around the world to adopt economic policies with the lowest impact on the environment [3]. In recent years, the development and increased use of information and communication technologies (ICTs) has led to the adoption of the concept of "Smart Cities"; ICTs are used for decreasing emissions and for improving the use of resources while improving the citizens' quality of life [4]. Some examples of smart technologies associated with smart cities include intelligent lighting, solar panels, wind turbines, transportation sensors, *etc.* the integration of these technologies and the interaction between the inhabitants leads to smart buildings, smart living, smart transportation and smart communication among others [5].

The European Union (EU) has put significant effort into climate change mitigation and increased urban sustainability, focusing primarily on the energy sector, which is responsible for 80% of the total greenhouse gas emissions [6]. Examples of the established legislative measures and goals (some of them discussed more in-depth in the following section) include the EU's 20-20-20 climate goals, the Energy Performance of Buildings Directive (EPBD), the Ecodesign of Energy Related Products Directive, the Renewable Energy Sources Directive (RES) or the Energy Efficiency Directive (EDD).

One of the EU's Member States, Sweden has for many years focused on utilizing energy in the most efficient and sustainable way, ranking several times as one of the most innovative countries in the world as well as an environmental front-runner and pioneer [7]. Moreover, Sweden has the second lowest carbon-intense economy among OECD countries, despite a relatively high per-capita energy use [8] making the country particularly interesting to analyze. The country's efficiency and sustainability visions have, for instance, led the country to count with reliable and efficient district heating and cooling systems (available since the 1950s) and to the deregulation of the electricity market in 1996, allowing in this way consumers to choose their electricity supplier [9]. Additionally, in line with the EU's 20-20-20 climate and energy goals, Sweden has established its national climate goals to be even more ambitious: CO_2 emissions should be 40% lower in 2020; at least 50% of the total energy consumption should be supplied from renewable sources; and the energy intensity should be reduced by 20% [10]. As part of the strategies for achieving these goals, the country became the pioneer in 2009 in completing in 100% of the households, the roll-out of electricity meters and since 2012 providing consumers with the right to get hourly metering of electricity [11]. Within the EU, Sweden was in 2014 one of the countries with the highest number of Smart Cities, as presented in the report, "Mapping Smart Cities in the EU." [12].

With such ambitious national goals, the climate and energy plans put in place by Swedish municipalities will play an essential role in achieving the sustainability targets for the country.

This paper focuses on the energy goals and actions established by the municipality of Eskilstuna (a small-medium seized city located in Sweden) in their "Climate Action Plan, 2012–2020". The action plan has been evaluated and discussed in this paper by following the structure and three main topics presented in the plan: increased use of renewable energy (wind and solar), energy efficiency in the transport sector and residential sectors, as well as the engagement of citizens. The use of biogas although a renewable energy source, has been included in the transportation section due to its utilization occurring mainly in the transport sector. The combined efforts and participation of the local government, building and energy sectors and the citizens have resulted in the municipality being selected as the "most environmentally friendly municipality in Sweden" in 2012, and ranked second in 2013 and 2014 [13].

The paper is structured as follows: Section 2 introduces the situation regarding energy efficiency and regulatory framework in Europe and in Sweden in more detail, including a description of the municipality of Eskilstuna; Section 3 presents the situation in Eskilstuna regarding renewable energy production and integration, followed by the municipality's goals and actions regarding the transport sector (Section 4) and the residential sector and citizens' engagement (Section 5); Section 6 presents a summary of the main aspects to be considered and their transferability to other cities.

2. Regulatory Framework

This chapter presents a detailed description of the regulatory framework related to energy efficiency and sustainability in the European Union and in Sweden, describing some of the most relevant goals and actions. A description of the municipality of Eskilstuna and its Climate goals has been included in the end of the section.

2.1. Energy Efficiency in the European Union

Several studies have presented the positive correlation between urbanization, energy consumption and CO_2 emissions; the increasing urban population is thus considered as an important contributor to CO_2 emissions and to a higher energy consumption [14,15]. In 2014, it was estimated that approximately 75% of the population in Europe lived in urban areas and this level of urbanization is expected to reach 84% by 2050 [16,17]. In order to reach the energy and climate goals established by the EU, all member-countries are committed to follow Directives such as the Energy Efficiency Directive (EED–2012/27/EU), which establishes a common framework of measures to promote energy efficiency and to achieve the Union's 2020 20% target and also to cover the way for further improvements beyond that date, imposing annual end-use savings of 1.5% in the total delivered energy [18]. Additionally, one of the most important legislative measures concerning energy supply and use in European buildings is the Energy Performance of Buildings Directive (EPBD), which requires all newly constructed buildings and buildings undergoing renovation in the Member States to fulfil nearly zero-energy buildings (NZEB) standards by 2020 [19] Apart from establishing legislative measures, the EU additionally supports different projects and initiatives targeting a combination of different aspects of the energy system: higher energy efficiency in the residential and transport sectors, increased use of renewables, greater citizens' awareness, among others. One example of this is the European Association of local authorities in energy

transition, "Energy Cities", which was created in 1990 and represents more than 1000 towns and cities, in 30 countries. The main goals of the association are: to strengthen the skills in the field of sustainable energy use; to present interests and influence the policies and proposals made by EU institutions in the fields of energy, environmental protection and urban policy; and to develop and promote initiatives through exchange of experiences, transfer of know-how and implementation of joint projects [20]. The Covenant of Mayors is another example of European long-term policy instrument that involves local and regional authorities that volunteer to increase energy efficiency and the use of renewable energy sources. After an organization decides to participate in the Covenant of Mayors, administrative structures are created; a "Sustainable Energy Action Plan" is implemented and monitored, followed by regular submission of implementation reports [21]. Another important action, which started in 2006, is the "Imagine" initiative, with the main objective of creating a long-term perspective and visioning approach of energy and urban issues. The initiative, with 10 partners and 8 pilot studies, focuses on developing the concept of a "low-energy city with a high quality of life for all" and contributing to the strategies of social, institutional and economic players at all levels [22]. "Planning for energy efficient cities" is another EU funded initiative (coordinated by the municipality of Eskilstuna), where 18 partners from 13 countries focus on developing a model for energy efficiency and sustainable city planning by assessing energy-saving solutions and potentials that should be integrated in city planning; and developing action plans that will be presented to decision makers and will lead the cities to become more energy efficient [23].

2.2. Energy Efficiency in Sweden

In Sweden, securing a sufficient amount of energy has been the main policy strategy until the 1970s due to energy being associated with social and economic development and growth. However, the worldwide oil crisis and an increased environmental awareness created a shift towards oil independence, energy conservation and pollution control. As a result, the current energy system is based on renewable sources, mainly water, wind and biofuels; the electricity mix being composed by hydropower and nuclear power. In 2011, the total final energy consumption accounted for 379 TWh (electricity 126 TWh; oil products 107 TWh; and biofuels, peat and waste 76 TWh), which is a reduction of 4% in comparison to 2010 levels. Additionally, distributed by sectors, the residential and services sector was responsible for 144 TWh; the industry sector used another 144 TWh; while the transport sector was responsible for 90 TWh [24].

In the transport sector, Sweden has been promoting the use of biofuels, mainly biodiesel, ethanol and biomethane, the use of which increased by 17% between the years 2011 and 2012. In 2013 the proportion of biofuels, including biodiesel, bioethanol, biomethane and electricity from renewable sources accounted for 10% of the total fuel used for transportation [25]. Regarding the implementation of solar and wind energy sources, they have been described more in detail in the following section due to their direct connection to Eskilstuna's "Climate Action Plan 2012–2020".

When it comes to the support provided to the different Swedish municipalities, in 1977, the Swedish Government created the Law for Municipalities' Energy Planning (1977:439), in order to tackle climate change and increase energy efficiency and use of renewable energy sources. The Law states that each municipality should have an updated plan for supply, distribution and consumption of energy and it was

implemented with the aim of minimizing the need for oil and also for optimizing the local energy system and to prevent unnecessary investments in infrastructure. Typically, the goals and actions set by the municipalities consider the environmental effects on a local, regional and global perspective although these goals and scope of the energy plans have varied over the years [26]. The analysis of the energy plans from different periods showed that plans adopted between 2006 and 2008 had a generally broader scope than older plans; environmental assessments were rare and rudimentary in the 1980s and with a broader scope in the 1990s (including wider range of emissions and effects related to energy utilization) [27].

In 2003, the Swedish Energy Agency started the "Sustainable Municipality" program with the aim of increasing the knowledge of cooperation between different actors to achieve sustainable municipalities. The program was divided into three stages: the first stage, 2003–2007, was a pilot stage including only five municipalities, and was intended to make the climate related questions an essential part of the municipalities' activities. In the second stage, 66 municipalities participated, and the work focused on creating energy and climate strategies and on improving the physical planning and energy efficiency of buildings and transportation. In the final stage (finishing in 2014), two main topics were considered: smart energy planning, and industry policies, with energy as a main growth engine.

This paper focuses on one of the municipalities that participated in the program and established one of the most detailed climate plans: the municipality of Eskilstuna.

2.3. The Municipality of Eskilstuna

The municipality of Eskilstuna, (located in central Sweden, 100 km west of Stockholm and with a population of *ca.* 100,000 inhabitants [28]), was historically known as the "weapon manufacturing" city. During the 1800s the city's number of factories producing steam engines and different kinds of machinery increased, helping the city improve its railway communication and contributing to the city's population growth (doubling in size between 1870 and 1990). During the 1990s, Eskilstuna's industrialization continued to grow in parallel to its population: the city recruited both national and international workers (mainly from Germany, but also from Greece, Italy and Yugoslavia). The lack of housing infrastructure, needed to cover the growing population needs, was solved by the city's large implementation in the 1960s of the so called "million residential program", where old houses were demolished and replaced with multi-family buildings [29]. The "million residential program" was the result of the Swedish political strategy to build one million homes in 10 years (between 1964 and 1975), which also contributed to the real breakthrough for district heating, following the fear for high oil prices after the oil crises, and leading to the buildings' high connection rates to district heating [30].

As a consequence of the municipality's participation in the "Sustainable Municipality" program, Eskilstuna developed its "Climate Action Plan 2012–2020" including the targets for reduction of gas emissions, increased use of renewable energy sources, efficient energy use, reduction of fossil fuels and electricity for heating, reduction of emissions of CO_2 from transportation as well as food and consumption [31].

One of the main advantages in Eskilstuna, is that the municipality as well as the building and energy sectors have a large role in meeting the climate action plan's goals. All the municipality owned companies, Eskilstuna Energy and Environment and Eskilstuna Municipality Real Estate Company—in

charge of the majority of the buildings in Eskilstuna-, are organized into one company group allowing an easy coordination, decision making and implementation of actions as well as an interdisciplinary vision. In fact, although the cooperation between the energy and building sectors with regards to achieving climate and energy goals has been found to play an essential role, current levels of cooperation and trust between the sectors in Sweden are rather low, making the case of Eskilstuna even more relevant to analyze [32].

The following sections present the most relevant goals and actions included in the Eskilstuna's "Climate Action Plan" with the corresponding discussion and suggestions.

3. Renewable Energy Sources (Wind and Solar)

With the implementation of climate plans in Sweden, the focus has been shifted from planning of central production and distribution of energy to distributed renewable energy production, mainly as photovoltaic (PV) and wind power. The increased interest in distributed renewable energy production is due to the decrease in the installation cost for PV systems, the Swedish electricity certificate and tax exemption for electricity produced by wind and solar power plants. A Swedish electricity certificate is awarded to the owner of a production plant for every 1 MWh of renewable electricity produced and the average value for a certificate in 2013 was 2 €-cent. Energy produced by wind and solar is also exempt from energy tax which at the end of 2014 was 3.5 €-cent/MWh, while the average price for electricity on the Nordic spot market during 2014 was 3.7 €-cent [33,34].

Following the Swedish goals for reaching 30 TWh in wind power production by 2020 [35], wind power production has experienced a large growth in Sweden reaching a total of 4194 MW by the end of 2013 which corresponds to 7% of the total yearly electricity used in the country, 210 MW of the total installed power consisted of offshore systems [36]. While cost reduction and incentive programs have resulted in a large increase of PV systems in Europe, in Sweden despite the lack of PV capacity goals the installed capacity is beginning to increase reaching approximately 80 MW at the end of 2014 (corresponding to only 0.06% of the total electricity usage in Sweden) [37]. The Swedish incentive program for PV systems started in 2009, initially covering 60% of the total installation costs, and it has been gradually reduced to currently cover 30% of the total investment cost for companies up to maximum of 140 k€ per system. Throughout the duration of the program, and up till 2013 the Swedish government allocated 49 M€ of which 1.8 M€ has been distributed to the municipality of Eskilstuna. There are plans to allocate 17.5 M€ to the incentive program by 2016, after which the program is expected to be terminated in favor of a new program.

Even though most cities in Sweden have set general goals regarding renewable energy production, the goals are not as specific and separated into PV and wind power, as in the case of Eskilstuna. Although currently, the majority of the Swedish municipalities are mainly focusing on meeting their goals with wind power production, some cities are also focusing on PV.

Eskilstuna municipality has plans to produce 9.5 GWh (~10.5 MW of peak power) or 95 kWh per inhabitant of PV electricity and 48 GWh or 480 kWh per inhabitant of electricity from wind per year by 2020. This production is planned to cover 60% of the municipality's annual electricity use [31]. In order to reach the goal of 48 GWh of wind production, the municipality needs to install 2.3 MW annually. The total annual investment, up to 2020, to meet the PV and wind power goals is estimated to be

5.6 M€, assuming a linear installation rate. The municipality has specifically decided to invest 580 k€ in PV systems during 2014 (66 kWp of which were installed during the first four months) resulting in an installed capacity of approximately 350–400 kWp. If Eskilstuna municipality maintains the current installation trend, there would be a total of 2.1–2.4 MWp installed by 2020, failing to reach the municipality's goals. In order to meet the goals the municipality would have to install 1.5 MWp every year corresponding to a roof area of approximately 9000–11,000 m^2. To put the required area for installations into perspective, an average roof area for multi-family buildings in another province of Sweden is 360 m^2 [38]. A possibility to promote PV systems to private companies and house owners, which would facilitate the implementation of PV on rooftops, is to identify suitable building surfaces as shown by the Örebro municipality that developed a solar map over the entire region [39]. Another possibility regarded by the municipality is the construction of large ground based PV plants. Although not a common practice in Sweden, the largest PV park (1 MW of peak power), was recently installed outside the city of Västerås (approx. 50 km from Eskilstuna). Additionally, in connection to the reduced emissions from transportation and although there are no specific goals for encouraging the use of electric vehicles, the municipality has included plans for installing PV powered charging stations for electric vehicles, with an installed PV power of 1 or 2 kWp per station depending on the type of station.

In order to successfully implement distributed PV systems, the main challenge is that the installations on rooftops tend to be larger than the overall building electricity usage resulting in surplus electricity generation during summer. It is important to consider that when a municipality owned company sells the electricity overproduction, the company has to pay energy tax on the total PV electricity production including the self-consumed electricity. Self-consumption is defined as the PV electricity used directly in the building as it is generated or stored in an energy storage for later use in the building. The electricity surplus is then usually fed into the grid and sold. Therefore, it is essential to complement the overall municipality goals with a goal for self-consumption in order to ensure that the systems are correctly sized for the specific building where the system will be installed. In cases where PV electricity is solely self-consumed in the building the company is exempt from energy tax on the generated PV electricity. Therefore, it is important that the municipality of Eskilstuna focuses on installing PV systems with high levels of self-consumption to avoid overproduction or to implement storage systems. This, on the other hand, restricts the overall installation capacity to reach the municipality goals.

4. Energy Efficiency in the Transport Sector

The targets established in the "Climate Action Plan" regarding transportation indicate a reduction by 30% of emissions (in CO_2 per citizen) by 2020 and to 75% by 2050. By 2020 the local transport should be composed of 39% cars, 16% public transport, 26% cycling and 19% walking. Additionally, by 2020, the municipality of Eskilstuna expects to decrease the use of gasoline, diesel and fossil gas to near-zero and replace it with biomethane, ethanol and electricity. In order to meet the transport targets by 2015, 100% of all passenger cars and light vans (>3.5 tonnes) should comply with the "green car" classification according to the local transport administration definition. Cars are considered "green" when based on the type of car, they have the following characteristics: petrol and diesel car CO_2 emissions do not exceed 120 g/km; alternative fuel cars have consumption lower than 0.92 L petrol/10 km, 0.84 L diesel/10 km or 0.97 m^3 gas/10 km; and electric cars with electric energy consumption not exceeding 3.7 kWh/10 km [40].

The municipality's climate plans do not only focus on the transportation fuel type, but also on reducing the private use of cars in general, targeting reductions of 10% in 2015 and 20% by 2020, and when it comes to public transportation, all the public buses in the city should be 100% fossil free by 2017. To fulfill the fossil-free targets, buses in Eskilstuna use mainly biomethane, and in November 2015 two pure-electric buses will be included in the public transportation fleet and tested in the city during March, 2015 [41]. The biomethane is produced and treated locally by Eskilstuna Energy and Environment- the municipality owned company responsible for the selling and distributing of electricity, district heating and cooling, water, sewage and waste management. The production of biogas from organic waste materials is a common scenario for waste treatment and energy recovery in Sweden. In 2013, 1686 GWh was produced in 264 facilities of which 52% (40% of the biogas production) is related to waste water treatment and about 9% (34% of the biogas production) to co-digestion plants [42]. 54% of the biogas produced was upgraded to biomethane as a vehicle fuel and 31% was used for heat production. In 2013, 1,872,581 Nm^3 of raw biogas with a methane content of 62% was produced [43]. The main share of the biogas is upgraded via water scrubbing to biomethane (97% ± 2% methane) which is then transferred via a pipe system to the bus depot where pressure is increased to a maximum of 300 bars. After the pressure has been increased, the gas can be stored or used by the buses used for public transportation in Eskilstuna city [44].

The amount of biomethane (703 tons assuming a density of 0.75 $kg \cdot Nm^{-3}$) corresponds to 1055 m^3 of petrol and 914 m^3 of diesel, respectively. Accordingly, 2490 t CO_2 compared to petrol (2.36 kg CO_2 per L petrol) or 2432 t CO_2 compared to diesel (2.66 kg CO_2 per L diesel) could be saved by using the vehicle fuels derived from organic waste instead of fossil fuels in public transportation. In 2008, CO_2 emissions within the transportation sector accounted for 150,000 t CO_2 (2% emission reduction by biomethane utilization) whereof 32,000 t CO_2 (8% emission reduction by biomethane utilization) can be allocated to heavy trucks and busses [31].

For the municipality of Eskilstuna to reach their goals related to replacing the use of fossil fuels with biofuels, several possibilities can be implemented that would increase the production of biogas. As an example, the heat demand of the digestion facility is currently covered by using 18% of the biogas produced per year in a gas fired boiler instead of upgrading the gas to a vehicle fuel. An alternative to cover the heat demand could be the implementation of pyrolysis using municipal green waste or parts of the residual digestate. In such a novel process configuration the pyrolysis gas is combusted to recover heat whereas carbon incorporated in the residual biochar is captured and can be used as a soil amendment. Additionally, the amount of digestate that is used as cover material for landfills can be reduced. This possibility of process integration is currently under investigation.

Regarding the utilization of organic household and food waste (organic municipal solid waste, oMSW) currently only the wet fraction is used for anaerobic digestion to produce biogas whereas the solid fraction is composted. The utilization of the whole fraction in its own digestion line has the advantage to recover energy in the form of biogas from all organic waste and additionally to recover nutrients from this feedstock. Unlike residues from the digestion of sewage sludge digestate generated from oMSW is suitable as fertilizer on arable land mainly due to lower amounts of heavy metals.

Currently, residual digestate from the co-digestion of sewage sludge and oMSW is separated. The nitrogen-rich liquid phase (reject water) is recirculated within the waste water treatment plant to remove the nitrogen. Additionally, research results showed that besides nitrogen phosphorous could also be

efficiently removed from the reject water by microalgae to reduce returning side streams within the treatment plant [45]. The microalgal biomass was anaerobically co-digested with the waste water sludge to increase the biogas productivity of the system.

In the "Climate Action Plan", the measures for reaching the targets for public transportation of 16% share by 2020 (in comparison to the 8% in 2006), not only include the use of fuel from renewable sources, but also a higher availability of buses. To encourage the citizens to use buses, a new route plan was developed, using the "metro-style": low number of bus lines and routes, represented by different colors, making the route maps easier to understand; additionally, citizens were able to purchase the bus ticket through a mobile phone application. As a results, public transportation use increased by approximately 300,000 (from 4.8 to 5.1 million) passengers between 2011 and 2012.

Some of the previously described measures, have helped achieve positive results not only with regards to the public transportation but also for private vehicles; as an example, the portion of "green cars" increased from 57% in 2009 to 67% in 2012; the use of renewable fuel sources used in private vehicles also increased, from 6% in 2009 to 10% in 2012 [46].

For reaching the goals of decreasing the number of private cars (from 61% in 2006 to 39% in 2020) the municipality has been striving to increase the use of bicycles and reaching the goal of 17% by 2020. The municipality adopted in August, 2013 the "Cycling Plan", which includes the improvement and better-maintenance of bicycle parking spaces; increasing the number of bicycle routes and making them more competitive in comparison to street infrastructure, improving security and safety, *etc.* [47]. Several indicators were included to follow up the progression of the share of bicycle trips: percentage of children biking to school, share of trips related to workplace, school, commercial and free time destinations.

With the previously described strategies however, the municipality might need more than the expected time, and will fail in reaching the goals. Moreover, the municipality should include additional strategies for those citizens that are planning to purchase a car in the near future, and have a more rigorous plan for promoting "green cars". In the case of electric vehicles (EVs) for instance, easily accessible information regarding this type of vehicles should be made available for potential EV drivers; the location of charging infrastructure should be based on EVs owners needs and driving patterns and should be included in the urban planning; also a larger number of PV-powered charging stations should be considered - which will additionally create awareness regarding the use of renewable energy sources. It is worth mentioning that despite the rather limited subsidies and incentives for purchasing EVs in Sweden, the number of EVs registered has been steadily increasing over the last few years, reaching a monthly record of 699 registered EVs in March, 2015 [48]. In order to prepare for a large-scale use of EVs, the municipality should include some adoption strategies that will allow for sustainable EV use in Eskilstuna. The municipality's main priority is to increase the number of people using bicycles and/or walking. However, the plans should also consider implementing some of the strategies currently adopted by other European cities, as for instance "park and ride", where the car drivers have the option to park their vehicles in specific areas (usually outside the city center), and use public transport connections (typically within central areas of the city) [49,50]. This type of initiatives can be further combined with electric carpooling, car sharing programs or complemented by free public transportation, which could act as an alternative to citizens looking to buy a car or current car owners that would like to replace their cars with joining such initiatives.

5. Residential Sector and Citizens' Engagement

The goals related to Energy efficiency in buildings and citizens' engagement are considered by the municipality as the most important groups of the "Climate Action Plan". The municipality's total energy consumption, (with special focus on more efficient use of electricity) should decrease by 20% by 2020 and the reduction is intended to target the total energy use per inhabitant.

Studies show that a large part of the energy consumption in buildings can be reduced by changing the consumers' habits and behavior (especially regarding indoor temperature, use of hot water and home appliances) [51–53]. Therefore the municipality's efforts are not only focused on the technical solutions and building structure improvements, but also on increasing consumer awareness about the impact of their everyday activities on the energy consumption and on the energy system in general. This section will present and discuss the municipality's activities related to increasing the buildings' energy efficiency, as well as different strategies implemented to engage the citizen's participation in the different parts of the action plan.

When it comes to the energy efficiency in buildings, currently in Sweden as well as in Eskilstuna, the main focus has been on the renovation of old buildings, particularly those built under the "million residential program", between 1965 and 1974. In Eskilstuna, "LaRS" is one of the most relevant projects targeting the "million program"-building areas (Lagersberg, Råbergstorp and Stenby). The "LaRS" project is intended to transform these areas into sustainable and attractive parts of the city, including increasing the employment rates, possibility for development through increased understanding of different cultures and backgrounds with special focus on children. Over the past three years, different actions have been carried out in the "LaRS" areas organized by the housing company responsible for the buildings, and the municipality. As an example, in the area of Lagersberg the initiative started by improving the buildings' facilities: improvement of insulation of outdoor walls, better kitchens facilities and bathrooms, and more energy efficient windows. More specifically, the renovation of the buildings included: 1.5 cm of extra wall insulation; extra roof insulation; changes in 50% of the windows (the rest were insulated); the air/water ventilation heat recovery system was replaced with an air/air ventilation heat recovery system; the apartments were provided with thermostats and regulation valves and individual hot water meters (allowing the providers to charge the consumers for their consumption of hot water, which had previously been included in their monthly rent). Regarding the tenants' engagement, strategies based on findings from previous studies were adapted to the group analyzed in this paper [54]. Energy advisers working for the municipality, visited the tenants providing energy and water saving tips in several languages (as most of the residents living there had foreign backgrounds and did not speak Swedish); several workshops were organized in the area, where researchers, advisers, municipality workers, *etc.* discussed energy related issues with the residents (e.g., easy-to-implement energy savings, making the information from electricity bills more understandable, explaining the processes of waste and water treatment, *etc.*). Customers of the municipality owned energy provider, additionally had the possibility to access their own consumption through a dedicated web-site, which is expected to help them adapt their behavior and activities in order to save energy.

In order to evaluate the overall impact of the different measures carried out in the areas, on the energy consumption, energy consumption trends for the periods before and after their implementation have been

collected and analyzed. The main changes in hot water consumption and heat demand of two of the buildings in the area are presented in Figures 1 and 2, respectively.

Regarding the technical infrastructure implementation, the only difference between Building 1 and Building 2, was that in Building 2 a solar thermal system dimensioned for 70 MWh/year was installed. The use of a thermal system, could explain the dramatic reduction in hot water consumption in Building 2, as observed in Figure 1. The differences, observed in Figure 1, in hot water consumption in Building 1 on the other hand, are mainly attributed to the individual consumption and to behavior change.

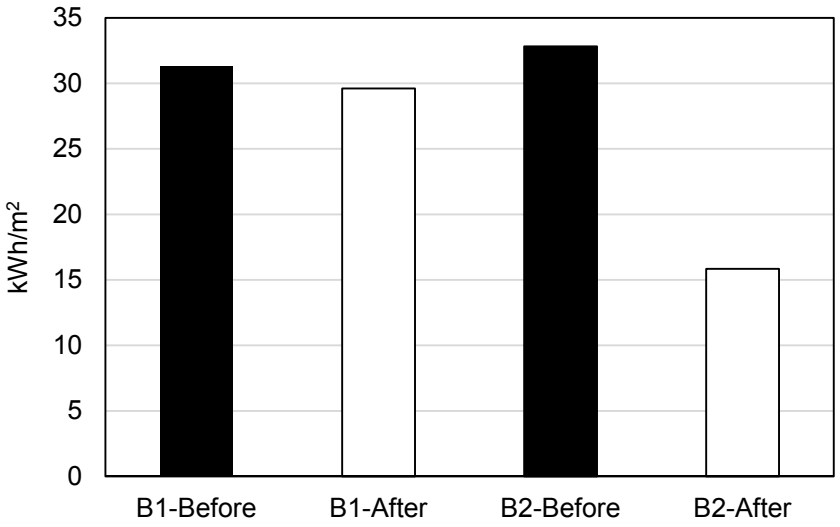

Figure 1. Hot water consumption in Buildings 1 (B1) and 2 (B2) before and after the renovation.

Regarding the heating consumption (Figure 2), the reductions were larger in Building 1 in comparison to Building 2, which can be explained mainly by the fact that some of the apartments in Building 2 had not gone through all the renovation measures yet. After the completion of the renovation activities, the demand for heating in Building 2 is expected to further decrease.

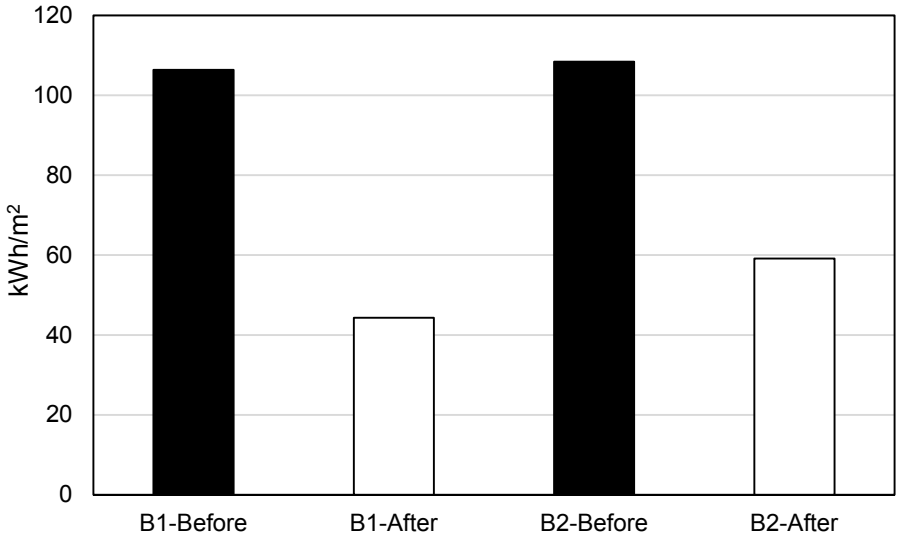

Figure 2. Heating consumption in Buildings 1 (B1) and 2 (B2) before and after the renovation.

In addition, variations in energy consumption that can be directly attributed to behavioral adjustments are related to household electricity consumption (due to the lack of temperature dependency and the changes not being attributed to any of the other improvements done in the buildings). For the case of Eskilstuna, the monthly average values reached between the years 2011 and 2013 have been presented in Figure 3.

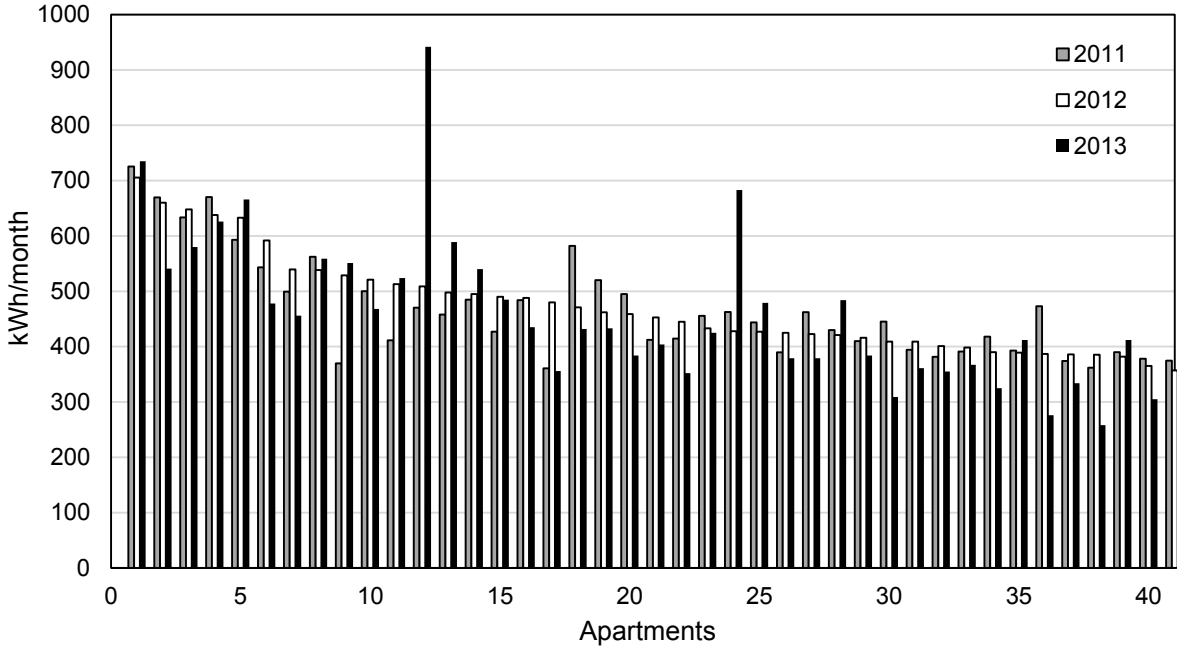

Figure 3. Average monthly electricity consumption between years 2011 and 2013; apartments with increased consumption during 2013 represented by black, solid filled bars.

From all apartments in the area, 41 apartments were selected as high consumers (monthly values higher than 4 kWh/m^2) and their consumption trend was followed between 2011 and 2013 to determine if any of the awareness measures, especially the visits and tips received from the energy advisers, had effects on the tenants. Although there was no available information regarding the number of people living in each of the apartments, it was made sure there were no changes in the tenants before and after the renovation. The floor area of the apartments varied between 64 m^2 and 116 m^2. Despite the measures taken to help consumers reduce their consumption, 13 households increased their consumption during 2013 (black, solid filled bars); the rest of the apartments reduced their electricity demand by up to 33% (in the case of apartment 33), reaching a total average saving of 1745 kWh/month for the 3-year period.

In general, the municipality and municipality-owned companies have a strong commitment to involve the citizens not only related to energy efficiency in their homes but in activities related to other parts of the energy system. For instance, before adopting the color sorting and recycling of waste in 2011, a group of households participated in testing the procedure and based on their positive response, Eskilstuna Energy and Environment then decided to implement it in a total of 16,000 households (living in houses), becoming the first in Europe to use this technique. The color recycling consists in sorting waste in different color bags depending on the type of waste and allowing a more effective collection and treatment process. The collected organic waste is treated and transformed into biogas which is then

used for the local buses (as described in the previous section). When it comes to the efforts towards increasing the awareness of citizens to avoid personal and even public transportation, a new mobility management has been used for the planning of the city: the minimum parking places per building have been reduced, in order to avoid citizens having a second car; companies are encouraged to create a bicycle friendly environments for example, by participating in the "bicycle challenge", a competition where employees from different companies gain points for each kilometer they use the bike when going and coming back from work. Increasing the awareness among young people regarding energy efficiency is one of the challenges the municipality is actively involved in: groups of teenagers are encouraged to participate in the City Festival arranged by the municipality every summer where they teach others about different ways to live in a sustainable way: e.g., behavior changes regarding energy, food, transportation and other sustainability issues; energy efficiency measures (e.g., presence sensors for lighting, PV systems, *etc.*) are used in schools, *etc.*

However, despite all the renovation measures one of the major challenges that remains, is to find a way to increase the citizens' awareness about energy consumption and engage them in long-lasting energy saving habits. For instance, although visualization of energy consumption in households has been proven effective and can help achieve saving of up to 20%, studies also show that the way of providing the information strongly determines the achieved results and it should be considered by the municipality and corresponding companies [55]. Previous findings show that at least consumer preferences and knowledge regarding energy visualization and usage should be considered before simply providing them with visualization tools [52]. Although the energy supplier provides the consumers with web-based information about their individual consumption this way of providing information needs the commitment of the people to use it (visit the website, log in, *etc.*) leading to the one of the larger issues being the overall low engagement [44]. The energy supplier together with the municipality involvement, need to focus their efforts on engaging a larger number of consumers to use the website as well as to consider providing information in other ways.

6. Concluding Remarks

This paper examines the climate goals set by the municipality of Eskilstuna (Sweden) paying special focus to the use and integration of renewable energy sources (mainly wind and PV), transport and building sector, including as well the strategies regarding citizens' involvement in decision-making processes and different energy related topics. The evaluation provided in this paper could be implemented by other small and medium sized cities in their efforts to become "smarter" and more sustainable. Although the transferability to other cities of some of the solutions and activities carried out in Eskilstuna would be dependent on the corresponding climate, socio-political and economic conditions the potential for replicability of some of the presented initiatives could be relatively high, especially if bearing in mind that from the 54% of the world population living in urban areas in 2015, the majority of the urban areas (15.2%) are made up of populations of under 100,000 people; moreover, 10.7% of urban areas have populations of 100,000 to 500,000 people [56]. As a comparison, 4.8% of the population lives in cities of 500,000–1,000,000 people and only 7.9% lives in "megacities" of more than 10,000,000 people. One of the main preconditions that allows Eskilstuna to develop and reach the climate goals, is the synergy and cooperation between different organizations and companies (energy suppliers, building

owners, *etc.*) and the municipality. By Eskilstuna municipality owning the local energy supplier (also responsible for waste and water treatment) and the company responsible for the maintenance of the majority of the buildings in the municipality, the setting and follow-up of common climate goals counts with the strong commitment of all sectors counting with the benefit of including an interdisciplinary approach, using the knowledge and experience of the companies' experts in urban planning, energy efficiency, waste and water treatment and buildings performance, among others. Good communication between the different sectors, as well as finding mutually beneficial cases in order to establish common goals and strategies is therefore an essential starting point to achieving sustainability goals.

The consideration of the different parts of the urban and energy systems in the "Climate Action Plan 2012–2020" constitutes an essential part of current and future policies that will help the municipality increase its sustainability and efficiency in the long-term. However, some small adjustments would be needed in order to reach the goals, for instance, for reaching the renewable energy goals a detailed analysis of the suitable rooftops for PV installation would be needed as well as better allocation of funds for the planned investments. Moreover, introducing specific goals for self-consumption will ensure the correct sizing of the PV systems, avoiding overproduction. Additionally, incentives and taxes must be established based on a combination of the targeted goals and the self-consumption goals.

When it comes to the transport sector, local public buses in Eskilstuna have already met some of the goals, by shifting all the buses in the fleet in the city area to biomethane. To achieve a transition to this type of sustainable transportation, it is essential for the cities to provide the production facility but also to engage the citizens' into sorting and recycling organic waste. The number of citizens using buses has also increased in Eskilstuna mainly due to the improvement of the route-plans and the possibility of online purchasing of tickets and providing online routes and timetables information. The increased use of ICTs constitutes an important possibility that cities have to explore and use to improve, facilitate and encourage the use of public transportation Reaching the goals for private use of transportation in Eskilstuna, on the other hand, would need the introduction of specific information and incentives available for the citizens for them to select the most sustainable vehicle type. With the imminent large-scale electric vehicles market penetration, specific plans for location of charging stations and their impact on the grid and urban planning should be considered. In the case of cities where the electricity mix does not include high portion of renewable sources, the strategies need to shift towards increasing the use of public or other sustainable transportation means.

In the area of building renovation and citizens participation concrete awareness/information campaigns need to be carried out (special attention should be paid to carefully selecting the target groups, and the energy saving potential, *etc.*). Citizens with low interest in environmental and energy topics should be identified and become the main target group of the strategies for increased sustainability. Independently of the physical renovation of buildings, their inhabitants need to know how their activities impact the energy use and the options they have to minimize such impact.

Acknowledgments

The authors are grateful to the people working for Eskilstuna municipality for the help and information provided, and also for taking time to participate in the interviews.

Author Contributions

Javier Campillo and Sebastian Schwede contributed with their knowledge and expertise in the analysis and recommendations regarding the area of transportation. Richard Thygesen contributed with his expertise in the evaluation and recommendations regarding renewable energy (wind and PV). Iana Vassileva contributed with the analysis and recommendations related to the energy efficiency in buildings as well as the users' perspective in transportation and energy consumption.

Conflicts of Interest

The authors declare no conflict of interest.

References

1. International Energy Agency (IEA). *World Energy Outlook*; IEA: Paris, France, 2008.
2. US Energy outlook 2008. Available online: http://www.eia.gov/oiaf/aeo/pdf/0383%282008%29.pdf (accessed on 23 June 2014).
3. UN. Agenda 21. In Proceedings of the United Nations General Assembly, Rio de Janeiro, Brazil, 3–14 June 1992. Available online: http://www.un.org/esa/sustdev/documents/agenda21/english/agenda21toc.htm (accessed on 14 June 2015).
4. European Commission. Digital Agenda—Smart Cities. Available online: https://ec.europa.eu/digital-agenda/en/smart-cities (accessed on 14 June 2015).
5. IEEE. Smart Cities. Available online: http://smartcities.ieee.org/about.html (accessed on 14 June 2015).
6. European Environmental Agency. Energy related greenhouse gas emissions. Available online: http://www.eea.europa.eu/data-and-maps/indicators/en01-energy-related-greenhouse-gas-emissions/en01 (accessed on 14 June 2015).
7. Sarasini, S. Constituting leadership via policy: Sweden as a pioneer of climate change mitigation. *Mitig. Adapt. Strateg. Glob. Change* **2009**, *14*, 635–653.
8. OECD. *OECD Environmental Performance Reviews: Sweden 2014*; OECD Publishing: Paris, France; 2014.
9. Swedish Competition Authority. Available online: http://www.kkv.se/globalassets/english/publications-and-decisions/deregulation-of-the-swedish-electricity-market.pdf (accessed on 20 April 2015).
10. Statsrådsberedningen. Europa2020-EU.s gemensamma tillväxt- och sysselsättningsstrategi. (In Swedish) Available online: http://www.regeringen.se/sb/d/18538/a/235794 (accessed on 1 June 2014).
11. Council of European Energy Regulators. Status Review of Regulatory Aspects of Smart Metering. Brussels, Belgium. Available online: http://www.ceer.eu/portal/page/portal/EER_HOME/EER_PUBLICATIONS/CEER_PAPERS/Customers/2013/7-1_C13-RMF-54-05-Status_Review_of_Regulatory_Aspects_of_Smart_Metering_FOR_PUBLICATION.pdf (accessed on 15 April 2015).
12. European Parliament. Policy Department; Economic and Scientific Policy. Mapping Smart Cities in the EU. Available online: http://www.europarl.europa.eu/RegData/etudes/etudes/join/2014/507480/IPOL-ITRE_ET%282014%29507480_EN.pdf (accessed on 23 June 2015).

13. Eskilstuna municipality. Ranking of most environmentally friendly municipalities, 2014. Available online: http://www.eskilstuna.se/sv/Bygga-bo-och-miljo/Miljo/Nyheter/Eskilstuna-behaller-topplacering-i-Miljoaktuellts-kommunranking-/ (accessed on 9 June 2015).
14. Al-Mulali, U.; Sab, C.N.B.; Fereidouni, H.G. Exploring the bi-directional long run relationship between urbanization, energy consumption, and carbon dioxide emission. *Energy* **2012**, *46*, 165–167.
15. Parikh, J.; Shukla, V. Urbanization, energy use and greenhouse effects in economic development. *Glob. Environ. Change* **1995**, 5, 87–103.
16. European Environment Agency. Available online: http://www.eea.europa.eu/themes/urban/intro (accessed on 21 April 2015).
17. United Nations. *World Urbanization Prospects. The 2007 Revision*; United Nations: New York, NY, USA, 2007.
18. Energy Efficiency Directive: EED–2012/27/EU. Available online: http://eur-lex.europa.eu/LexUriServ/LexUriServ.do?uri=OJ:L:2012:315:0001:0056:EN:PDF (accessed on 4 June 2014).
19. European Commission. Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings. *Off. J. Eur. Union* **2010**, *153*, 13–35.
20. Energy Efficient Cities. Available online: http://www.energy-cities.eu/ (accessed on 15 June 2014).
21. Covenant of Mayors. Available online: http://www.covenantofmayors.eu/about/covenant-step-by-step_en.html (accessed on 22 May 2014).
22. Imagine. Available online: http://imaginelowenergycities.eu/ (accessed on 22 May 2014).
23. Planning for energy efficient cities (PLEEC project). Available online: http://www.pleecproject.eu/ (accessed on 25 May 2014).
24. Energy in Sweden 2013. Available online: http://www.energimyndigheten.se/ (accessed on 11 June 2014).
25. Swedish Energy Agency. Transport sector 2013. (In Swedish) Available online: http://www.energimyndigheten.se/Global/Statistik/Transportsektorns%20energianv%C3%A4ndning%202013.pdf (accessed on 15 April 2015).
26. Swedish parliament. (In Swedish) Available online: http://www.riksdagen.se/sv/Dokument-Lagar/Lagar/Svenskforfattningssamling/Lag-1977439-om-kommunal-ene_sfs-1977-439/?bet=1977:439 (accessed on 3 June 2014).
27. Ivner, J. Municipal Energy Planning—Scope and Method development. Linköping Studies in Science and Technology. Dissertation No. 1234. Available online: http://www.diva-portal.org/smash/get/diva2:139412/FULLTEXT01 (accessed on 19 April 2015).
28. Eskilstuna municipality. Eskilstuna 100 000. Available online: https://www.eskilstuna.se/sv/Kommun-och-politik/Eskilstuna-100-000/ (accessed on 10 June 2014).
29. Eskilstuna municipality. Eskilstuna's history. Available online: http://www.eskilstuna.se/sv/Kommun-och-politik/fakta-om-eskilstuna/ (accessed on 14 June 2015).
30. Energy in Sweden 2012. Available online: https://www.energimyndigheten.se/Global/Engelska/Facts%20and%20figures/Energy_in_sweden_2012.pdf (accessed on 13 July 2015)
31. Eskilstuna climate plan. (In Swedish) Available online: http://www.eskilstuna.se/PageFiles/193374/Klimatplan%20KF%202012-12-13.pdf?epslanguage=sv (accessed on 13 June 2014).

32. Bulut, B.M.; Wallin, F.; Stigson, P.; Vassileva, I. Cooperation for climate-friendly developments—An analysis of the relationship between the energy and buildings sector. *Energy Effic.* **2015**, doi:10.1007/s12053-015-9369-8.
33. Swedish Tax Agency. (In Swedish) Available online: https://www.skatteverket.se/foretagorganisationer/skatter/punktskatter/energiskatter/skattesatser.4.77dbcb041438070e0395e96.html?q=skattesatser+el+2014 (accessed on 10 June 2015).
34. Nordpool. Available online: http://www.nordpoolspot.com (accessed on 10 June 2015).
35. Swedish Energy Agency. Available online: https://www.energimyndigheten.se/en/About-us/Press-/Press-releases/Swedish-Energy-Agency-in-new-report-Planning-for-30-TWh-wind-power-in-Sweden-by-2020-/ (accessed on 10 June 2015).
36. Swedish Energy Agency. Svensk vindkraftsstatistik (Swedish wind power statistics 2012). (In Swedish) Available online: https://www.energimyndigheten.se/Global/Statistik/officiell%20statistik/Vindkraftsstatistik%202013.pdf (accessed on 13 July 2014).
37. International Energy Agency. National Survey Report of PV Power Applications in SWEDEN 2014. Available online: www.iea-pvps.org/index.php?id=93&eID=dam_frontend_push&docID=2606 (accessed on 13 June 2015).
38. Widén, J.; Weiss, P. *Solenergi i Dalarnas bebyggelse. Potential till år 2020 och 2050*; Rapport 2012:05; Länsstyrelsen Dalarna, Sweden, 2011. (In Swedish)
39. Örebro municipality, Status report climate plan 2012. (In Swedish) Available online: http://www.orebro.se/download/18.861ae581408afe3a58800011741/1392724419935/Klimatplanen+l%C3%A4gesrapport+2012.pdf (accessed on 3 June 2014).
40. Low Carbon Vehicle Partnership. Available online: http://www.lowcvp.org.uk/news,sweden-introduces-cashback-on-purchase-of-greener-cars_625.htm (accessed on 21 April 2015).
41. BYD Europe. Available online: http://www.bydeurope.com/news/news.php?Action=readnews&page=1&nid=198 (accessed on 12 April 2015).
42. Swedish Energy Agency. *Produktion och användning av biogas och rötrester år 2013*; Swedish Energy Agency: Eskilstuna, Sweden, 2013. (In Swedish)
43. Miljörapport Ekebyverket. *Eskilstuna Energy and Environment*; Miljörapport Ekebyverket: Eskilstuna, Sweden, 2013. (In Swedish)
44. Eskilstuna Energy and Environment. Available online: http://www.eem.se (accessed on 21 May 2014).
45. Rusten, B.; Sahu, A.K. Microalgae growth for nutrient recovery from sludge liquor and production of renewable bioenergy. *Water Sci. Technol.* **2011**, *64*, doi:10.2166/wst.2011.722.
46. Swedish Energy Agency. Performance indicators for energy and climate (In Swedish). Available online: http://webbutik.skl.se/bilder/artiklar/pdf/7585-014-6.pdf (accessed on 27 March 2015).
47. EU2020; Going Local; Eskilstuna Cycling plan. Available online: http://www.eu2020goinglocal.eu/%5CExtDocUploads/Presentations/Ljubljana/14.%20Cycling%20Plan%20%28S%C3%B6rmland,%20Eskilstuna,%20SE%29.pdf (accessed on 27 March 2015).
48. Power Circle. Available online: http://elbilsstatistik.se/ (accessed on 22 April 2015).
49. Amsterdam. Park and Ride. Available online: http://www.iamsterdam.com/en/visiting/plan-your-trip/getting-around/parking/park-and-ride (accessed on 22 April 2015).
50. Aachen. Park and Ride. Available online: http://www.aachen.de/en/ts/50_how_to_get_to/50_80/50_80_30/index.html (accessed on 22 April 2015).

51. Rishee, K.J.; Taylor, J.E.; Culligan, P.J. Investigating the impact ECO-feedback information representation has on building occupant energy consumption behavior and savings. *Energy Build.* **2013**, *64*, 408–414.
52. Vassileva, I.; Odlare, M.; Wallin, F.; Dahlquist E. The impact of consumers' feedback preferences on domestic electricity consumption. *Appl. Energy* **2012**, *93*, 575–582.
53. Balaras, A.C.; Droutsa, K.; Dascalaki, E.; Kontoyiannidis, S. Heating energy consumption and resulting environmental impact of European apartment buildings. *Energy Build.* **2005**, *37*, 429–442.
54. Vassileva, I.; Campillo, J. Increasing energy efficiency in low-income households through targeting awareness and behavioral change. *Renew. Energy* **2014**, *67*, 59–63.
55. Vassileva, I.; Wallin, F.; Dahlquist, E. Understanding energy consumption behavior for future demand response strategy development. *Energy* **2012**, *46*, 94–100.
56. Demographia World Urban Areas. Available online: http://www.demographia.com/db-worldua.pdf (accessed on 24 April 2015).