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## **Sociotechnical transition to smart energy**

The case of Samsø 1997–2030

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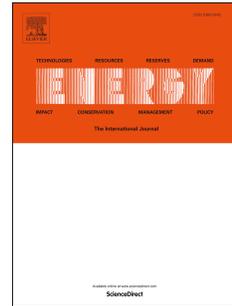
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# Sociotechnical transition to smart energy: the case of Samsø 1997-2030<sup>☆</sup>

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## Abstract

This case study analyses an ongoing practical transition to a smart energy system. The Danish island of Samsø, 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 Samsø 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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22 The Danish island of Samsø promises to rid the island of fossil fuels by the year  
23 2030 – twenty years ahead of Denmark – as a pilot case for the rest of the country.  
24 The island is already a renewable energy island with respect to the annual energy bal-  
25 ance. Sea cables connect Samsø with the mainland, and electricity flows both ways,  
26 but mostly in the export direction. Smart energy is part of the overall energy plan for  
27 the year 2030 [2]. The objective is to minimise the electricity export by maximising the  
28 internal use of renewable energy. The plan includes a biogas plant, which will convert  
29 biomass to gas, electricity, heat, and fertilizer. The island already has a ferry fuelled  
30 by liquid natural gas. The idea is to produce fuel for the ferry, and other means of  
31 transportation, on the island instead of buying it from outside of the island.

32 In 1997 the Danish government appointed Samsø as Denmark's renewable energy  
33 island. This entailed a commitment to work towards a 100% renewable community in  
34 the sense that the renewable energy production should balance the energy consumption,  
35 when calculated at the end of the year. Cooperatives, farmers, and the municipality  
36 installed district heating plants fuelled by biomass, as well as wind turbines on land  
37 and in the sea [3]. Private house owners invested in hot water solar collectors, heat  
38 pumps, and biomass heating units. The island started to produce electricity in the year  
39 2001, and a few years later the electricity production was up to three times larger than  
40 the electricity consumption. The electricity export compensated for the fossil fuels  
41 consumed by tractors, buses, cars, and ferries, and by the year 2007 the island achieved  
42 its 100% target.

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

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

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

56 The need for further integration towards shared interpretative frameworks,  
57 the quest for a constructive and future-oriented research attitude, the im-  
58 portance of connecting different planes of analysis to foresee alternative  
59 scenarios, and the need for proposals and solutions to be addressed to de-  
60 cision makers. [4]

61 The concept of a *common* is central in this context, as Melville, Christie, Burningham,  
62 Way and Hampshire recognized [5]. Hermansen and Nørretranders provide examples  
63 of successful commons as well as threats to commons, such as centralisation [6]. A  
64 common is a resource owned and managed by a community with a system of rules,  
65 norms, and values regulating its use. An island can be regarded as a common, where

66 the community or the municipality administers the limited land in such a way that no  
67 single interest jeopardizes the wealth of the community. It also applies to a suburb, a  
68 city, or more generally to an area that can be regarded as an island. Local ownership is  
69 of primary concern, often practised under the legal construction of a cooperative.

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

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

93 Also, the sociotechnical approach is common for studies of energy transitions  
94 within the Science and Technology Studies (STS) field, where the social and the tech-  
95 nical are perceived as closely intertwined and interdependent entities as demonstrated  
96 in the article by Skjølvold, Ryghaug & Berker [12] and the book by Strengers [13].  
97 An example is the study of how time-shifting electricity consumption in households de-  
98 pends on the design of technologies as well as existing everyday practices of families  
99 [14].

100 *Our approach.* An introductory paper to a special journal issue by Clark and Lund  
101 advocate a description of practical cases in order to illustrate sustainable developments  
102 [15]. The Samsø energy system is one such case, because it spans both the past, the  
103 present, and the future. It appears there is a need for all of the previously mentioned  
104 approaches, and possibly more, in order to understand the transition to smart energy  
105 adequately. To come to grips with the sociotechnical causes and effects of a transi-  
106 tion, system dynamics, or more precisely, Alfeld and Graham's *urban dynamics* model  
107 provides a useful framework [16]. Urban dynamics tries to simulate the long term, time  
108 dependent (dynamic) developments in a city or an urban area. Dynamic simulation is

109 beyond the scope of this article, but the model is general, and it can be adapted to the  
 110 workings of an island community. As with an urban model, the population level, the  
 111 amount of enterprises, and the amount of housing are three so-called *level variables* (or  
 112 stock variables, integrators, state variables) of interest. In an urban area, the growing  
 113 population is usually a cause for concern. Oppositely, the *decline* of the population is  
 114 often a cause for concern in an island community. This is the case in areas, or countries,  
 115 where urbanization is a general trend.

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

## 123 2. Theory

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

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

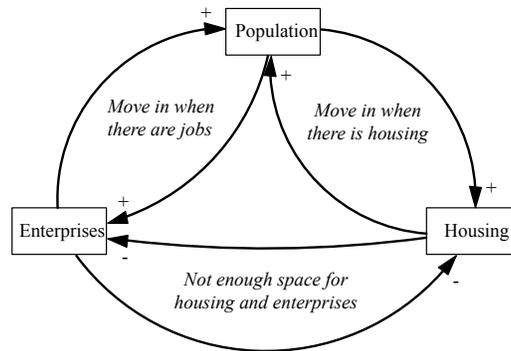


Figure 1: General mechanism of an urban model with three level variables.

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

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

### 162 3. Materials and Methods

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

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

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

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

#### 194 4. The Case of Samsø

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

##### 200 4.1. Political energy targets

201 The leaders of the EU countries agreed at a summit meeting in 2007 on an action  
 202 plan with three targets for the year 2020: to reduce emissions by 20%, to reduce the  
 203 energy consumption by 20%, and to include 20% renewable energy in the energy mix  
 204 [19]. This is in order to mitigate climate changes, to secure the energy supply, and to  
 205 stimulate competition on the energy market within the EU.

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

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

219 In 2009 the municipal council on Samsø approved a master plan for becoming a  
 220 fossil fuel free island by 2030. The following are some of the subordinate objectives of  
 221 the master plan: To maintain and expand the renewable energy production, to rely on

222 renewable energy for transportation, to increase energy efficiency, and to participate in  
223 partnerships. Half of the vehicles and all public transportation shall be electric by 2020.  
224 The Samsø municipality participates, together with 18 fellow municipalities, in the  
225 energy reporting and planning of the Central Denmark Region. Samsø municipality, as  
226 an enterprise, participates in the Klimakommune (Climate Municipality) initiative by  
227 the Danish Society for Nature Conservation, which obliges the municipality to decrease  
228 its CO<sub>2</sub> emissions by at least two percent every year in at least five years. Samsø's  
229 mayor signed the Covenant of Mayors which obliges the municipality to implement  
230 or even go beyond the EU 2030 climate and energy targets, which means at least 40%  
231 less greenhouse gas emissions by 2030 and the adoption of a joint approach toward  
232 climate change [22]. By signing the Pact of Islands, which is a parallel initiative to  
233 the Covenant of Mayors, Samsø committed itself to go beyond the EU 2020 targets  
234 and reduce CO<sub>2</sub> emissions by at least 20% by the year 2020 [23]. Under the Smart  
235 Islands Initiative five members on Samsø have signed a declaration to focus on seven  
236 areas: energy; transport; water; waste; governance; information and communication  
237 technology; and economy [24]. The five members are organisations that cover public  
238 authorities, businesses, academia and civil society actors, the so-called *quadruple helix*.  
239 The idea is that islands are test-beds that can host pilot projects, which will generate  
240 knowledge on smart resource management. The knowledge can then be transferred to  
241 other areas.

#### 242 4.2. Sociotechnical priorities on Samsø

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

##### 247 4.2.1. Population on Samsø

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

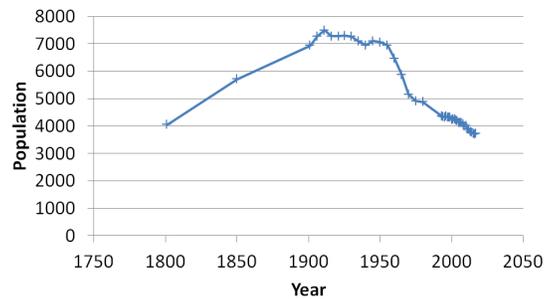


Figure 2: Overshoot and 'collapse' of the Samsø population.

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

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

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

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

#### 291 4.2.2. Enterprises and jobs on Samsø

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

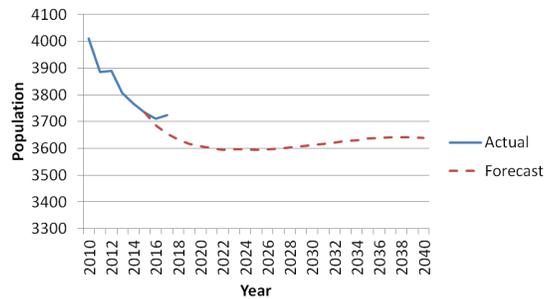


Figure 3: Recently the population increased slightly and deviated from the forecast.

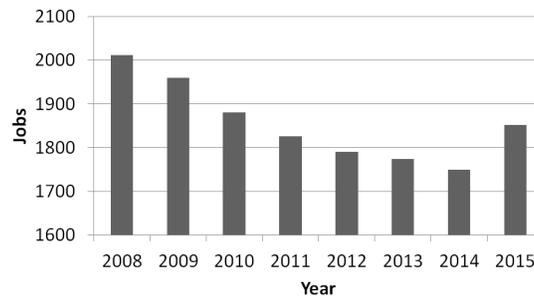


Figure 4: Jobs on Samso.

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

304 There are 81 workplaces per 100 citizens, which is similar to the region and the  
 305 country as a whole, but the tendency is decreasing [28]. According to the statistics,  
 306 5.3% of the workforce is unemployed (in 2016). However, during the summer season  
 307 almost everybody is employed thanks to agriculture and tourism. The tourist season  
 308 now starts at Easter, it accelerates in June, and it peaks in July. In the middle of Oc-  
 309 tober most hotels and restaurants close for the winter. There are 70 000 tourist visits  
 310 every year, equivalent to 350 000 overnight stays in tourist accommodations with a  
 311 registration obligation [25].

#### 312 4.2.3. *Housing on Samsø*

313 There are 2200 single-family houses on Samsø [25] and almost 2000 households  
 314 [26]. People from other parts of Denmark are allowed to buy a house and use it as  
 315 a second home, without having their permanent address there. There are about 60  
 316 dwellings put up for sale, and this has been the level since 2009 [27]. However, before  
 317 that year there was a dip to a minimum of 10 dwellings up for sale. The minimum  
 318 occurred in 2006, which is when the economy boom was at its highest. It seems that  
 319 the temporary wealth in the rest of the country resulted in a high demand for second  
 320 homes; prices went up as a consequence.

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

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

#### 327 4.3. *Civic engagement on Samsø*

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

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

340 Jakobsen wrote a thesis about the local ownership and social acceptance at Samsø  
 341 [32]. Local ownership has been a cornerstone of the renewable energy island project.  
 342 An example is the district heating company in Ballen-Brundby. The consumers them-  
 343 selves own the company in a cooperative (coop) with limited liability. The members  
 344 both own and manage the coop. The coop must be of the greatest possible use to the  
 345 members, rather than give a profit. Every member has one vote, independently of the  
 346 magnitude of the member's investment. The municipality issued a guarantee for a con-  
 347 struction loan in the so-called Credit Institution for Local and Regional Authorities in  
 348 Denmark (Kommunekredit) in order to finance the construction of the plant.

#### 349 4.4. *Samsø energy vision*

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

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

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

364 The wind energy production is already large, and the island exports twice as much as it  
365 consumes (2015) [34]. The potential photovoltaic production has been analysed using  
366 a 'solar atlas' and a geographical information system [33]. The analysis shows that if  
367 all rooftops are included the potential is 87 GWh per year, which is more than three  
368 times the current electricity demand. However, if only roofs with an annual production  
369 higher than 90 kWh/m<sup>2</sup> are counted, then the potential is more than 60 GWh and  
370 comparable to the current wind production. In Denmark the average number of full load  
371 hours is 961; that is, one kilowatt of photovoltaic panels produces 961 kilowatt-hours  
372 in a year [35]. Fortunately, Samsø has more sunny hours and higher solar intensity  
373 than average, and the number of full load hours is perhaps 10 percent higher than  
374 average. By means of simulations the energy vision develops scenarios for supporting  
375 the conversion of Samsø into a 100% renewable energy system by 2030 [33]. The focus  
376 is on the integration of local renewable resources and whether the local potentials are  
377 sufficient to meet the demands [36]. The simulation study uncovers impacts on energy,  
378 economy, and the environment.

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

390 The study concludes with the following list of recommendations.

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

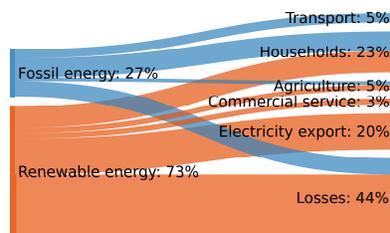


Figure 5: Samsø energy balance 2015. Units are percentages of the total available energy (901 TJ).

- 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. Samsø 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 Samsø 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 Samsø, 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. Samsø energy action plan

The action plan for Samsø 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

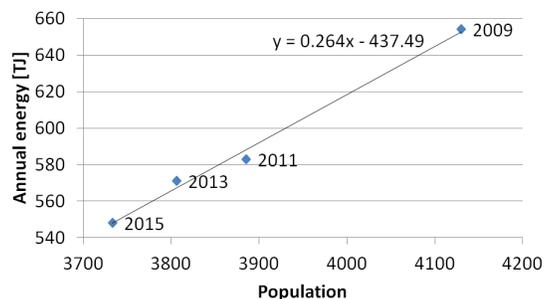


Figure 6: Energy consumption per capita. The energy is measured in terms of final energy, that is, production less export and losses. The marginal energy consumption is 264 GJ/year per capita.

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

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

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

#### 455 4.7. Policy implications on Samsø

456 The *municipal plan* documents the policies that the municipal council has agreed  
 457 upon [25]. It is written for the citizens and authorities to plan future activities in specific  
 458 areas of the island. The municipal plan contains political goals, development plans, and  
 459 binding guidelines for the land use. It is updated once every two years. The last update  
 460 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 <sup>3</sup> methane/yr
Ferry demand	2 650 000 m <sup>3</sup> methane/yr
Plant self consumption	440 000 m <sup>3</sup> methane/yr
Land transport demand	400 000 m <sup>3</sup> methane/yr
Total demand	3 490 000 m <sup>3</sup> methane/yr
Utilization factor	83%
Initial investment	5.8 million euro
Production cost	0.42 euro/m <sup>3</sup> methane
Selling price	0.47 euro/m <sup>3</sup> methane
Payback period	8.5 years
Upgrade plant investment	2.1 million euro
Liquidation 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.

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

#### 465 4.7.1. Attractiveness

466 The municipal council aims to attract a widely composed group of people, includ-  
 467 ing resourceful people, families with children, and elderly people.

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

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

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

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

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

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

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

#### 515 4.7.2. *Maintaining the building stock*

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

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

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

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

#### 538 4.7.3. Land use

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

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

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

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

#### 558 4.7.4. Smart energy

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

- 560 • *A flexible energy system.* Examples of actions: Establish a biogas plant, new  
 561 wind turbines, expand the district heating network, more solar energy, increase  
 562 the biomass fraction, phase out oil boilers, more vehicles on electricity and gas.
- 563 • *Propellants for transportation, including ferries, based on fossil free fuel.* Ex-  
 564 amples of actions: erect charging stations for electric vehicles; make use of smart  
 565 energy meters; install electric buses; use electric vehicles for taxis; vocational  
 566 education of craftsmen to enable them to service electric vehicles; establish a  
 567 biogas unit that produces compressed or liquid biogas to ferries, lorries, tractors,  
 568 and buses; establish filling stations; and put projects out to tender, if possible.
- 569 • *Significant heat savings.* Examples of actions: Reduce heat consumption in  
 570 dwellings and businesses. New buildings with minimal heat consumption.
- 571 • *Significant electricity savings.* Examples of actions: an awareness campaign  
 572 toward energy consumption; vocational education of skilled craftsmen; and re-  
 573 placement of old circulator pumps, compressors, and electric motors.

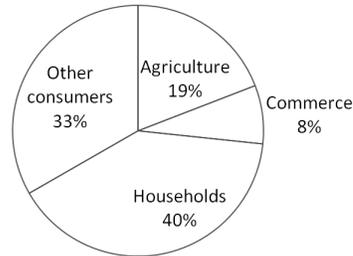


Figure 7: The relative electric energy consumption of the three target groups of interest: agriculture, commerce and households. The group 'Other consumers' includes public and private service, construction and production industry, and transport. The total corresponds to 100 TJ (2015).

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

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

#### 578 4.8. Demand-side management on Samsø

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

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

587 On Samsø, the target groups, so far, are the farmers, the shop owners, and the  
 588 private house owners. Figure 7 shows the share of the electricity consumption of the  
 589 three target groups. Regrettably, a simulation study on the national level showed that  
 590 the value of flexible demand is limited, because more than a quarter of the classic  
 591 electricity demand would need to be flexible within a month, which is highly unlikely  
 592 [41]. In any case, working with the target groups is an excellent way to campaign for a  
 593 future smart energy system.

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

601 In order to make some pilot experiments, the Samsø Energy Academy installed  
 602 various pieces of equipment, commercially available or developed with external part-

603 ners, and the Samsø Energy Academy received feedback from the involved individu-  
 604 als. In several cases measurements support conclusions, for example from electricity  
 605 meters, temperature sensors, calorimeters, and energy bills.

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

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

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

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

#### 621 4.8.1. *Farmers and demand response*

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

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

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

$$635 \quad Q = 1800 \text{ [kg]} \times 4.2 \text{ [kJ/kg·K]} \times (38 - 4) \text{ [K]} = 257\,000 \text{ kJ} = 71 \text{ kWh}$$

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

642 A dairy farm was analysed in detail in order to understand better what the possibil-  
 643 ities for load shifting are in reality. It is a small farm (8 cows) which produces organic  
 644 milk, butter and cheese. The diagram in Fig. 8 gives an overview of the production,  
 645 and it also identifies storages, which, by their nature, are possible candidates for con-  
 646 trolling delays. The farmer agreed that it would be possible to use some of the storages

647 in order to force a delay of some of the energy demand. The diagram points to several  
648 possible options for load shifting related to storages.

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

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

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

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

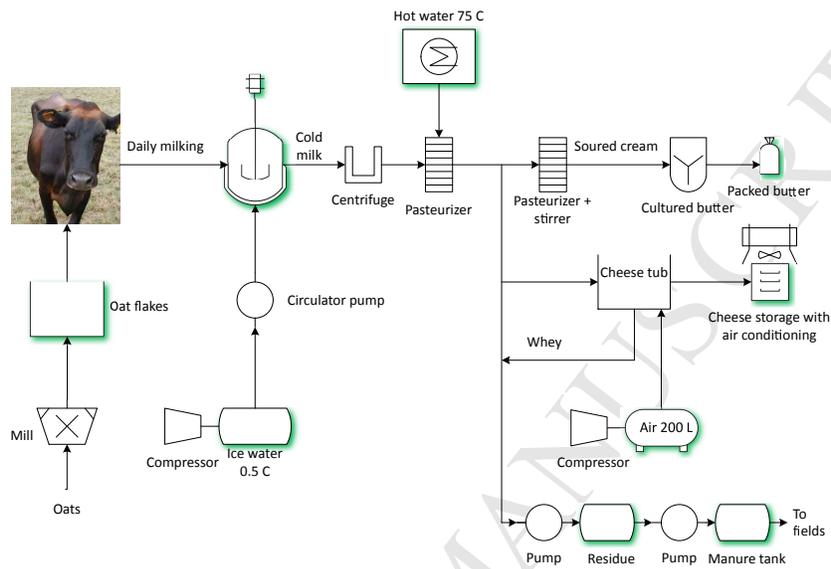


Figure 8: Process flow diagram of dairy. The shaded components are storages.

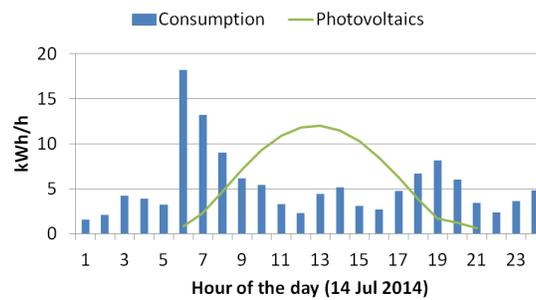


Figure 9: Nominal photovoltaic production (line) and actual consumption (bars) on a small dairy farm. Cows are generally milked at 6 in the morning and 6 in the evening.

679 4.8.2. *Shop owners and energy efficiency*

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

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

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

$$696 f = (20 - 19) \text{ [K]} / (20 - 8) \text{ [K]} = 1 / 12$$

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

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

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

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

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

- 718 • Lower the room temperature
- 719 • Nightly room temperature setback
- 720 • Nightly temperature setback on bottle coolers

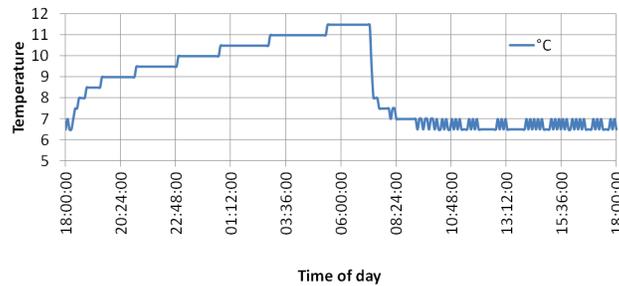


Figure 10: Temperature in a bottle cooler. A timer switches it off at 6 pm until 7 am next morning.

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

737 **Example 3.** Superbrugsen achieved 7.5% savings on the energy bill. Table 2 lists the  
 738 individual advices together with their respective savings, in terms of energy and ex-  
 739 penses. The table provides the magnitude of the individual saving measures, and it is  
 740 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
	Nightly temperature setback in shop. Saves district heating.	2826	241	0.2
Heat	Total		8400	7.5

Table 2: Savings advices for Superbrugsen.

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

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

751 Calculate a saving factor  $f$ , as described previously, and multiply it onto the estimate  
752 of the annual consumption. Finally, multiply by the unit price. Use the marginal price,  
753 that is, the direct cost of the first saved kilowatt-hour (disregarding fixed costs). The  
754 total electricity cost amounts to 98 400 euro/year, and the total heating cost amounts to  
755 13 100 euro/year using marginal prices.  $\square$

## 756 5. Discussion

757 As mentioned previously, one challenge is whether the citizens will accept more  
758 changes. Working with the target groups promotes civic engagement, and it is an op-  
759 portunity to map nontechnical barriers toward sociotechnical changes. The following

760 two sections discuss the relationship with the citizens and the policy implications of  
761 smart energy.

### 762 5.1. *The complexities of carrying out energy savings*

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

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

779 The following illustrates the complexity of actors and considerations involved in  
780 developing and carrying out energy saving measures. Also, the role of the SE in secur-  
781 ing energy savings is discussed.

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

- 791 • *The supermarket.* Obviously, the supermarket (and its staff members) plays a  
792 crucial role in realizing the energy savings. The supermarket is the site of in-  
793 tervention, and the active and co-operative participation by the manager and the  
794 staff is decisive. The SE does not have any formal jurisdiction over the supermar-  
795 ket, and the only way of realizing energy saving measures is through dialogue  
796 and persuasion.
- 797 • *The supermarket chain.* However, the supermarket is also the local branch of  
798 a larger chain of supermarkets. The supermarket chain has a central unit that,  
799 among other things, organises renovations of the individual branches, sets up  
800 general rules and procedures for the interior design of the shops etc. The central  
801 unit have in-house expertise on various technical fields, which is supervising the  
802 local branches.

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

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

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

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

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

839 Another example of the distributed knowledge and competences relates to the cool-  
840 ers provided by the suppliers of, for instance, beverages. An agreement is made  
841 between the supplier and the local shop, which gives the shop higher profits of, for  
842 instance, beverage sales in exchange for accepting the supplier to install their coolers  
843 (with their logos etc.) in the shop. The supplier has the responsibility for the main-  
844 tenance of the cooler, while the energy consumption costs are paid by the local shop.  
845 This illustrates the so-called principal-agent problem (e.g. Eisenhardt 1989) [48], that

846 is, an uneven distribution of, for instance, energy saving investment costs and energy  
847 saving benefits between agents. In this specific example, the beverage supplier does  
848 not have an incentive to provide the shops with more energy efficient (and more ex-  
849 pensive) coolers, as the energy costs are paid by the shops themselves. In addition, as  
850 also mentioned earlier, the coolers are third-party property, which complicates things  
851 further.

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

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

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

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

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



Figure 11: Meat counters with spot lights above.

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

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

### 899 5.2. *Smart energy*

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

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

911 However, although the municipal plan is comprehensive, it is not coherent, because  
 912 it calls for growth in all areas. For example, separated protected areas (18%) are to  
 913 be joined and thereby enlarged, agriculture (70%) is to enjoy better conditions, enter-  
 914 prises and tourism (2% urban zone) are to be increased, and more energy structures are

915 foreseen in the rural zone. Planners should be aware that housing and business struc-  
916 tures, including renewable energy businesses, will compete for the same land within  
917 the urban zone of the island. On Samso, only two percent of the land is urban zone,  
918 while the larger part is allocated to agriculture and protected nature. The urban zone is  
919 to be developed by filling the vacant gaps. More tourism requires more parking spaces,  
920 hotels, and restaurants. Where shall the nontouristic enterprises find enough space?  
921 One option is to promote small businesses based on information and communication  
922 technology, such as accountants, applications programmers, editors, or other liberal  
923 occupations, where much of the work can be done from home. Access to the Internet  
924 is therefore important. The planning should allow for an extent of enterprises in the  
925 urban zone, but not at the expense of the existing housing.

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

937 There is a strong correlation between the size of the population and the energy  
938 demand (Fig. 6). An increase in population will require more energy, the amount  
939 of which can be estimated rather accurately. Planners should therefore not just aim  
940 at maintaining the present level of renewable energy production, but they should aim  
941 for a higher production. In fact, Fig. 6 suggests that a 10% increase in population  
942 requires 18% more final energy. Presently, the electricity export covers more or less  
943 the fossil fuel demand, but the onshore wind turbines were commissioned in the year  
944 2000 and their age is getting close to their expected lifetime. There are no actual  
945 plans for repowering the sites, because of poorer subsidies and lower selling price for  
946 electricity on the market. The onshore wind turbines taken together cover more or less  
947 the total electricity demand on the island.

### 948 5.3. Results

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

955 The study combines quantitative and qualitative analyses, in order to encompass  
956 both technological and social aspects in a transition toward a smart energy system. It is  
957 clearly feasible to achieve energy savings and flexible electrical loads among farmers,  
958 shop owners, and house owners. Civic engagement, through field studies, is necessary  
959 to gain the stakeholders' acceptance. The complexity analysis of energy initiatives

960 demonstrates that many different actors and skills are involved in carrying out smart  
961 energy measures.

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

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

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

## 982 6. Conclusions

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

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

- 1000 • *Suggestions for policy changes.* The use of land is the underlying bottleneck for  
 1001 a (small) island. In the case of Samsø, seventy percent of the land is occupied  
 1002 by agriculture while two percent is urban zone. Energy installations, such as  
 1003 arrays of field mounted photovoltaic panels, will compete with agriculture for  
 1004 space, and enterprises will compete with housing for space in the small urban  
 1005 zone. The overall policy is to increase the population, therefore policy makers  
 1006 must reach a consensus on trade-offs, instead of planning for growth within all  
 1007 land zones.
- 1008 • *Principal contribution.* The case study covers twenty years of past experience  
 1009 and thirteen years of future planning. Although the case study concerns a small  
 1010 island, the urban model fits the island well, and possibly other islands too. The  
 1011 model focuses on three main variables to explain the workings of the island:  
 1012 population, enterprises, and housing. In the case of Samsø, depopulation is the  
 1013 topmost priority under which the energy transition must take place.
- 1014 • *Potential replication.* There will most likely be many other islands that can apply  
 1015 the urban model to organise their planning. Furthermore, other islands may wish  
 1016 to apply the planning elements described in this article. Indeed, many islands  
 1017 already work with an energy balance and an island sustainable energy action  
 1018 plan (iSEAP). As claimed previously, the energy side must be connected with  
 1019 the social side, and that can be done by means of the urban model.
- 1020 • *Method.* The urban model is simple, and it has shown its value in the past. This  
 1021 study uses just the top level consisting of three main variables for simplicity, but  
 1022 it can be extended, even to a degree of detail where it lends itself to dynamic  
 1023 simulations on computer. The advantage of the model is its ability to combine  
 1024 engineering with social studies. The urban model portrays the social mechanisms  
 1025 with a view to population size. It is perhaps a disadvantage, from an engineer's  
 1026 viewpoint, that it is difficult to evaluate the correctness of the results (as always in  
 1027 social studies). The approach may seem unscientific and lacking of background,  
 1028 scientific and technical knowledge to a theoretician who expects concrete ele-  
 1029 ments such as data, equations, and simulations. However, being a case study,  
 1030 the background is field work, which may serve as an inspiration for theoreticians  
 1031 and for other islands. On the other hand, the model may seem too stringent to  
 1032 a scientist within the social studies. However, the model attempts a step in the  
 1033 direction of engineering to open up for computer simulations.
- 1034 Finally, a list of five concrete recommendations.
- 1035 • Look at the land use. There lies the most likely cause of tension on an island.
- 1036 • Decide whether the goal is to increase or decrease the population, increase/diminish  
 1037 the number of enterprises, or increase/diminish the amount of housing. Be care-  
 1038 ful that this can happen in concert.
- 1039 • Energy planners should consider the dynamics of the population size, because  
 1040 the energy consumption grows with an increasing population.

- 1041 • Smart energy planners should consider the social side, which may hinder the  
1042 implementation of an optimal solution.
- 1043 • Policy makers should see smart energy as a means to increase the attractiveness  
1044 of an island, that is, a means to create jobs and good quality housing.

1045 The urban model is very simple, and future work should extend the model to include  
1046 more variables. These should preferably be measurable quantities that are reported in  
1047 public statistics or documents. An example is the actual density of buildings in an  
1048 urban zone, and the official regulations that limit the amount of floor space relative to  
1049 the area of a cadastral parcel. Another natural step is to apply the approach to other  
1050 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

ACCEPTED MANUSCRIPT