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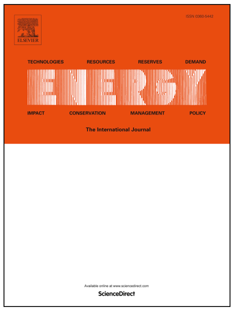

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Sociotechnical transition to smart energy: the case of Samso 1997-2030[☆]

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Abstract

This case study analyses an ongoing practical transition to a smart energy system. The Danish island of Samso, with 3700 inhabitants, aims for a fossil fuel free energy system in the year 2030. Owing to natural limitations, it is necessary to exploit the available energy sources in a manner, which requires careful planning. Furthermore, civic engagement is necessary for a democratic transition to a smart energy system. Therefore the transition has a social side and a technical side, which is analysed. The analysis applies the causal loop diagram of an urban model in order to explain the inner workings of the island community. The analysis illustrates many planning elements, such as political energy targets, sociotechnical priorities, energy vision, energy balance, energy action plan, and examples of demand-side management. The analysis shows that the current municipal plan is comprehensive, but not coherent. It will be necessary to consider trade-offs, that is, set a goal that would balance housing, jobs, agriculture, tourism, biomass and energy. An open question for further research is whether this insight from Samso can be scaled or replicated to other regions.

Keywords: Smart islands, civic engagement, commons, renewable energy systems, energy policy, energy planning.

1. Introduction

A *smart energy* system combines the heating sector with the other sectors of the energy system in order to focus on how the sectors may assist one another (Lund 2017) [1]. Smart energy is especially relevant for an island – or an islandlike system – that experiences bottlenecks in the internal electricity network, an external cable connection, or if the energy production is insufficient to meet the demand. Furthermore, electricity consumers may be billed on an hourly basis, with a high price during peak hours, and it is therefore of interest for a consumer to shift the electricity consumption away from expensive periods of the day. Smart energy concerns not only the electricity supply, but also other energy products such as oil, gas, coal, and biomass. It is *smart* to combine the electricity sector with the heating sector whenever there is an abundance of electricity from renewable energy sources.

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The Danish island of Samso promises to rid the island of fossil fuels by the year 2030 – twenty years ahead of Denmark – as a pilot case for the rest of the country. The island is already a renewable energy island with respect to the annual energy balance. Sea cables connect Samso with the mainland, and electricity flows both ways, but mostly in the export direction. Smart energy is part of the overall energy plan for the year 2030 [2]. The objective is to minimise the electricity export by maximising the internal use of renewable energy. The plan includes a biogas plant, which will convert biomass to gas, electricity, heat, and fertilizer. The island already has a ferry fuelled by liquid natural gas. The idea is to produce fuel for the ferry, and other means of transportation, on the island instead of buying it from outside of the island.

In 1997 the Danish government appointed Samso as Denmark's renewable energy island. This entailed a commitment to work towards a 100% renewable community in the sense that the renewable energy production should balance the energy consumption, when calculated at the end of the year. Cooperatives, farmers, and the municipality installed district heating plants fuelled by biomass, as well as wind turbines on land and in the sea [3]. Private house owners invested in hot water solar collectors, heat pumps, and biomass heating units. The island started to produce electricity in the year 2001, and a few years later the electricity production was up to three times larger than the electricity consumption. The electricity export compensated for the fossil fuels consumed by tractors, buses, cars, and ferries, and by the year 2007 the island achieved its 100% target.

The present-day energy plan requires a further sociotechnical transition, and one challenge is whether the citizens will accept more changes. This article's objective is to analyse the Samso case from a sociotechnical point of view in order to review policies for its transition to smart energy. The existing policies in the EU, the nation, and the region are more or less fixed, or they change slowly. The article focuses therefore on the more agile local policies formulated by the municipal politicians and the citizens.

Energy transition requires an approach that includes several disciplines within the humanities and the sciences.

Social approaches. With respect to the European energy transition Sarricaa, Brondia, Cottoneb & Mazzaraa propose a cultural approach to overcome the separation between the technical and the human sides of energy transition [4]. Their approach focuses on the interactions between the citizen and the society. They consider norms, material culture, and energy practices which lead to their identification of four main challenges:

> The need for further integration towards shared interpretative frameworks, the quest for a constructive and future-oriented research attitude, the importance of connecting different planes of analysis to foresee alternative scenarios, and the need for proposals and solutions to be addressed to decision makers. [4]

The concept of a *common* is central in this context, as Melville, Christie, Burningham, Way and Hampshire recognized [5]. Hermansen and Nørretranders provide examples of successful commons as well as threats to commons, such as centralisation [6]. A common is a resource owned and managed by a community with a system of rules, norms, and values regulating its use. An island can be regarded as a common, where the community or the municipality administers the limited land in such a way that no single interest jeopardizes the wealth of the community. It also applies to a suburb, a city, or more generally to an area that can be regarded as an island. Local ownership is of primary concern, often practised under the legal construction of a cooperative.

Technical approaches. Smart energy is a technical extension of a smart grid; it widens the focus from the electricity sector to the whole energy sector, including heating and transport. It is introduced in the book by Lund (2014) [7] and in the same book, the chapter by Hvelplund et al. [8]. Smart energy is an intelligent combination of various energy sectors in order to optimise some criterion. For example, the use of electricity for heat pumps is a way to combine the electricity sector and the heating sector. That could result in economic savings, because the cost of thermal storage per energy unit is two orders of magnitude smaller than electrical storage [1]. Although a simulation of a smart energy system requires many detailed input data, which can be difficult to procure, it is a well defined engineering activity in contrast to understanding the causes and effects in the surrounding society.

Sociotechnical approaches. A new energy system affects the society, and vice versa, and attempts have been made to understand the socioeconomic interactions. Mathiesen, Lund & Karlsson point out that a Danish national smart energy system can have positive socioeconomic effects, create jobs, and lead to earnings on export [9]. Lund and Hvelplund also focus on job creation, in this case by means of so-called *concrete institutional economics* in relation to sustainable development as a whole [10]. Those authors base their conclusions on a computer simulation of the present and future energy systems. Timma, Blumberga, Bazbauers and Blumberga take this a step further by proposing tools to study sociotechnical transitions [11]. They try to link engineering and social sciences. They start their approach by means of social psychology and *system dynamics* models, and their next step is *statistical data analysis*. They studied energy efficiency and storage in households.

Also, the sociotechnical approach is common for studies of energy transitions within the Science and Technology Studies (STS) field, where the social and the technical are perceived as closely intertwined and interdependent entities as demonstrated in the article by Skjølsvold, Ryghaug & Berker [12] and the book by Strengers [13]. An example is the study of how time-shifting electricity consumption in households depends on the design of technologies as well as existing everyday practices of families [14].

Our approach. An introductory paper to a special journal issue by Clark and Lund advocate a description of practical cases in order to illustrate sustainable developments [15]. The Samso energy system is one such case, because it spans both the past, the present, and the future. It appears there is a need for all of the previously mentioned approaches, and possibly more, in order to understand the transition to smart energy adequately. To come to grips with the sociotechnical causes and effects of a transition, system dynamics, or more precisely, Alfeld and Graham's *urban dynamics* model provides a useful framework [16]. Urban dynamics tries to simulate the long term, time dependent (dynamic) developments in a city or an urban area. Dynamic simulation is beyond the scope of this article, but the model is general, and it can be adapted to the workings of an island community. As with an urban model, the population level, the amount of enterprises, and the amount of housing are three so-called *level variables* (or stock variables, integrators, state variables) of interest. In an urban area, the growing population is usually a cause for concern. Oppositely, the *decline* of the population is often a cause for concern in an island community. This is the case in areas, or countries, where urbanization is a general trend.

This article presents the case of Samso based on the theoretical elements presented in the following section. In order to structure the analysis, the methodology follows a list of eight general planning elements ranging from political energy targets and energy visions to policy implications. The case is described with reference to the theory and the planning elements. The policies are then reviewed with respect to the overall goals, resulting in a recommendation to balance the policies toward the limitations in land use on an island.

2. Theory

Hardin, a biologist, pointed out long ago, that “freedom in a common brings ruin to all” (1968) [17]. Each individual will try to maximise his return. Some form of corrective feedback and regulation is necessary for it to work. A modern common thus becomes “a resource + a community + a set of social protocols” (Bollier in Melville et al. 2017) [5]. An example is a dairy cooperative of cattle farmers or a wind turbine cooperative of citizens [6]. Melville et al. propose to trial a common based local electricity institution [5]. Furthermore, large systems should be organised as “multiple layers of nested enterprise” according to the political economist Elinor Ostrom (in Melville et al. 2017) [5]. Such an organisation already exists, namely the following regional hierarchy: the European Union -> the nation -> the region -> the municipality, and -> the citizen.

Urban dynamics is an application of system dynamics. A system dynamics model simulates a nonlinear system over time using level variables, flows, and feedback loops. Alfeld and Graham constructed such a model to portray the behaviour of an urban area [16]. The model is quite general. Later, other researchers published a simplified version together with its programming code [18]. Figure 1 shows an adaptation with three level variables and their interactions in a so-called *causal loop diagram,* which portrays causes and effects by means of directed arcs. The three variables of interest are: Population, Housing, and Enterprises. Population affects Housing in a positive manner, hence the plus symbol on the arrow from Population to Housing. That is, an increase in Population will cause the construction of more housing. Conversely, more Housing will increase Population, because housing prices will fall, and it will be more attractive to move in. Together, the directed arcs form a loop, and since the signs around the loop are positive, the loop is *reinforcing*; an increase in Population leads to an increase in Housing, which in turn leads to a further increase in Population. The situation is similar with respect to Population and Enterprises via the number of jobs available. The situation is different in the bottom of the diagram. An increase in the number of Enterprises will require more space, but space is limited in an urban area, and Enterprises and Housing compete for the available space. The more Enterprises

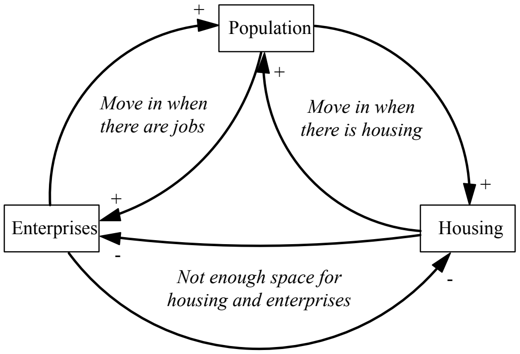

Figure 1: General mechanism of an urban model with three level variables.

the less Housing, hence the negative sign on the arrow from Enterprises to Housing. Conversely, more Housing requires more space, which leads to fewer Enterprises.

An island, which suffers from depopulation, would wish to increase Population by applying policies, such as the following: to increase the frequency of ferry departures, to build an airport, or to build a bridge to the mainland. This should be done with diligence, however, because Housing and Enterprises must follow the increase in Population in a controlled manner. Due to the competition for land, the inhabitants must reach a consensus on trade-offs: Which of the various components of attractiveness should be improved, and which are they willing to forego?

3. Materials and Methods

The analysis proceeds according to the following list of planning elements.

1. *Political energy targets*. These are officially negotiated and recorded, for instance to reduce the energy consumption by 20% before the year 2020 (EU target). There are targets on each level of the regional hierarchy.
2. *Sociotechnical priorities*. These are related to the urban model's level variables: Population, Housing, Enterprises. Which is more important?
3. *Civic engagement*. This concerns the participation of citizens and their acceptance, which is necessary for a democratic energy transition. Citizens participate on several levels of the regional hierarchy.
4. *Energy vision*. This concerns the future, long-term strategy, based on simulations. Various scenarios are available depending on policy. There are energy visions on several levels of the regional hierarchy.
5. *Energy balance*. This is an account of the past energy production and consumption. The energy balance shows the relative contribution of the different fuels. The energy balance is also the starting point for the construction of various indicators as well as analyses of energy efficiency. There are energy balances on several levels of the regional hierarchy.

6. *Energy action plan*. This is a catalogue of actions toward achieving the energy targets. There may be actions that are never implemented due to barriers. There are energy actions on several levels of the regional hierarchy.
7. *Policy implications*. These are local policies concerning land use, jobs, housing, and energy.
8. *Demand-side management*. This is a special action related to smart systems concerning the modification of consumer demand. It includes energy efficiency actions (energy savings) and demand response actions to reduce peak loads. There are actions on several levels of the regional hierarchy.

The list is composed by the present authors in order to create a framework dimension, which covers the human and the technical sides. The first three items concern the human side, while the next three items concern the technical side. Item 7 can be seen as the result of planning, and item 8 is special to smart energy. All of the above items are planning elements with the purpose of supporting the transition to smart energy.

4. The Case of Samso

Because the energy transition on Samso started in 1997, and a new energy transition is planned for 2030, the Samso case contains an amount of experience from the past, but also an amount of unknowns regarding the future. The following is a comprehensive description of the case which follows the previously mentioned methodology step-by-step.

4.1. Political energy targets

The leaders of the EU countries agreed at a summit meeting in 2007 on an action plan with three targets for the year 2020: to reduce emissions by 20%, to reduce the energy consumption by 20%, and to include 20% renewable energy in the energy mix [19]. This is in order to mitigate climate changes, to secure the energy supply, and to stimulate competition on the energy market within the EU.

The Danish energy policy is congruent with the EU policy in the sense that it includes the same targets. Furthermore, the government has an ambition to be rid of fossil fuels (coal, oil, gas) by the year 2050. Consequently, the country should be able to cover its energy consumption by renewable energy. The transition to renewable energy is ongoing, and if successful, it will help to mitigate climate changes and to secure the energy supply. In 2016, renewable energy covered 31% of the Danish final energy consumption – and 54% within the electricity sector taken separately [20]. Furthermore, renewable energy is to cover 100% of the electricity and heat supply by 2035, and wind energy is to cover 50% of the electricity consumption by 2020 [21]. The latter target is achieved already.

The Central Denmark Region (Region Midtjylland), which includes the Samso municipality, also has an energy strategy and a target: 50% of the energy consumption – in average over the entire region – shall be renewable energy by the year 2025 [21].

In 2009 the municipal council on Samso approved a master plan for becoming a fossil fuel free island by 2030. The following are some of the subordinate objectives of the master plan: To maintain and expand the renewable energy production, to rely on renewable energy for transportation, to increase energy efficiency, and to participate in partnerships. Half of the vehicles and all public transportation shall be electric by 2020. The Samso municipality participates, together with 18 fellow municipalities, in the energy reporting and planning of the Central Denmark Region. Samso municipality, as an enterprise, participates in the Klimakommune (Climate Municipality) initiative by the Danish Society for Nature Conservation, which obliges the municipality to decrease its CO_2 emissions by at least two percent every year in at least five years. Samso's mayor signed the Covenant of Mayors which obliges the municipality to implement or even go beyond the EU 2030 climate and energy targets, which means at least 40% less greenhouse gas emissions by 2030 and the adoption of a joint approach toward climate change [22]. By signing the Pact of Islands, which is a parallel initiative to the Covenant of Mayors, Samso committed itself to go beyond the EU 2020 targets and reduce CO_2 emissions by at least 20% by the year 2020 [23]. Under the Smart Islands Initiative five members on Samso have signed a declaration to focus on seven areas: energy; transport; water; waste; governance; information and communication technology; and economy [24]. The five members are organisations that cover public authorities, businesses, academia and civil society actors, the so-called *quadruple helix*. The idea is that islands are test-beds that can host pilot projects, which will generate knowledge on smart resource management. The knowledge can then be transferred to other areas.

4.2. Sociotechnical priorities on Samso

The sociotechnical priorities are related to the historical development of the population, the conditions for enterprises with a view to the job market, and finally land use. Obviously, land is scarce, and this creates some tension with regard to the political priorities of various stakeholders.

4.2.1. Population on Samso

Contrary to the Danish urban population, Samso's population is declining and has been since the beginning of the last century, as Fig. 2 clearly shows. The population peaked in 1911 at 7500 inhabitants, but it declined, and today the population is just over 3700, which is the lowest level ever recorded. A large part (15%) of the population works within agriculture, which is more than the national average (3.5%) [25]. At the time when the population peaked, more people lived together on less space. Today the average is 1.9 persons per household [26]. Therefore, the island's housing capacity is now less than the 7500 inhabitants. Still, the decline is alarming. There are more deaths than births, so the net contribution from within the island is negative. On average the population is older than the national average, because school children leave the island when they are 16-17 years old to continue their education. Therefore the birth rate is lower than the national average, and the death rate is higher than the national average. There is in-migration from other municipalities in Denmark, but the out-migration is larger, so the net domestic inflow is negative. However, the net inflow from foreign countries is positive. The top four foreign nationalities are Polish, Lithuanian, Syrian, and Bulgarian [27]. Workers from eastern Europe come to work in the fields, and later they may settle on the island and start a family. The last couple of years a number of

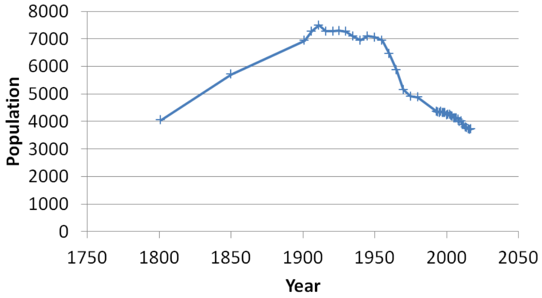

Figure 2: Overshoot and 'collapse' of the Samso population.

refugees have contributed positively to the headcount, and it is hoped that some will settle in as permanent residents and perhaps even start small businesses. The net result is a recent population growth, for the first time since the second world war. This is a deviation from the official forecast in Fig. 3, which predicts a turn somewhat later, in 2025 [27]. The group of elderly inhabitants above the age of 65 is relatively large. They are outside the labour market, but they contribute to the economy, because they refurbish old buildings, they buy goods in the shops, and they attract guests to the island. Furthermore, a large group of volunteers in that age group work to improve the quality of life for others.

There is no airline service, but two ferries serve the island: one from the eastern side and one from the western side. The transfer takes one and a half hour with 2-3 departures per day (eastern line) and one hour with 7-8 departures per day (western line). The western line, which is now owned and operated by the municipality, transports twice as many passengers as the eastern line, annually. The total number of passengers has been increasing for at least 25 years [27], and that is believed to affect the population level as follows: The more visitors, the more people will know the island, and the more will buy a summer residence or even settle on the island permanently.

The Danish government has agreed that ferry access to the islands should cost the same as driving the same distance on roads. Recently, the government contributed a subsidy to all small islands and islands consisting of just one municipality, in order to lower the ticket prices. The Samso passenger numbers went up immediately [27], and at the same time it became less expensive to transport goods, such as food products, to the market outside of the island.

It is usually the combination of nature and a wish for a change in life style that convinces people to settle on the island. But, of course, for many it is necessary that there is a job opportunity and housing too.

4.2.2. Enterprises and jobs on Samso

One-third of the jobs are in the public sector according to regional statistics [28]. This is not unusual for Denmark. The two largest economic sectors are tourism and agriculture; together they account for about one-third of the jobs on the island. The renewable energy island project has created jobs, and it has been included as a third

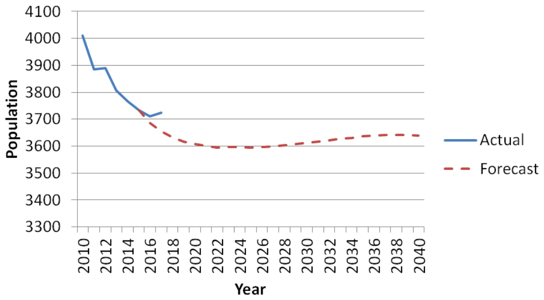

Figure 3: Recently the population increased slightly and deviated from the forecast.

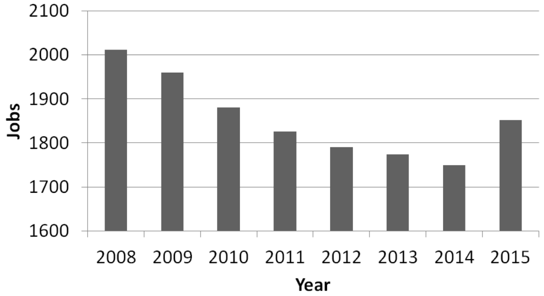

Figure 4: Jobs on Samso.

political focus area besides agriculture and tourism. Traditionally, farmers and tourist workers have had some disagreements over the use of the land, but the two sectors also depend on each other; farmers sell fresh produce to the tourists, and tourists enjoy the farming landscape and activities. There are more than 300 tourist induced jobs [28], but some of these are filled by nonresidents. There are more than 200 jobs in agriculture [27]. For comparison, the municipality employs 350 full time equivalents, some of which are nonresident commuters [29]. Figure 4 shows that the number of jobs increased in 2015, when the municipality started its own ferry company.

There are 81 workplaces per 100 citizens, which is similar to the region and the country as a whole, but the tendency is decreasing [28]. According to the statistics, 5.3% of the workforce is unemployed (in 2016). However, during the summer season almost everybody is employed thanks to agriculture and tourism. The tourist season now starts at Easter, it accelerates in June, and it peaks in July. In the middle of October most hotels and restaurants close for the winter. There are 70 000 tourist visits every year, equivalent to 350 000 overnight stays in tourist accommodations with a registration obligation [25].

4.2.3. Housing on Samso

There are 2200 single-family houses on Samso [25] and almost 2000 households [26]. People from other parts of Denmark are allowed to buy a house and use it as a second home, without having their permanent address there. There are about 60 dwellings put up for sale, and this has been the level since 2009 [27]. However, before that year there was a dip to a minimum of 10 dwellings up for sale. The minimum occurred in 2006, which is when the economy boom was at its highest. It seems that the temporary wealth in the rest of the country resulted in a high demand for second homes; prices went up as a consequence.

At a first glance, there is generally no shortage of housing. However, there may be a shortage in the future in the urban zone. The urban zone is just 2% of the whole area of the island [30], and new buildings are restricted to urban zone by the municipal plan. In comparison, the agricultural land constitutes 70% of the whole.

The competition for land between housing and enterprises thus takes place in the urban zone, which constitutes a bottleneck.

4.3. Civic engagement on Samso

The immediate concern is whether the citizens will accept a transition to a smart energy system. Neighbours often oppose development plans, and often for a good reason: they fear the value of their property will decrease. On Samso, it is common to share investments between stakeholders, such as citizens, farmers, or the municipality. If the financial profit is kept within the island, it is for the common good. Nevertheless, there is still opposition from neighbours. It is therefore important to inform the public, and to engage groups of citizens early in the planning.

It is common practice to call for public meetings. All interested stakeholders may turn up to receive information about a project. In some cases the meeting is a workshop, where the participants are asked to give their opinions. These are summarised and written down. Techniques and insights from meetings with citizens are collected in a guide for communities published by the Samso Energy Academy [31].

Jakobsen wrote a thesis about the local ownership and social acceptance at Samso [32]. Local ownership has been a cornerstone of the renewable energy island project. An example is the district heating company in Ballen-Brundby. The consumers themselves own the company in a cooperative (coop) with limited liability. The members both own and manage the coop. The coop must be of the greatest possible use to the members, rather than give a profit. Every member has one vote, independently of the magnitude of the member's investment. The municipality issued a guarantee for a construction loan in the so-called Credit Institution for Local and Regional Authorities in Denmark (Kommunekredit) in order to finance the construction of the plant.

4.4. Samso energy vision

There are at least three reasons for working toward a smart energy system on the island.

- Renewable electricity is abundant on the island, but the amount of biomass is limited by the size of the island and the allocation of the land (zoning). If electricity and biomass can be combined for heating purposes, then more of the 'home-made' electricity can be consumed internally rather than just exporting it [33].

- The capacity of the sea cable (40 MW) is exploited to 83% if all wind turbines operate at full production without load. Furthermore, in a certain network fault situation, there is a tighter electric bottleneck on the island (an aerial line between two transformer stations loaded to 96% of its capacity). If the wind turbine and photovoltaic production increases in the future, the bottlenecks must be considered. Curtailment of the power generation could become an option.
- It is less expensive to utilize the storage options in a combined energy system, rather than installing electric batteries or capacitors [33].

The wind energy production is already large, and the island exports twice as much as it consumes (2015) [34]. The potential photovoltaic production has been analysed using a 'solar atlas' and a geographical information system [33]. The analysis shows that if all rooftops are included the potential is 87 GWh per year, which is more than three times the current electricity demand. However, if only roofs with an annual production higher than 90 kWh/m2 are counted, then the potential is more than 60 GWh and comparable to the current wind production. In Denmark the average number of full load hours is 961; that is, one kilowatt of photovoltaic panels produces 961 kilowatt-hours in a year [35]. Fortunately, Samso has more sunny hours and higher solar intensity than average, and the number of full load hours is perhaps 10 percent higher than average. By means of simulations the energy vision develops scenarios for supporting the conversion of Samso into a 100% renewable energy system by 2030 [33]. The focus is on the integration of local renewable resources and whether the local potentials are sufficient to meet the demands [36]. The simulation study uncovers impacts on energy, economy, and the environment.

With respect to renewable energy, the scenario which consumes the least primary energy consists of the following elements: electric vehicles (cars, vans, half of the busses), biogas with a hydrogenation step by electrolysis, as well as liquid and compressed biogas for ferries, busses, and other heavy vehicles. With respect to economy (investment costs; fuel costs; operation and maintenance costs; and carbon dioxide costs), the scenario with the least costs consists of just converting cars, vans and half of the busses to electric vehicles. The costs are low owing to the better efficiency of electric motors compared to combustion engines; they save fuel, which is expensive fossil fuel. With respect to the environmental impact, in terms of carbon dioxide emissions, the best scenarios combine the previously mentioned scenario, where vehicles are converted to electricity, and biofuels. All such scenarios are carbon dioxide neutral.

The study concludes with the following list of recommendations.

- Find heat savings as a first step.
- Interconnect existing district heating networks.
- Install large heat pumps for district heating, and small heat pumps for individual heating outside of the heating networks.
- Electrify the transport sector and the industry.
- Use the available biomass primarily in the transport sector. Boost the biomass with electricity through hydrogenation technologies.

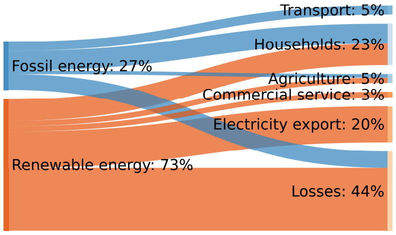

Figure 5: Samso energy balance 2015. Units are percentages of the total available energy (901 TJ).

- Use biogas technologies in order to use the wet fraction of the biomass potential.

In summary, the island must exploit its electric resources better and prioritize the available biomass more carefully.

4.5. Samso energy balance

The EU calculates and publishes an annual energy balance [37]. It is based on data reported by the member states. The Danish Energy Agency reports to the EU and publishes a report and data in a spreadsheet annually [20]. The Central Denmark Region updates its energy balance once every two years [21]. The Samso municipality updates its energy balance once every two years also, and it is published by the Central Denmark Region [34].

The energy balance has an input side — energy supply — and an output side with the demand of various groups of consumers. There are many details, but the diagram in Fig. 5 provides an aggregated view of the energy flows. In the diagram the total supply is consumed by the transport sector, households, agriculture and businesses. The transport sector, including the ferries, uses almost entirely fossil fuels.

Despite the declining population on Samso, the energy consumption per capita is remarkably steady. Figure 6 shows a plot of the total energy consumption against the population in four different years. Some variation in the fuel for heat is to be expected, because colder heating seasons require more fuel for heat. However, the points are more or less on a straight line, from which the marginal energy consumption can be deduced. It is only a local approximation (the straight line fit does not pass through the origin of the coordinate system, as would be expected). It shows that the energy demand increases with the population. Vice versa, it is possible to predict the energy demand given a future size of the population, other things being equal. This relationship links energy to the sociotechnical model (Fig. 1). Clearly, an increase in population requires more enterprises and more housing, and that requires more energy.Today, heat is mostly produced from biomass and oil, but the transition to the future energy system may rely more on electric heat pumps. The electricity share will thus increase, replacing biomass fuel for heat. The excess biomass is to be used in a future biogas plant instead.

4.6. Samso energy action plan

The action plan for Samso as a fossil fuel free island is a work document, which changes from time to time [38]. The action plan is divided in three main areas with the

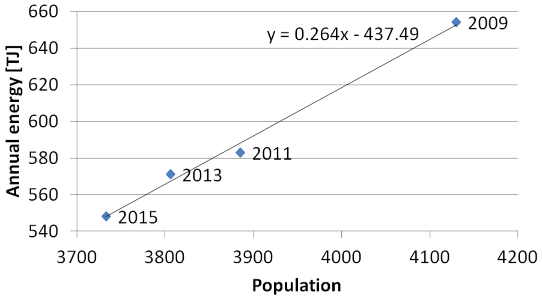

Figure 6: Energy consumption per capita. The energy is measured in terms of final energy, that is, production less export and losses. The marginal energy consumption is 264 GJ/year per capita.

following headings: (1) “smart fossil fuel free energy system”, (2) “food production in balance”, and (3) “the resource landscape”. The plan thus covers more than a smart energy system, and sustainability is the main topic.

The planned actions toward a smart energy system include a strategy for the renewal of existing wind turbines toward 2030 and the definition of new candidate sites. The energy system is to be extended with a biogas plant, and the site is decided and included in the municipal plan. Furthermore, the action plan proposes to establish goals for reducing the heat consumption in housing and enterprises, and this has now been included in the municipal plan. It is generally assumed that electric vehicles belong in cities, but it is also possible to promote electric mobility in rural districts. The Samso municipality has worked closely together with the Samso Electric Vehicle Association in order to promote electric vehicles, and this has given citizens know-how about advantages and disadvantages. The municipality and the electric vehicle association have established charging stations with a low charging price in order to support the electric vehicle target.

The proposed biogas plant is economically viable with a payback period of 8.5 years [36], see the key figures in Table 1. The idea is, however, to produce liquid gas in a high quality for the gas ferry. The biogas must therefore first be upgraded to pure methane and then cooled to liquified bio natural gas (LBNG). Upgraded gas for other transportation purposes must be compressed, instead of liquified, to form compressed bio natural gas (CBNG). The upgrade and liquidation steps are expensive and economically viable only with subsidies from the government. Farmers will get their animal manure (slurry) picked up by lorry, and they receive digested, dry fertilizer in return, all without payment.

4.7. Policy implications on Samso

The *municipal plan* documents the policies that the municipal council has agreed upon [25]. It is written for the citizens and authorities to plan future activities in specific areas of the island. The municipal plan contains political goals, development plans, and binding guidelines for the land use. It is updated once every two years. The last update is from 2017, and it covers a period of 12 years into the future [25]. The main goal

Item	Amount
Realistic biomass supply	4 200 000 m^3 methane/yr
Ferry demand	2 650 000 m^3 methane/yr
Plant self consumption	440 000 m^3 methane/yr
Land transport demand	400 000 m^3 methane/yr
Total demand	3 490 000 m^3 methane/yr
Utilization factor	83%
Initial investment	5.8 million euro
Production cost	0.42 euro/m3 methane
Selling price	0.47 euro/m3 methane
Payback period	8.5 years
Upgrade plant investment	2.1 million euro
Liguidation plant investment	1.6 million euro

Table 1: Key figures for the proposed biogas plant [36]. The site will be next to a vegetable pickling factory, which will deliver sludge and receive heat. Other main biomass sources are energy crops, animal manure, and straw.

related to energy is the following: Fossil fuels and propellants will no longer be used on Samso. With reference to the urban model (Fig. 1), the following gives an account of the policies related to attractiveness, the building stock, land use, and smart energy. Evidently the declining population is a threat.

4.7.1. Attractiveness

The municipal council aims to attract a widely composed group of people, including resourceful people, families with children, and elderly people.

According to a questionnaire survey, there is a number of general reasons for migrating to Samso, including: the nature, the neighbourhood life style, the secure environment for children, and the need for a change in life style [39]. However, most job holders do not move until they have a job on the island. Commuters move primarily due to a wish for a change of life style, but for them the ferry connections are more important than the job market. Other factors that affect the decision to move are, for instance: tax rate, housing availability and price, children and nursery, school and education, culture and leisure time, service offered to the elderly, crime rate, the municipal economy, the population, and the politics. Potential businesses can find information about the number and kind of other businesses, the amount of square metres available for office space, broadband coverage, and taxes. All these items are quantified and available on the World Wide Web for all municipalities and it is possible to make comparisons [26].

The municipal council will work to attract more tourists, and try to make leisure areas attractive and accessible for both tourists and residents. The council will work to achieve good transport internally and externally, and it will optimise the ferry connections with regard to prices, frequency, and travel time. The council will also investigate if it is possible to establish a third ferry line for passengers on foot or bicycle into the city of Aarhus.

The municipal plan does not directly address a policy of business expansion. However, Samso municipality's department for businesses, tourism and culture has developed a strategic plan to increase the number of businesses and settlers [40]. Tourism and food production depend on the summer season today, but there is also a potential on both sides of the season. This is to be exploited by means of sustainable food products and sustainable tourism, including experiential travel. Renewable energy can be combined with food production and tourism to create new brands. New initiatives in education can be offered both summer and winter. Better options for commuting between Samso and the mainland, and good conditions for startup businesses such as mentoring, sparring and sharing of office space could attract new enterprises. The goal is to become a live society all year round.

Innovation, financing and infrastructure is to aid in the development of new startup companies. Innovation applies to both tourism, food production, and renewable energy. Better ferry connections and Internet connections are necessary. New partnerships and projects can develop the infrastructure and thereby create new jobs. The goal is to create growth.

The municipal plan ensures that the municipal council will work toward developing the tourist business on the harbour of the east coast village of Ballen, and to open for new settlements by allowing a higher density of the buildings there.

Marketing and branding of food products, tourism, and renewable energy helps to improve the image of Samso as a sustainable island. Digital media will be used more in the future marketing of the island. Citizens and enterprises are to be encouraged to create and disseminate themselves a positive image of the food production, tourism, and renewable energy. The goal is to be known and recognised for what the island can offer.

The renewable energy island has created jobs, and it is believed that the fossil free island project will create more jobs. For example, a biogas plant is estimated to create more than ten jobs while it is being designed, constructed, and commissioned.

4.7.2. Maintaining the building stock

To stimulate business expansion, one theoretical strategy would be to switch housing space to commercial use. But this is politically unacceptable. On the contrary, the municipal plan tries to secure a diverse and attractive supply of housing. This could be apartments with a view to the sea in the coastal villages, and well located building sites in the larger towns and villages. Obsolete farm buildings may be converted to workshops, small shops with a dwelling, or storage and office use – as long as the existing building remains more or less intact. Building construction outside of the reserved areas will not be permitted.

New buildings in villages should fill gaps within the existing village limits, and they must respect those farms that are inside the village limits.

With reference to the energy island project, new buildings and larger refurbishments must seek to minimise the energy consumption (below 15 kWh per square metre annually) by using energy efficient materials and components. New buildings in defined town areas must comply with the building code for low energy buildings, the so-called energy class 2015. Furthermore, the heating consumption in business buildings must be reduced.

Of the small houses, 2000 are built before the year 1980. It is estimated that it pays off to energy refurbish 1800 of those houses [25]. Approximately 300 houses are heated by an oil burner, the rest are heated by district heating, heat pumps, or biomass furnaces. The goal is to be rid of all oil burners by 2030. According to the plan, the heat consumption in private housing should be reduced by 30% and in business constructions by 5% before the year 2021.

4.7.3. Land use

The municipal plan keeps the clear delineation between urban and rural areas as it is, the rural area is protected from new building constructions, and agriculture is allowed possibilities for new developments. New buildings must include adequate parking, so that residents and visitors can park their vehicles within the cadastral parcel.

The existing nature areas will remain fixed, or may even be extended with a focus on creating coherent areas.

A farming area can only be changed to nonagricultural purposes if the area has limited agricultural purpose, or if an overall assessment deems it preferable to place an enterprise in farmed land. A rising sea level and intensive rain events, as a result of climate changes, will cause flooding in certain areas marked on maps. Locally, a rising water table will change drainage and farming conditions, and perhaps decrease the useful farming area.

New large wind turbines can be erected in designated areas only. Household wind turbines can be erected close to solitary houses in the rural zone. The maximum allowed height is 25 metres, and the turbine must have at least three nonreflecting blades. However, the municipal council wishes to prepare a further extension of the renewable energy production. They have reserved a site for a biogas plant, they will work toward a decision about new wind turbine areas, and they will work toward upgrading the existing wind turbine areas.

4.7.4. Smart energy

The following list of items relate to goals of the master plan for 2030.

- *A flexible energy system*. Examples of actions: Establish a biogas plant, new wind turbines, expand the district heating network, more solar energy, increase the biomass fraction, phase out oil boilers, more vehicles on electricity and gas.

- *Propellants for transportation, including ferries, based on fossil free fuel*. Examples of actions: erect charging stations for electric vehicles; make use of smart energy meters; install electric buses; use electric vehicles for taxis; vocational education of craftsmen to enable them to service electric vehicles; establish a biogas unit that produces compressed or liquid biogas to ferries, lorries, tractors, and buses; establish filling stations; and put projects out to tender, if possible.

- *Significant heat savings*. Examples of actions: Reduce heat consumption in dwellings and businesses. New buildings with minimal heat consumption.

- *Significant electricity savings*. Examples of actions: an awareness campaign toward energy consumption; vocational education of skilled craftsmen; and replacement of old circulator pumps, compressors, and electric motors.

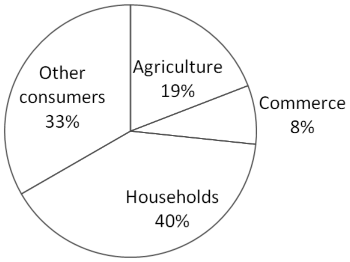

Figure 7: The relative electric energy consumption of the three target groups of interest: agriculture, commerce and households. The group 'Other consumers' includes public and private service, construction and production industry, and transport. The total corresponds to 100 TJ (2015).

- *Establish and extend partnerships*. Examples of actions: Joint ventures with consumers, utility companies, distributors, and energy producers.

The primary technical challenge for the future energy system is to deliver adequate energy for the transport sector.

4.8. Demand-side management on Samso

The objective of *demand-side management* is to modify the demand profile in order to fit the demand better to the available energy supply. For an owner of a photovoltaic (PV) plant, for instance, it could be an advantage to shift some electricity consumption to productive periods of the PV plant. For an island, demand-side management is a technique to reduce peaks or to increase the use of renewable energy.

Demand response seeks to reduce or shift peak demand of an end-user or a group of end-users. *Energy efficiency* seeks to reduce peak demand by using less power, either by cutting superfluous energy use or by using more efficient components.

On Samso, the target groups, so far, are the farmers, the shop owners, and the private house owners. Figure 7 shows the share of the electricity consumption of the three target groups. Regrettably, a simulation study on the national level showed that the value of flexible demand is limited, because more than a quarter of the classic electricity demand would need to be flexible within a month, which is highly unlikely [41]. In any case, working with the target groups is an excellent way to campaign for a future smart energy system.

All consumers on Samso are equipped with a smart meter, which communicates the consumption to the utility company almost continually. As of 2018, the government allows billing on an hourly basis. Electricity is likely cheaper during the night, when other loads are low, and consumers may soon wish to act according to the market price and become flexible consumers. Furthermore, the utility company may introduce a tariff where electricity is more expensive during peak hours, for instance between 5 pm and 8 pm. Such a tariff has already been announced in the Copenhagen area for 2018.

In order to make some pilot experiments, the Samso Energy Academy installed various pieces of equipment, commercially available or developed with external partners, and the Samso Energy Academy received feedback from the involved individuals. In several cases measurements support conclusions, for example from electricity meters, temperature sensors, calorimeters, and energy bills.

Farmers may have options to delay or shift electric loads [42]. Cattle farmers use an ice bank for cooling milk, and they are willing to produce more ice water than normal during the night and leave it off during the day, rather than operating it all day. Photovoltaic panels motivated a farmer to consider delaying the milking of the cows enough to fit the productive hours of the panels.

Shop owners have a potential for electricity savings. They are willing to save energy during the night and on days when the shop is closed, and 11% savings on average were achieved with little or no investments at all [43].

House owners have a potential for heat and electricity savings. By means of home energy checks [44], it is almost always possible to find 5% savings in households, often more [45], with simple saving advices, such as switching to LED lighting or awareness measures [46].

The following two sections briefly present demand response, based on a voluntary behaviour change, and energy efficiency in shops, which does not require a behaviour change.

4.8.1. Farmers and demand response

The most immediate loads to be shifted in time are the following: pumping for irrigation of fields, water heaters for cleaning and preheating, and coolers and freezers. Together, those loads consume one quarter of the electric energy consumption of farms in the whole country [42]. Milk cooling is particularly interesting.

Immediately after milking, the milk must be cooled from 38 °C to 4 °C. An ice bank is one way to cool the milk. An electric compressor drives the ice bank, and the ice storage can in principle be charged and recharged when there is a surplus of inexpensive electricity. The milking of the cows always takes place at the same times of the day, and it is therefore necessary to know the charging time of the ice bank.

Example 1 (Hansen 2015 [42])**.** A herd of 165 cows are milked twice a day at 5 am and 5 pm. The cows produce together 1.8 tonnes of milk per milking session. The milk from one milking requires the following cooling energy, when the heat capacity of the milk is 4.2 kJ/kg·K,

$Q = 1800\ [\text{kg}] \times 4.2\ [\text{kJ/kg}\cdot\text{K}] \times (38 - 4)\ [\text{K}] = 257\ 000\ \text{kJ} = 71\ \text{kWh}$

Since a milking session takes about three hours, the required cooling capacity is 71 [kWh] / 3 [h]. A refrigeration plant's efficiency (coefficient of performance, COP) is typically 3.5, therefore the electrical compressor load is 71 [kWh] / (3 [h] × 3.5) or 6.8 kW, which could be shifted. Denmark produces about 5500 million kilograms of milk per year (in 2016) [27]. Scaling the example to the whole country, the potential energy consumption, which could be shifted, is 53 500 MWh per year. ☐

A dairy farm was analysed in detail in order to understand better what the possibilities for load shifting are in reality. It is a small farm (8 cows) which produces organic milk, butter and cheese. The diagram in Fig. 8 gives an overview of the production, and it also identifies storages, which, by their nature, are possible candidates for controlling delays. The farmer agreed that it would be possible to use some of the storages in order to force a delay of some of the energy demand. The diagram points to several possible options for load shifting related to storages.

- Superheat hot water for pasteurisation, install a timer
- Preheat hot water for pasteurisation
- Superheat the building (winter), subcool the building (summer)
- Precool cooling water
- Subcool ice bank
- Keep cold milk in tank until electricity price is low
- Produce butter and cheese to storage when electricity price is low
- Defer washing and hosing, and thereby pumping to waste storage
- Compress air when price is low
- Produce fodder to storage when price is low
- Chop firewood to storage when price is low
- Consider using old car batteries for storage of electricity

The same farmer agreed that it would be possible to shift the milking time from early morning until later. He was interested in photovoltaic panels, and the graph in Fig. 9 of the potential solar production (12 kWp) showed a peak around 1 pm. He would be willing to delay the milking some hours, in order to fit better with the production from a photovoltaic plant on the roof.

Another possibility is to pump water when the electricity price is low. Fields are drained in order to remove excess water from the root zone. The drained water flows into a reservoir, in some cases, where it is pumped away. Today, the pumps are typically on or off, controlled by a level sensor, but they could be controlled smarter according to a price signal by means of a remote switch [42]. The switch is supposed to be operated by the distribution system operator, within certain limits, depending on the prices on the electric power market.

On the other hand, drying of for instance onions or grain is difficult to manipulate. An automatic control system controls the air flow and temperature over a fairly long period. The products are delicate, and the farmers did not wish to interfere with the automatic controller. Vegetables are kept in a cold storage. The temperature should preferably be 1 °C always, controlled by a thermostat, and there is very little opportunity to shift the load.

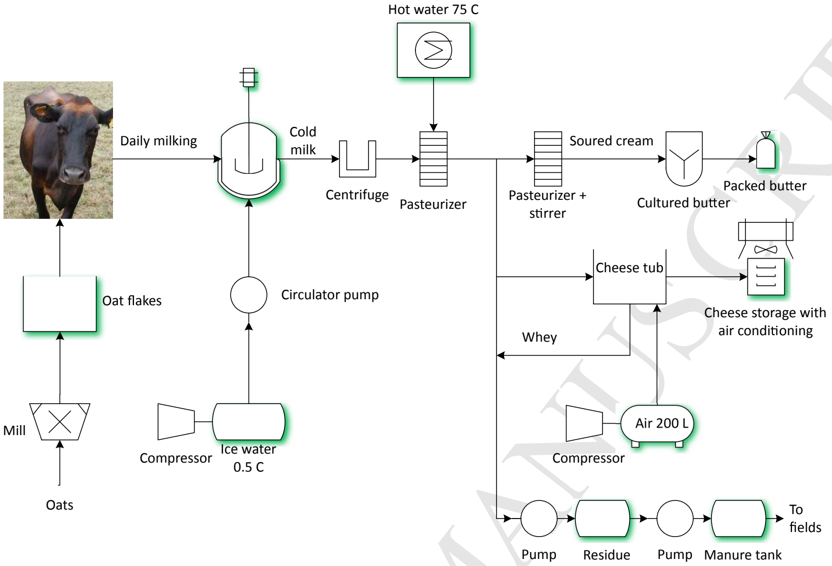

Figure 8: Process flow diagram of dairy. The shaded components are storages.

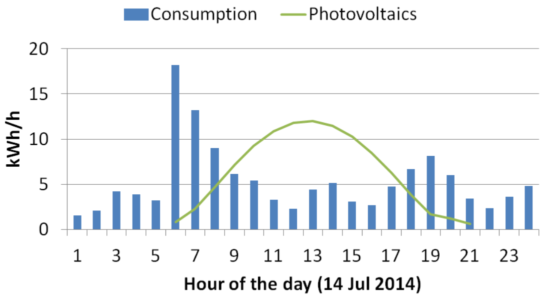

Figure 9: Nominal photovoltaic production (line) and actual consumption (bars) on a small dairy farm. Cows are generally milked at 6 in the morning and 6 in the evening.

4.8.2. Shop owners and energy efficiency

A night walk is an energy survey in a shop, at a time when the shop is closed to the public. The idea is to discover unnecessary energy consumption, when all should be on standby. It was applied in 123 shops in eight European regions as part of an EU-funded project, and the average savings were 11% from measures that required very low investments [43]. The retail shops are highly exposed to the citizens, and there are plenty of opportunities to communicate energy efficiency to the customers.

For example, a supermarket on Samso (Superbrugsen) is open from 8 am to 8 pm, and thus closed half of the time. The primary advice was to lower the nightly room temperature during the heating season. Savings are proportional to the reduction in average temperature (Jantzen & Kristensen 2014) [44].

Example 2. The average outdoor temperature on Samso during the heating season (October to April) is 8 °C [47]. Assume the average indoor temperature is 20 °C. Propose to lower the average temperature, so the average becomes 19 °C. Notice that all temperatures are *average* temperatures. Lowering the average to 19 °C in a shop is possible by means of nightly temperature setback when the shop is empty; that does not affect the shoppers comfort temperature during the day. The saving factor is thus

$f = (20 - 19)\ [\mathrm{K}] / (20 - 8)\ [\mathrm{K}] = 1/12$

In other words, the shop will save 8.3% on the heating bill if it lowers the average temperature one degree. ☐

If the shop lowers the average indoor temperature, even if it is only by night, the coolers and freezers save some work. For example, assume the temperature inside a food cooler is 5 °C. If the room temperature is lowered, the temperature difference becomes smaller, and energy will be saved by the same type of calculation (7% for every degree, if the starting point is 20 °C). The savings are easily calculated, and it is possible to document the savings just by measuring temperatures before and after the action.

A bottle cooler can consume as much as a small average Danish home with two residents (3000 kWh/year), but a timer switch will save energy. Figure 10 shows the temperature inside a bottle cooler, measured by a battery driven data logger (Lascar Easylog USB-2+). The temperature is just below 7 °C, but around 6 pm a timer switches it off. The temperature rises during the night, and at 7 am the timer switches it back on. It takes about one hour to reach a steady temperature just below 7 °C. In this case, the timer saved 13% of the energy. The refrigerator cools drinks such as soda, water, and beer; therefore the contents are sufficiently robust to withstand temperature changes.

All in all, the saving advices amounted to 7.5% of the annual energy budget of the supermarket, corresponding to 8400 euro. They used the savings toward hiring another young worker.

For future reference, the following is a small catalogue of the saving measures.

- Lower the room temperature
- Nightly room temperature setback
- Nightly temperature setback on bottle coolers

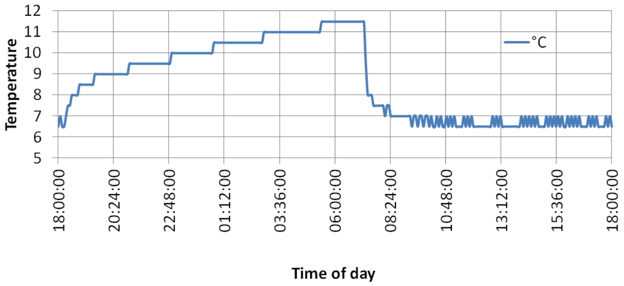

Figure 10: Temperature in a bottle cooler. A timer switches it off at 6 pm until 7 am next morning.

- Shut off unnecessary outdoor lights during the night
- Remove nightly standby consumption in a Solarium
- Correct the balance between heating and cooling
- Replace lamps by LED, especially spotlights
- Decrease ventilator speed
- Lower the hot water temperature
- Save a bottle cooler
- Replace a display cooler by a fridge
- Replace old circulator pumps
- Replace electric heating by district heating
- Replace old thermostat valves
- Replace gas cooker by an electric induction cooker
- Replace oil boiler by an air-to-water heat pump
- Install photovoltaic panels
- Correct the official area measure
- Tax exemption on process energy

Example 3. Superbrugsen achieved 7.5% savings on the energy bill. Table 2 lists the individual advices together with their respective savings, in terms of energy and expenses. The table provides the magnitude of the individual saving measures, and it is clear that many small advices add up to a significant amount. To give an idea of the size

Supply	Advice	Saved supply (kWh)	Saved money (EUR)	Saved money (%)
Electricity	Nightly temperature setback in shop. Saves compressor work.	773	124	0.1
	Same advice, saves plug-in cooling.	123	20	0.0
	Same advice, saves electricity in the bottle coolers.	586	94	0.1
	Same advice, saves electricity in the milk room.	682	109	0.1
	Nightly temperature setback in butcher shop.	8648	1380	1.2
	Raise low temperature in bottle coolers from 6.5 to 10 deg.	5658	905	0.8
	Lower the average level of lighting from 650 to 550 lux.	16085	2570	2.3
	Stop ventilator after baking.	18450	2950	2.6
Heat	Nightly temperature setback in shop. Saves district heating.	2826	241	0.2
	Total		8400	7.5

Table 2: Savings advices for Superbrugsen.

of the site, the heated area is 1600 square metres, the recorded annual electricity consumption was 615 000 kWh (electric), and the recorded district heating consumption was 154 000 kWh (thermal).

To arrive at Table 2, it was necessary to perform some background calculations, first of all to estimate how the energy is distributed between various load classes. For example, if one advice concerns compressor cooling, it is useful to know the share of energy for compressors relative to the whole electricity consumption, as in an energy balance. This may be found by means of measuring equipment with current clamps in the distribution board. If that is not possible, estimate the consumption from the power rating and an estimated number of running hours.

Calculate a saving factor f, as described previously, and multiply it onto the estimate of the annual consumption. Finally, multiply by the unit price. Use the marginal price, that is, the direct cost of the first saved kilowatt-hour (disregarding fixed costs). The total electricity cost amounts to 98 400 euro/year, and the total heating cost amounts to 13 100 euro/year using marginal prices. □

5. Discussion

As mentioned previously, one challenge is whether the citizens will accept more changes. Working with the target groups promotes civic engagement, and it is an opportunity to map nontechnical barriers toward sociotechnical changes. The following two sections discuss the relationship with the citizens and the policy implications of smart energy.

5.1. The complexities of carrying out energy savings

This section presents a detailed discussion of the experiences with the involvement of the users – and the network of actors they are part of – in energy saving initiatives. The focus is on the previously mentioned case involving a supermarket (Superbrugsen). The Samso Energy Academy (SE) carried out an energy audit of the supermarket and suggested several changes and improvements that would save energy, including nightly setback of indoor temperatures and replacing inefficient light bulbs with efficient LEDs etc. Subsequently, the employees at the shop also came up with a few of their own energy saving ideas.

In explaining the underlying approach behind the initiative, the SE several times emphasises that it was important for them to come up with ideas that would not compromise comfort, sales or the daily work routines at the supermarket. For the same reason, SE had a frequent dialogue with the manager and the staff during their planning and realisation of the energy saving measures. For instance, they had to plan the nightly setback of indoor temperatures according to the work schedules of different members of the staff (e.g. the staff in the butcher corner who start work early in the morning).

The following illustrates the complexity of actors and considerations involved in developing and carrying out energy saving measures. Also, the role of the SE in securing energy savings is discussed.

The SE was the initiator of the process that led to the energy savings. What triggered SE to contact the supermarket for collaboration was the European project. As a site of intervention, the supermarket is surprisingly complex. Through their interaction with the manager and employees at the supermarket, the SE soon discovered that many kinds of actors were involved in decisions related to the energy management. Thus, instead of being a *simply technical* intervention, it turned out to be a complex social and organisational task, which also means that a successful intervention in general depends on many actors' active involvement. The following are the most important actors involved in the energy saving initiative:

- *The supermarket*. Obviously, the supermarket (and its staff members) plays a crucial role in realizing the energy savings. The supermarket is the site of intervention, and the active and co-operative participation by the manager and the staff is decisive. The SE does not have any formal jurisdiction over the supermarket, and the only way of realizing energy saving measures is through dialogue and persuasion.

- *The supermarket chain*. However, the supermarket is also the local branch of a larger chain of supermarkets. The supermarket chain has a central unit that, among other things, organises renovations of the individual branches, sets up general rules and procedures for the interior design of the shops etc. The central unit have in-house expertise on various technical fields, which is supervising the local branches.

- *Suppliers*. The supermarket (chain) owns the buildings, the heating and ventilation installations, most of the cooling appliances, etc. However, some of the refrigerators (e.g. the bottle coolers) are owned and maintained by the suppliers (e.g. the suppliers of beers and soda), even though the electricity costs are paid by the local shop. This complicates carrying out initiatives, such as installing timers on the refrigerators, as this would be interference with the private property of third parties (not owned by the local shop or the SE).
- *The Samso Energy Academy*. Obviously, the SE is also a central actor as the initiator of the energy saving process and its key role as local energy expert and facilitator.

In addition to these social actors or organisations, it is also important to mention the materiality of the supermarket. The energy consumption is, essentially, related to the operation of the appliances and HVAC systems at the site, and much of the energy savings were achieved through changing the controller settings.

An illustrative example of the complexity created by the interrelations between actors is the inefficient light bulbs placed above the refrigerated counters in the meat section (sliced meat, minced meet etc.); see Fig. 11. The SE noticed that these light bulbs were not only inefficient, but also (through heat radiation) added heat to the cold counters, resulting in an unnecessary waste of energy. Therefore, they suggested the local supermarket manager to replace them with efficient LEDs. However, it turned out, through the manager's communication with people at the central unit of the supermarket chain, that the choice of lighting above the cold counters with meat was restricted to a specific type of spot light with a red filter. The reddish light has a better colour rendering, which avoids making the meat look grey to the customers, thus promoting higher sales. As a result of corporate policy, it was not possible to replace the existing lighting. As the manager explained in an interview:

> … there's some fixed agreements on what has to be on different places [in the shop], and it is one of these things… That belongs to the butcher corner, it is like that everywhere [in all shops] (…) There is someone [at the central office of the chain] who's developing all these concepts and how it should be.

This exemplifies how an otherwise simple measure like replacing inefficient light bulbs can be complicated by actors external to the site of intervention, such as the central office of the supermarket chain. In this way, an energy saving intervention is no simple, one-directional activity, but it is carried out within a complexity of distributed knowledge, responsibilities and competences.

Another example of the distributed knowledge and competences relates to the coolers provided by the suppliers of, for instance, beverages. An agreement is made between the supplier and the local shop, which gives the shop higher profits of, for instance, beverage sales in exchange for accepting the supplier to install their coolers (with their logos etc.) in the shop. The supplier has the responsibility for the maintenance of the cooler, while the energy consumption costs are paid by the local shop. This illustrates the so-called principal-agent problem (e.g. Eisenhardt 1989) [48], that is, an uneven distribution of, for instance, energy saving investment costs and energy saving benefits between agents. In this specific example, the beverage supplier does not have an incentive to provide the shops with more energy efficient (and more expensive) coolers, as the energy costs are paid by the shops themselves. In addition, as also mentioned earlier, the coolers are third-party property, which complicates things further.

The role of SE was very much about providing an overall perspective and analysis showing the most obvious possibilities for savings. This was in part due to the organisational structure of the supermarket chain with specialisation of the expertise in different units. Here, the SE contributed with a more comprehensive and 'holistic' approach on how the different systems and sections of the shop work together and sometimes result in unintended extra energy consumption. As one of the SE staff members explained in the interview:

> So, they [larger chains like the supermarket chain] have their own internal staff who's doing this [working with different aspects like cooling, heating, interior design etc.]... One of the findings we made here (...) [was that] when it goes wrong, it is when they are not getting these areas coordinated. So, those who can manage the heat, they are not – for instance – thinking about ventilation or the settings of the cooling in the butcher's corner and things like that. So, ... there is a potential for savings ... when you get up in a helicopter and look at it as one big energy unit...

In other words, SE provides the external and integrated view on the site (in this case a shop) that is otherwise managed by diversified sets of expertise (not always coordinating among themselves) and often with no local energy expertise among the managers or staff members.

One of the major savings in the shop was, indeed, an example of two systems working 'against each other'. From their initial observations, SE noticed that the meat in the butcher's corner was moved from the open counters (in the shop) to a cooler for the evening. For this reason, it did not make sense to cool down the butcher's corner during the night, as had been the case until then. Therefore, SE suggested to turn off the cooling for the night and let it start again a few hours before the staff arrived next morning. This not only saved electricity for cooling the butcher's corner, but as there where no physical separation (partition wall) between the butcher's corner and the rest of the shop (heated up to about 20 ºC), the new solution also saved energy for heating (from heat flowing into the cooled butcher's corner). SE takes this as an example of how lack of coordination between various kinds of expertise (fields of responsibility), and not taking the daily working routines of the staff into consideration, can result in a waste of energy or that otherwise evident energy saving measures are not taken.

As an external, the SE can play the role of identifying examples of energy waste and evident energy saving measures. An important reason why the SE has managed to do this at this particular supermarket (and other places on the island of Samso, which have also been interviewed) seems to be that the SE enjoys a high level of trust among many actors on the island. This might relate to the year-long history of the SE and the energy initiatives on the island (Papazu 2016) [49], but also because the SE staff

Figure 11: Meat counters with spot lights above.

members seem to have a widespread local network of relations to local citizens. The local trust in the SE seems to be an important ‘resource’ at the SE.

The role of the SE appears to be central for the successful realization of these initiatives; the SE contributes with an external and integrated view on the possibilities for energy savings that cuts across the established divisions of expertise and responsibilities within, e.g., the organisation of the supermarket. Here, the successful realization depends very much on the communicative skills, the local anchoring and the facilitating role of the SE, which illustrates that realising the future smart energy vision includes a much broader set of competences and knowledge than technical expertise alone.

5.2. Smart energy

Samso aims to combine the electricity sector, the heating sector, and the transportation sector in one smart energy system. One characteristic is, as Vandevyvere and Stremke remark, that electricity is easy to transport and difficult to store, while the opposite applies to heat and cold [50]. The technical and economical aspects lend themselves to numerical processing, while urban planning requires qualitative assessments.

Although smart energy seems important from many points of view, the ultimate goal for Samso is to increase its population. This is a matter of survival. According to the urban model, the size of the population depends on the available housing and the available jobs. It seems there is enough housing, at least for the moment, therefore it is the enterprises and the job market that require stimulation in order to attract settlers.

However, although the municipal plan is comprehensive, it is not coherent, because it calls for growth in all areas. For example, separated protected areas (18%) are to be joined and thereby enlarged, agriculture (70%) is to enjoy better conditions, enterprises and tourism (2% urban zone) are to be increased, and more energy structures are foreseen in the rural zone. Planners should be aware that housing and business structures, including renewable energy businesses, will compete for the same land within the urban zone of the island. On Samso, only two percent of the land is urban zone, while the larger part is allocated to agriculture and protected nature. The urban zone is to be developed by filling the vacant gaps. More tourism requires more parking spaces, hotels, and restaurants. Where shall the nontouristic enterprises find enough space? One option is to promote small businesses based on information and communication technology, such as accountants, applications programmers, editors, or other liberal occupations, where much of the work can be done from home. Access to the Internet is therefore important. The planning should allow for an extent of enterprises in the urban zone, but not at the expense of the existing housing.

Because 70% of the land is agricultural, there may be a potential conflict with smart energy. For example, large arrays of PV plants or solar hot water collectors on the ground will need space in the rural zone. New onshore wind turbines may require more space, although one new area is already defined in the municipal plan. The planned biogas plant needs space, although a site is already approved. An extension of the district heating networks will require pipes that cross farm fields. District heating plants may require more space for new hot water storage tanks. Planners should therefore reserve space for smart energy in the rural zone, but not at the expense of farming, which provides jobs and biomass. The biomass resource is limited by the extent of the rural zone, and any reduction of agricultural and forestry land would reduce the amount of biomass available, which would decrease the renewable energy potential.

There is a strong correlation between the size of the population and the energy demand (Fig. 6). An increase in population will require more energy, the amount of which can be estimated rather accurately. Planners should therefore not just aim at maintaining the present level of renewable energy production, but they should aim for a higher production. In fact, Fig. 6 suggests that a 10% increase in population requires 18% more final energy. Presently, the electricity export covers more or less the fossil fuel demand, but the onshore wind turbines were commissioned in the year 2000 and their age is getting close to their expected lifetime. There are no actual plans for repowering the sites, because of poorer subsidies and lower selling price for electricity on the market. The onshore wind turbines taken together cover more or less the total electricity demand on the island.

5.3. Results

This analysis is based on a few theoretical elements, most notably urban dynamics. An eight item framework structures a sociotechnical analysis. The Samso case is filled into the framework, and two special cases of demand-side management illustrate the civic engagement on Samso. The analysis is comprehensive, in the sense that it concerns both the past, present and future. Statistics and planning documents substantiate the analysis.

The study combines quantitative and qualitative analyses, in order to encompass both technological and social aspects in a transition toward a smart energy system. It is clearly feasible to achieve energy savings and flexible electrical loads among farmers, shop owners, and house owners. Civic engagement, through field studies, is necessary to gain the stakeholders' acceptance. The complexity analysis of energy initiatives demonstrates that many different actors and skills are involved in carrying out smart energy measures.

In summary, the ultimate goal for Samso is to increase its population by making the island more attractive. Smart energy is thus a subordinate goal. The population size depends on housing and enterprises, according to the urban model. The following list of four policy recommendations is a result of the analysis.

- There is enough housing, at least for the moment, therefore the focus should be on stimulating enterprises and the job market.
- The planning should allow for more enterprises in the urban zone (2% of the land), but in balance with the available housing and the desired touristic level.
- The rural zone should allow for more renewable energy constructions, but in balance with agriculture (70% of the land), which provides jobs and biomass for energy.
- An increase of the population will require more renewable energy, but the potential is limited by the available amount of biomass and the economic viability of new wind turbine projects.

It is therefore necessary to reach a consensus on trade-offs. That is, set a goal that would balance housing, jobs, agriculture, tourism, biomass and energy. Such a goal could be in the form of politically agreed *land use percentages*, which limit each type of land use within an area – in the manner of the widely accepted *floor area ratio*, which regulates the density of buildings within an area. Policy changes toward long-term goals for the entire island have powerful cumulative effects.

6. Conclusions

The present work concerns a transition to smart energy, but the emphasis is on the sociotechnical transition, rather than the technical transition alone. It is a case study of an island, and the time horizon is one generation, which is remarkable. On the one hand, the future technical transition prescribes a change of the existing energy system toward a new distribution of the use of the island's renewable energy resources. On the other hand, the community (people) have requirements that sometimes supersede technically or economically optimal solutions, such as the threat from depopulation. The technical side and the social side must develop hand in hand, and the policy makers must be ready to make compromises. For a small island, the root of all problems is the land use. The following list presents some conclusions with a wider perspective.

- *Importance for the energy sector*. The study emphasises the social aspects of a transition to smart energy. Energy consumption is connected with the size of the population, which again is connected with enterprises and housing according to that urban model, which is applied in this study. Long term energy plans should therefore consider the dynamics of the population. Energy consumption increases with an increasing population, and in the case of Samso it is possible to estimate a linear dependency within a reasonable interval of population change.

- *Suggestions for policy changes*. The use of land is the underlying bottleneck for a (small) island. In the case of Samso, seventy percent of the land is occupied by agriculture while two percent is urban zone. Energy installations, such as arrays of field mounted photovoltaic panels, will compete with agriculture for space, and enterprises will compete with housing for space in the small urban zone. The overall policy is to increase the population, therefore policy makers must reach a consensus on trade-offs, instead of planning for growth within all land zones.

- *Principal contribution*. The case study covers twenty years of past experience and thirteen years of future planning. Although the case study concerns a small island, the urban model fits the island well, and possibly other islands too. The model focuses on three main variables to explain the workings of the island: population, enterprises, and housing. In the case of Samso, depopulation is the topmost priority under which the energy transition must take place.

- *Potential replication*. There will most likely be many other islands that can apply the urban model to organise their planning. Furthermore, other islands may wish to apply the planning elements described in this article. Indeed, many islands already work with an energy balance and an island sustainable energy action plan (iSEAP). As claimed previously, the energy side must be connected with the social side, and that can be done by means of the urban model.

- *Method*. The urban model is simple, and it has shown its value in the past. This study uses just the top level consisting of three main variables for simplicity, but it can be extended, even to a degree of detail where it lends itself to dynamic simulations on computer. The advantage of the model is its ability to combine engineering with social studies. The urban model portrays the social mechanisms with a view to population size. It is perhaps a disadvantage, from an engineer's viewpoint, that it is difficult to evaluate the correctness of the results (as always in social studies). The approach may seem unscientific and lacking of background, scientific and technical knowledge to a theoretician who expects concrete elements such as data, equations, and simulations. However, being a case study, the background is field work, which may serve as an inspiration for theoreticians and for other islands. On the other hand, the model may seem too stringent to a scientist within the social studies. However, the model attempts a step in the direction of engineering to open up for computer simulations.

Finally, a list of five concrete recommendations.

- Look at the land use. There lies the most likely cause of tension on an island.

- Decide whether the goal is to increase or decrease the population, increase/diminish the number of enterprises, or increase/diminish the amount of housing. Be careful that this can happen in concert.

- Energy planners should consider the dynamics of the population size, because the energy consumption grows with an increasing population.

- Smart energy planners should consider the social side, which may hinder the implementation of an optimal solution.
- Policy makers should see smart energy as a means to increase the attractiveness of an island, that is, a means to create jobs and good quality housing.

The urban model is very simple, and future work should extend the model to include more variables. These should preferably be measurable quantities that are reported in public statistics or documents. An example is the actual density of buildings in an urban zone, and the official regulations that limit the amount of floor space relative to the area of a cadastral parcel. Another natural step is to apply the approach to other islands or islandlike areas.

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- The technical side of a smart energy transition is intertwined with the social side
- Energy consumption increases with the size of the population
- Population, enterprises, and housing are main variables
- Limited land causes competition for space on an island
- An optimal energy vision is subordinate to concern over depopulation of an island