Orchestration of Renewable Integrated Generation in Neighbourhoods

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D6.2 Community Recommendations

WP6 –Identification of complementary energy systems

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Synopsis: In this Work Package the consortium makes recommendations to the Communities on complementary energy storage, generation, and transfer technologies with potential to increase overall Community energy system performance and reduce future reliance on fossil fuels.

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Summary

The overall ORIGIN project aim is to enhance local use of renewables and minimise the use of imported grid electricity. The ORIGIN demonstration sites existing energy systems with high penetration of renewables are the focus of the ORIGIN research and technology demonstration.

The ORIGIN project has involved mapping, monitoring and modelling of the existing energy systems at the demonstration sites in order to develop algorithms and evaluate their impacts. This provides a basis for considering means of improving the overall performance of the energy network through addition of complementary energy systems.

This deliverable D6.2 captures the outputs from task 6.3: Advising the Communities on most effective complementary technologies, and task 6.4: Selection of most appropriate energy market options.

The evaluation process used in work package 6 to identify the complementary energy systems was also explored and recommendations put forward for how such a process may be applied in future for these communities or for other community scale energy systems.

In line with the ORIGIN project primary aim, the initial optimisation criteria for evaluating future scenarios was the minimisation of fossil fuel based energy use. A secondary investigation of financial and market models was also carried out.

This report is in 3 main sections: the first covers the advice given to the communities on the most effective complementary technologies; the second gives an illustration of the possible financial value that could be attached to the ORIGIN system in a multi-tariff import export situation; the third gives more general advice to Communities on identification of appropriate technologies and market models.

Contents

1. Advising the Communities on the most effective complementary technologies

Based on the scoping studies (deliverable 6.1) recommendations were formulated and delivered to the Communities. The feedback of these recommendations has been through a series of interactions and exchanges throughout the project.

The vehicles for exchanges have included:

- Face to face WP6 meetings arranged to coincide with ORIGIN management meetings and other visits to each of the sites.
- Presentations of WP6 specific outputs at Turin Conference, and follow up discussions with Damanhur and Tamera representatives.
- Presentation of WP6 specific outputs with Findhorn representatives at Findhorn.
- Numerous scoping studies: where inputs and support was provided by the Communities, and feedback given through presentations and documentation.
- Formulation and delivery of academic publications and associated presentations to the Communities.
- Documentation on identified complementary energy systems transferred is detailed in the D6.1 report.
- Dialog with the Communities will continue as academic publications and follow on funding applications based on Community recommendations and overall ORIGIN project continue to be generated.

1.2 Community Recommendations and ORIGIN Design Process

Work package 6 involved the use of Community models calibrated by monitoring data to identify complementary technologies for the demonstration sites. Intended outcomes were:

- useful recommendations to the Communities to inform their future direction;
- to demonstrate how such modelling can be used as a design tool for integration of technologies, including the ORIGIN system, in future developments.

The complementary technologies and expansion scenarios investigated were identified based on Community input and Academic suggestions informed by analysis of ORIGIN monitoring datasets. Technologies investigated included: expansion of the deployment of ORIGIN thermal load shifting systems; electrical storage systems (Compressed Air, Flow Battery, Conventional Battery); optimized battery charging schedules; expansion of electrical generation (PV, Wind, Tidal); expansion of renewable district heating systems (Solar Thermal with Biomass or Heat Pump).

Modelling was carried out at building level and community level using the open source ESP-r and MERIT software tools, and the commercial HOMER software which is commonly viewed as state-of-the-art in community scale design.

Research was carried out to inform the Communities of characteristics and feasibility of each of the technologies. The suggested range of technologies and expansions was broad and this diversity was covered through a number of scoping studies. Both Damanhur and Findhorn are considering expansion of their biomass heat networks, background information on the carbon intensity of biomass produced heat from various supply chains was provided to inform these expansion plans, in particular the environmental impacts of local naturally air-dried wood fuel (chips or logs) were contrasted with those of internationally sourced artificially dried wood pellets. The recent directives on including the indirect impacts of land use change in carbon and global warming potentials were highlighted (Figure 1), and the land area required to produce wood fuel sustainably.

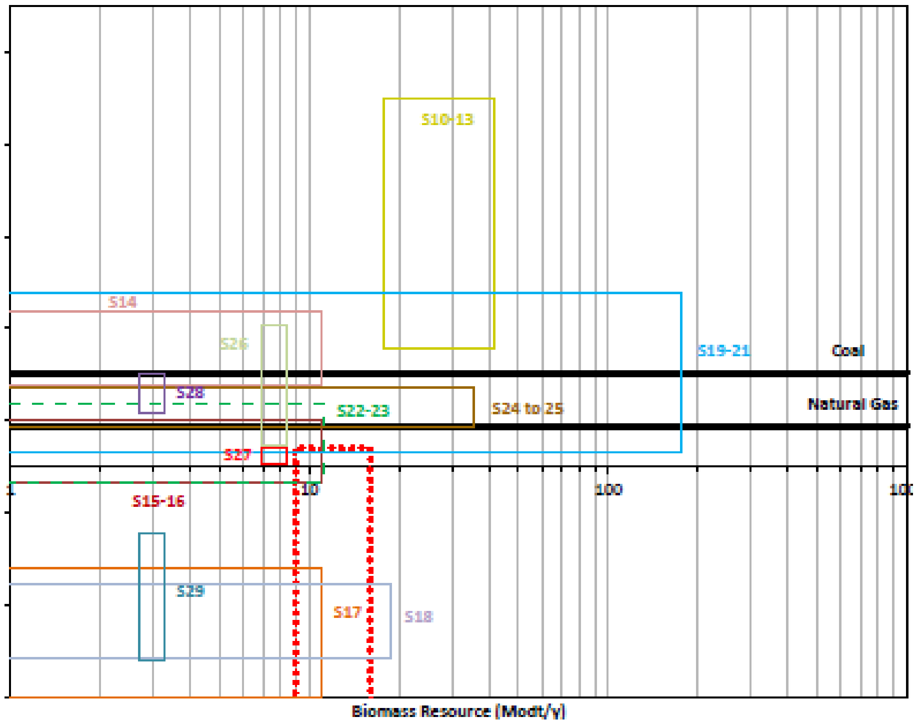


Figure 1: Global warming potentials for biomass power production from a range of different sources (coloured boxes represent ranges in emissions and available resources) compared to power production from coal and natural gas [Stephenson and MacKay]

1.2.1 Community recommendations: Findhorn

A design evaluation was carried out using HOMER software of realistic future complementary technical options for Findhorn which currently has 75 buildings on a private wire network with a significant quantity of Wind and smaller PV, which currently could be described as 'net zero' but imports 45% of its energy demand from the grid (figure 2). The evaluation considered energy independence ('autarky') as well as financial criteria for best case (net metering) and worst case (zero value export) grid financial interactions. Expansion of PV and Wind Generation technologies and the addition of electrical storage (flow, Li-ion, LA batteries) were also considered (figure 3). In the most autarkic combination grid imports were reduced to 0.8%, the largest battery storage evaluated gave the best results for autarky.

For the worst case financial scenario only ORIGIN thermal load shifting was financially beneficial. For the net metering financial scenario, increased wind generation gave financial benefit from exports, the largest storage option was financially unattractive. The financial benefit from wind generation in the net metering scenario could be used to offset other technologies and deliver 4% grid dependence with the same cost as the current situation, this could be viewed as a potential optimum. Securing long term financial arrangements was found to be key for planning the optimum path, it was recommended that these be determined and then analysis carried out with the created models.

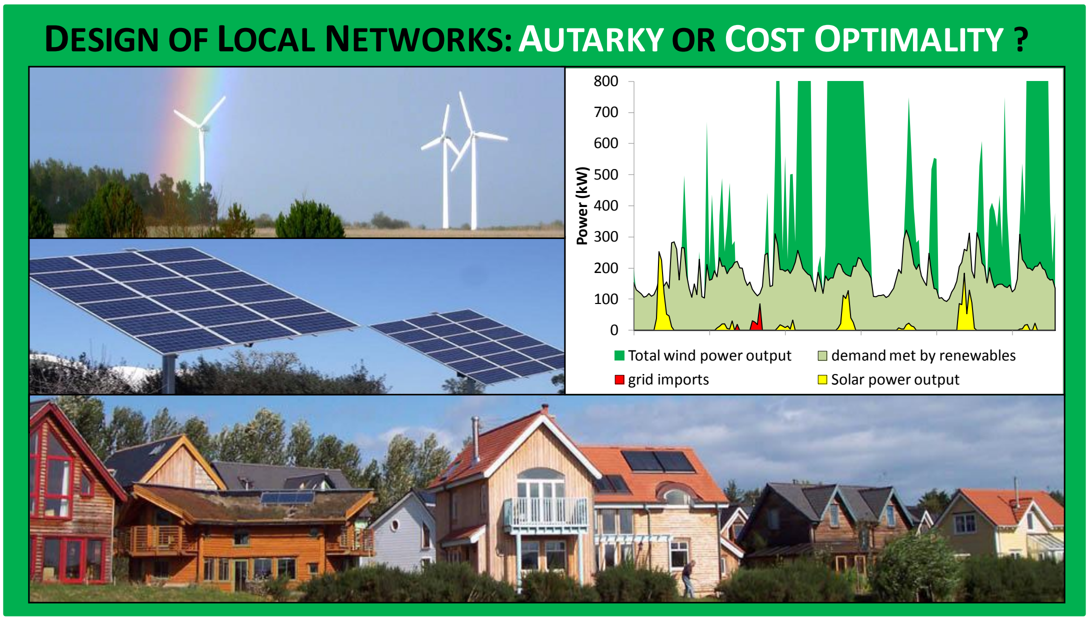


Figure 2: Findhorn, Wind and PV, Low carbon buildings, and Calibrated Model outputs.

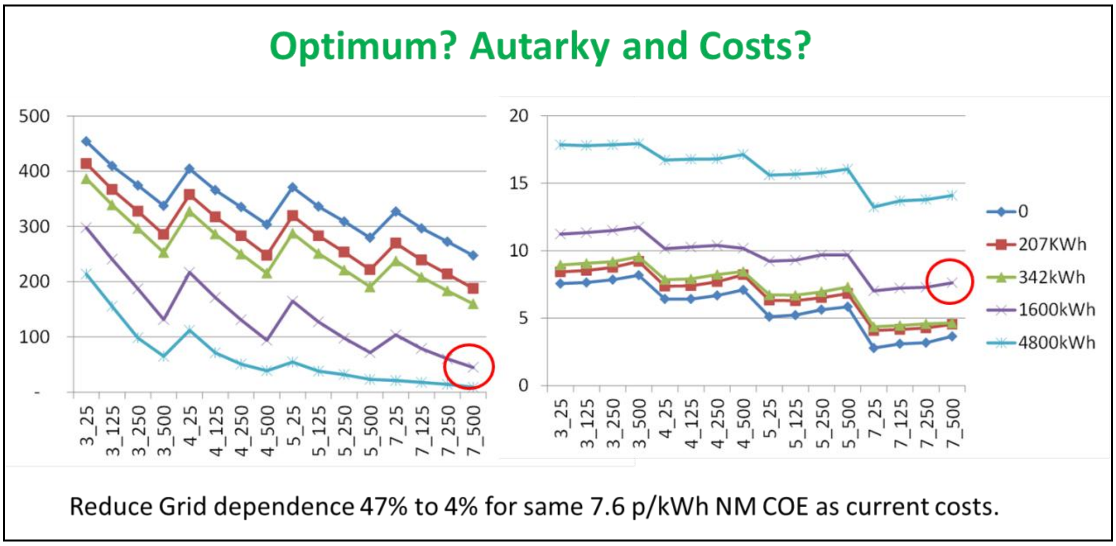


Figure 3: Left: y-axis = Grid imports (MWh per year), Right: y-axis = Cost in p/kWh of electricity supplied to the Community. x-axis = (#225kW wind turbines)_(kWp PV) (currently '3_25' = 3 wind turbines, 25kWp PV). legend = kWh electrical storage. Red circles: 7 wind turbines + 500kWp PV + 1600kWh electrical storage gives only 50MWh per year grid imports and same p/kWh as current situation (currently 0 electrical storage).

Beyond the main modeling study, other expansion scenarios put forward by the Community included tidal generation in the nearby river estuary. A quantification of tidal resource, and modeling with tidal and addition electrical storage was carried out using MERIT software (figures 4, 5, 6). Costs did not look attractive and environmental concerns would be potentially problematic in taking this forward.

Figure 4: Tidal flow generation device of type evaluated.

Figure 5: Tidal estuary and locations with highest flows.

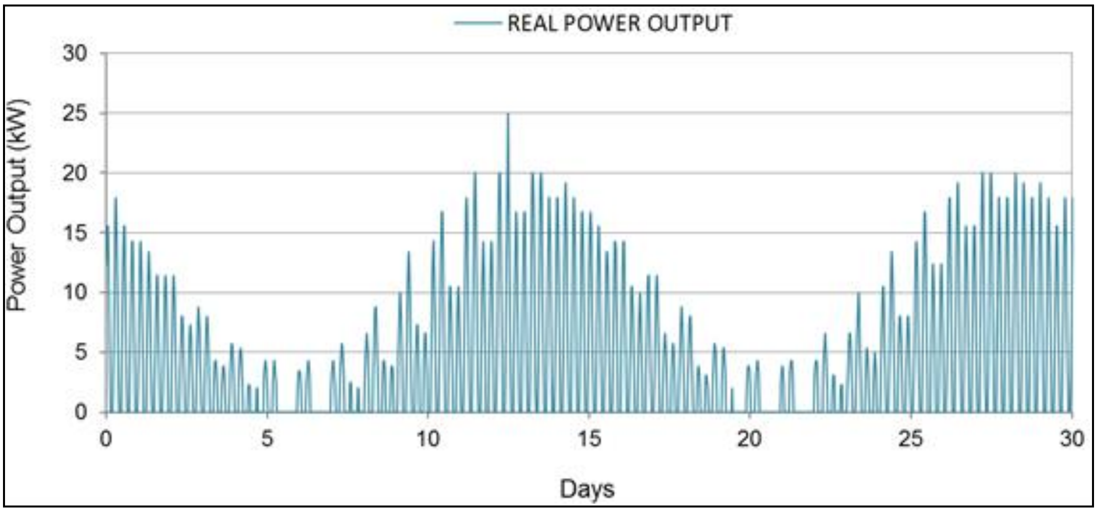


Figure 6: Tidal flow generation device power output.

Future community expansion plans include additional dwellings at Findhorn. The community were originally considering wood pellet plus solar district heating systems for these dwellings. The recommendation from the ORIGIN team was that this new development be designed to incorporate and maximize the benefits of the ORIGIN system, with a district network with significant thermal store, heat pump instead of wood pellets for backup heating, and ORIGIN thermal algorithm deployed within controls that maximize solar inputs and align backup heating with renewable electrical generation from PV and Wind. A funding proposal has been put forward for this system.

1.2.2 Community recommendations: Tamera

The Tamera energy flow analysis and HOMER modelling (figure 7) showed that a significant amount of solar electrical generation potential from the PV systems was being lost during the day.

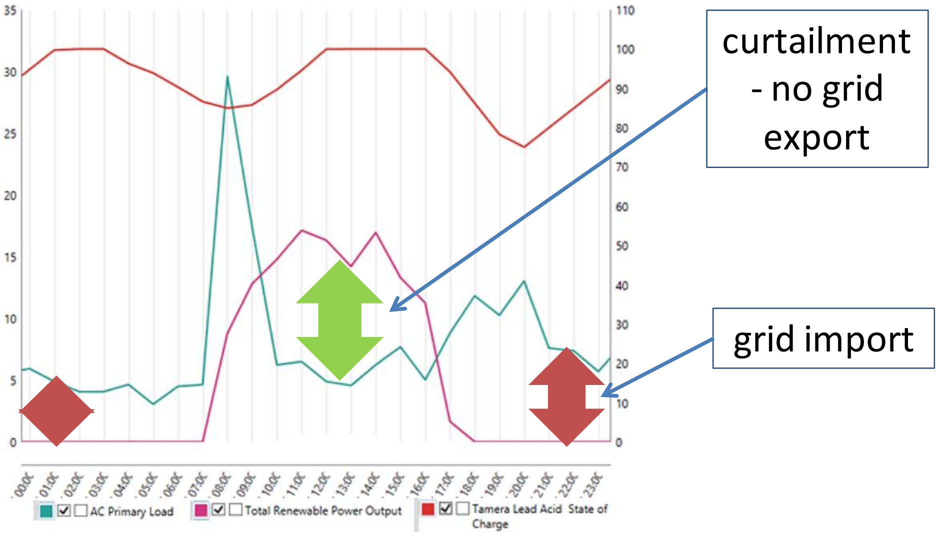


Figure 7: Current electrical situation at Tamera and Tamera PV system.

Battery banks are charged from the grid with low tariff electricity overnight, no exports to the grid are allowed. Opportunities to address this were identified, including optimization of the charging of the batteries, and shifting of loads into the peak generation times (ORIGIN control of water pumping, EV charging etc.).

The model has been used to evaluate a range of scenarios, beneficial upgrades identified include: Orchestration through ORIGIN of the night charging from the grid to maximize storage available for renewable energy and minimize grid electricity; Orchestration of shift-able loads through ORIGIN when there is surplus renewable energy forecast; Addition of further electrical storage; Enhanced use of electric vehicle charging incorporating ORIGIN smart charging system; Water pumping synchronization and potential for hydro storage between reservoirs; Potential addition of wind generation; ORIGIN controlled refrigerated food store; Potential for ORIGIN solar thermal orchestration algorithm and display technology to minimize use of backup gas heating; Potential for anaerobic digestion of wastes.

1.2.3 Community recommendations: Damanhur

The Damanhur pilot site consists of a series of both domestic and commercial buildings. Domestic buildings are residential units called "nucleos" with approximately 20 to 25 residents in each (figure 8). These building are heated using biomass boilers augmented with solar hot water systems. Electrical demand is met by a combination of large solar-PV arrays and grid electricity. All the buildings are grid connected allowing any surplus renewable electricity generation to be exported to the grid. Damanhur are actively looking at the upgrade of the Crea gas heating system and have been using the ORIGIN data to help inform their decision, they are also looking into electrical storage options.

Damanhur electrical models were constructed in HOMER. Modelled scenarios that showed potential benefits for renewable generation and self-consumption included similar options to those reported for Findhorn and Tamera such as: Electric storage to allow greater self-consumption of solar PV generation; ORIGIN orchestrated electric vehicle charging (and expanded EV use) to enhance self-consumption of solar PV generation; ORIGIN orchestration of person controlled electrical loads; Addition of wind generation; Addition of hydro generation with hydro pump storage; Expansion of Crea district heating to adjacent nucleos and replacement of gas with ORIGIN orchestrated biomass / solar system with thermal store, fed from local sourced naturally air-dried biomass; Expansion of Crea district heating to adjacent nucleos with ORIGIN orchestrated biomass CHP / solar system with thermal store; Solar biomass hot water systems in all nucleos to be orchestrated by ORIGIN algorithm and display technology to maximise solar and minimize backup heating requirement.

Addition of wind and hydro electricity generation in combination with electrical storage was identified as having the potential to provide a better year round electricity supply. There are probably sufficient local hydro and wind resources to make this feasible. The biomass options need careful consideration of the biomass supply chain as discussed above. The CHP option also needs careful consideration and comparative lifecycle carbon and financial assessment including maintenance and replacement etc.

Long term electrical import and export tariffs should be determined and then optimum system performance determined from the models.

Figure 8: Damanhur Nucleo 'Magilla' with large PV systems.

1.2.4 ORIGIN Design Process

The Community level design process using HOMER and MERIT software was demonstrated and discussed, and suggestions made for future applications, including the use of more advanced optimization and robustness analysis, and the incorporation of more detailed time-of-day tariff scenarios. This community level design process needs inputs from more detailed design assessments of thermal load shifting from building and system level modelling tools such as those developed in ORIGIN WP4 (figure 9). The ORIGIN optimization software itself has potential to be developed to be used directly for assessment of technology options and also evaluation of alternative orchestration algorithms.

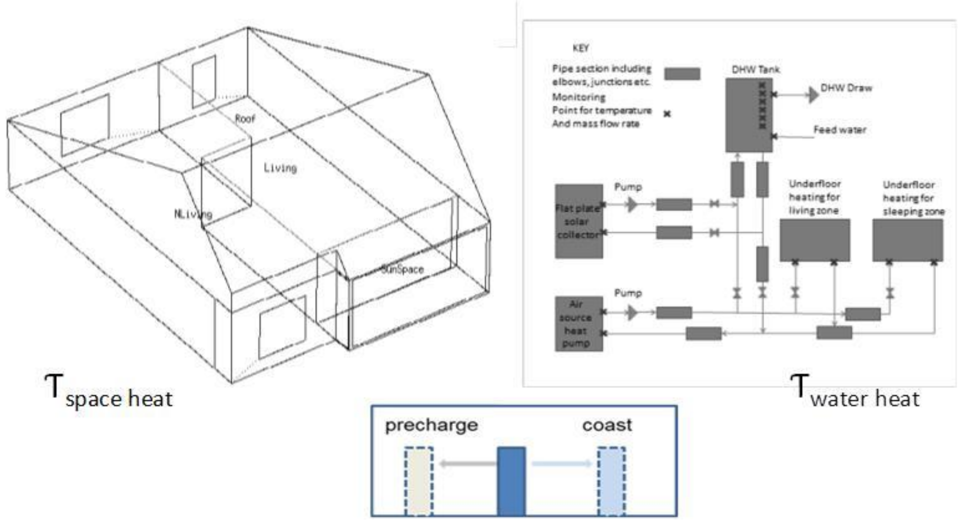


Figure 9: Detailed building and system models used to determine time constants for pre-charge and coast opportunity quantification for feeding into community level models (HOMER, MERIT) in the design stage.

1.2.5 Conclusions on community recommendations and ORIGIN design process

The ORIGIN monitoring data was used to inform building, system, and community level models and generate community energy system recommendations. The core of this work has been the use of modelling methods calibrated by ORIGIN data to inform decisions on future directions for the demonstration sites but more importantly to demonstrate the methods that can be more generally applied to inform future strategy in local energy networks.

The range of options for potential upgrades is large. Scoping studies were undertaken to answer questions of specific interest to the sites, these have provided useful insights for the demonstration communities, and for future applications of ORIGIN elsewhere.

Financial optimisation is highly dependent on specific arrangements to import and export electricity at different times of day, tariff arrangements over longer term than current 1-3 year deals should be secured and then financial optima determined by re-running the models. The importance of financial tariffs is further illustrated in the next section.

2. Community Energy Business Models and Commercialisation

This section details a scoping study to investigate potential financial flows associated with ORIGIN system deployment and to give insight into differences between optimising for self-consumption and grid independence as opposed to financial optimisation. This scoping study illustrates the mechanisms involved and the opportunities using Findhorn as an example.

The research project ORIGIN [1] is supposed to provide communities with tools to monitor and orchestrate energy consumption and generation on a community level. Communities and their residents are allowed to:

- shift and/or save energy demand,
- increase the share of environmentally friendly and/or local electricity generation
- optimize the cost-benefit relation for their community energy supply system

The ORIGIN energy management approach is configured to serve energy supply and energy demand services from selected sources. The services are based on algorithms for prediction of demand and supply and optimization of energy management actions cross the considered energy networks.

One of the communities where the ORIGIN system will be implemented is the Ecovillage Findhorn. Findhorn has 75 buildings on its own private wire electricity network and an established multi-tariff import / export trading relationship with the grid supplier [2]. Besides other innovative solutions for managing internal energy demand and supply there are 4 wind turbines covering on a yearly basis the full electric demand of the settlement and feeding in about the same amount of electricity to the public grid. There are also PV and solar thermal systems but these are relatively much smaller in the current energy system and not considered here. Findhorn is used as the basis of this business models and commercialisation analysis but the methods and findings are intended to be directly applicable elsewhere.

The primary intention of the operation of the ORIGIN EMS in Findhorn is to increase local self-consumption of generated wind energy and reduce grid imports, a secondary intention is to achieve financial benefits by exploiting variable by-sell rates for electricity. “Self-consumption” in this context is quantified by the ratio between locally consumed wind generation and the total amount of wind generation, measured on a quarter-hourly basis.

The reality is that financial imperatives tend to drive decision making in practice. Policy objectives to be successful need to have sufficient financial support if they are to succeed.

This section describes the methodology for economic optimisation and analyses possible contradictions between a solely financial evaluation and the simultaneous requirement of a maximum increase of self-consumption. The quantification of the financial benefit allows an estimation of the upper limit for investment - and operational costs of the energy management system, if it is meant to re-finance on those benefits. The evaluation presented in the following chapters shows that for Findhorn no heavy difference in consumer behaviour is required when adding self-consumption increase to the economic optimization target.

2.2 Economic Evaluation

The ORIGIN project team started the monitoring campaign in the communities in 2014, storing generation and consumption data as well as energy import and export. This allows quantifying financial transactions between the actors based on the supply and consumption of electricity for a certain period. Tariff data are either available on the internet (NFD) or result from personal communication to the companies. Figure 10 shows as an example the tariffs applicable for May 2014 and customers with standard tariff. It should be noted that tariffs are currently re-negotiated every 2 or 3 years, it would be better for financial certainty to reach a longer term agreement in future. The approach taken here is to do evaluation based on representative 'typical' weeks using the 2014 tariffs. Of course it would be advisable in future to agree long term rates and carry out multi-year assessment incorporating more rigorous uncertainty and risk analysis.

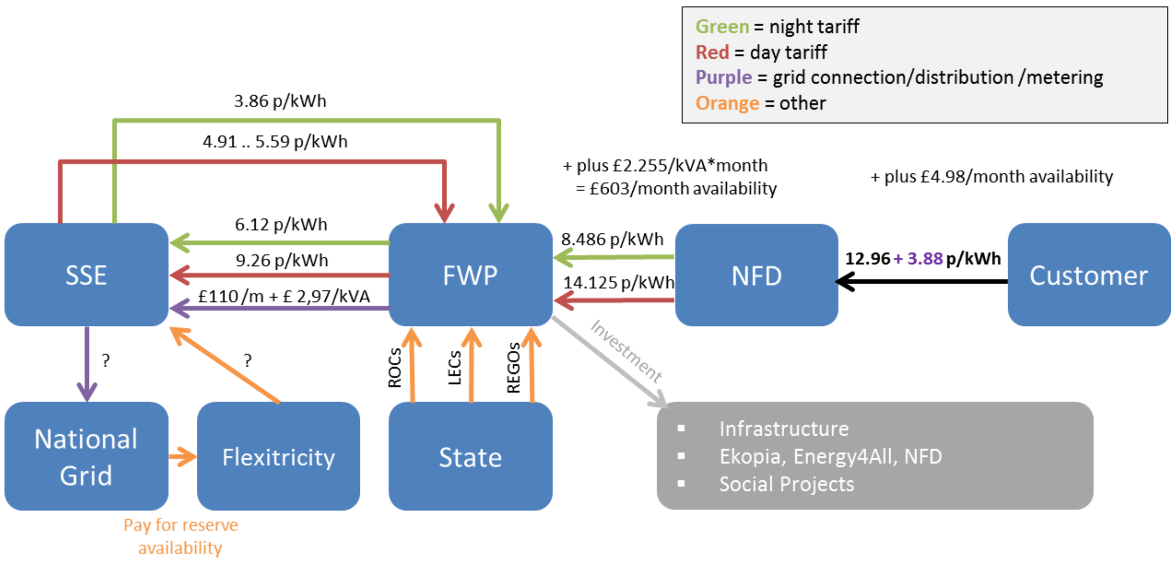


Figure 10: Tariffs and financial transactions between actors involved in the electricity supply at the Findhorn Community (example, showing customers with standard tariff, tariff data: May 2014).

Starting point for the example economic evaluation presented here are two key questions:

- **What operational economic benefits could be achieved by the ORIGIN system by optimization measures focused to generate benefits from variable tariffs? What are the conclusions regarding the acceptable investment and operations costs for the energy management system?**
- **What is the economic implication if self-consumption of locally generated electricity is considered as additional optimization target with same priority? Are there any contradictions between the economic optimization and increased self-consumption or do they lead to the same operation schemes?**

To answer this question the integral economic situation of the community as "one" actor is be analysed. Due to the ownership situation of "New Findhorn Directions (NFD) Ltd" (trading subsidiary of the Findhorn Foundation) and Findhorn Wind Park (FWP) Ltd. (with NFD being a major investor) the three actors "Customer + NFD + FWP will be considered a one actor "Findhorn" and the economic balance will be determined for this integral actor. Thus it is assumed that any financial benefit generated by either FWP or NFD will be conveyed to the customers adequately (either directly or indirectly). With this assumption the financial yield $Y_{Findhorn}$ for a certain time period t can be calculated just from the financial balance with SSE, considering costs for energy purchase C_{Import} and revenues from energy export R_{export}:

$$Y_{Findhorn}(t) = R_{export}(t) - C_{import}(t) \qquad (1)$$

Starting point for the evaluation is the existing situation as determined by the monitoring actions. For an initial evaluation April is selected as the time period. Figure 11 shows the daily energy balance of generation, load and self-consumption calculated on the basis of quarter-hourly measured values. The selected time period contains periods with high wind generation exceeding clearly the local load and periods with very low wind generation. It can be seen that even in periods with loads being clearly higher than the wind generation self-consumption values are mostly below 100%, illustrating the potential for intelligent energy management for increasing the self-consumption. Nevertheless the graphic shows a well-adjusted dimensioning of the wind generation power compared to the typical local load of the settlement.

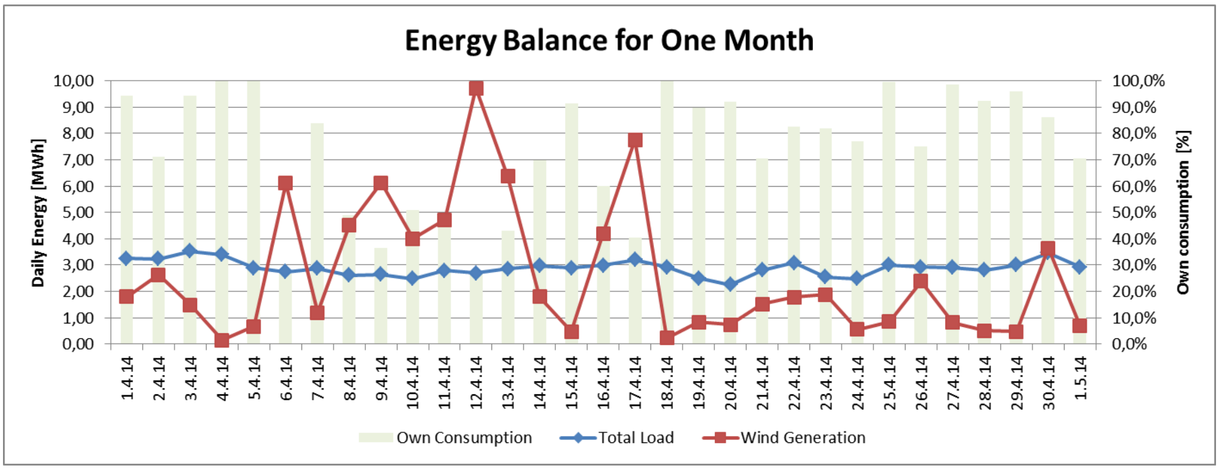


Figure 11: Self consumption, total load and wind generation for April 2014. Values represent daily energy balances calculated from quarter-hourly measuring parameters.

2.2.1 Energy balance of exemplary days

For the following evaluation, 6 different days are be selected showing different combinations of weekdays and week-end days as well as high and low wind generation:

Weekday, high wind generation: 17.04.2014

Weekday, low wind generation: 18.04.2014

Saturday, high wind generation: 12.04.2014

Saturday, low wind generation: 05.04.2014

Sunday, high wind generation: 13.04.2014

Sunday, low wind generation: 20.04.2014

The pictures in Figure 12 show the daily relation between self-consumption and wind generation for single hours. Hourly balances were calculated on the basis of quarter-hourly measuring data. Note that for higher resolutions there are different scales for the energy-axis, nevertheless the absolute load level is roughly the same for all days. A comparison of the absolute values is given in

Table 1.

LOW WIND GENERATION HIGH WIND GENERATION

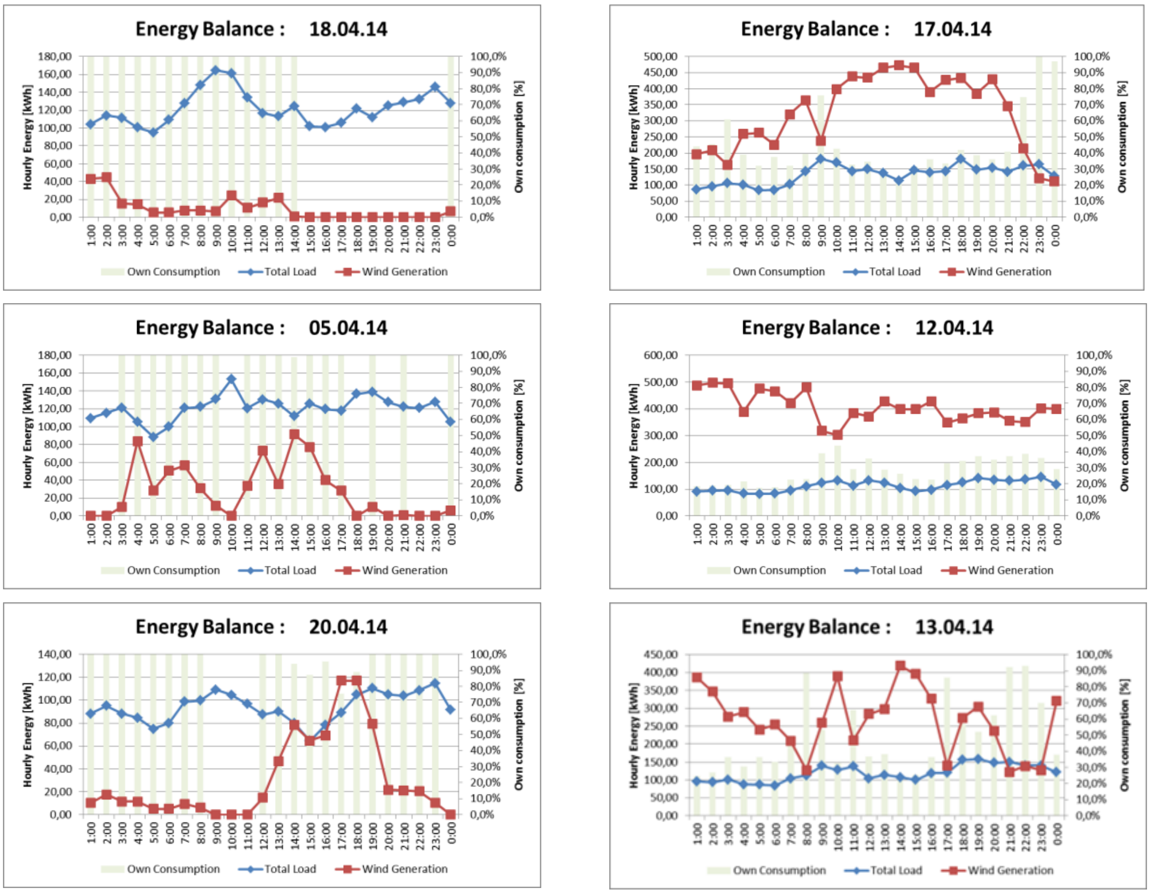


Figure 12: Wind generation, load and self-consumption for selected days in April 2014.

Table 1: Generation and consumption data for the selected days. All values have been calculated on the basis of 1/4h measurements both for generation and load.

Day	17.04.14 (Thu)	18.04.14 (Fri)	12.04.14 (Sat)	05.04.14 (Sat)	13.04.14 (Sun)	20.04.14 (Sun)
Total Load [MWh]	3,20	2,92	2,69	2,90	2,85	2,25
Total Generation [MWh]	7,76	0,23	9,72	0,67	6,38	0,74
Total Import [MWh]	0,07	2,69	0,00	2,23	0,10	1,57
Total Export [MWh]	4,63	0,00	7,03	0,00	3,63	0,06
Self-consumption [%]	40,3	100,0	27,7	99,9	43,1	92,2

The evaluation of the data (Figure 11 and Figure) shows for the Findhorn Community only a minor dependence of the daily loads from the day of the week, so no special consideration of the week-end situation will be necessary. During the day, consumption maxima are in the early morning hours (around 9...10 a.m.) and in the evening (at 7 an 11 p.m.).

During times of rather low wind generation the self-consumption is about 100%. This can be explained by existing base load, fully consuming smaller wind generation regardless of the time of the day. As can be seen in Figure there is a continuous base load of around 100 kW leading to full consumption of smaller amounts of wind generation. Maximum hourly load values are up to 200 kW, roughly twice the base load value. This is a rather small variation, compared e.g. to other standardised load profiles[1] with a factor of 4 to 5 between low and high load periods.

2.2.2 Assessment of energy management potential

There are two major aspects that could be relevant for energy management actions:

- Increase of the self-consumption of wind generation (or any other types of local generation or feed-in) in the settlement
- Optimization of the financial cost/yield ratio for certain time periods.

Measures available for energy management are:

- Load shifting
- (momentary and total) load lowering
- (momentary and total) load increase.

The third option (load increase) might be relevant in situations where either other energy consumption besides electricity is considered (e.g. consumption of oil or gas is replaced by consumption of electricity), or where electrical demand can be shifted from outside the settlement to inside the settlement (charging of electric vehicles).

For the Findhorn community the price system for electricity exchange between FWP and SSE follows a few “rules of thumb” setting the framework for optimization. These “rules of thumb” can be formulated as:

- ✓ HT import is very expensive
- ✓ NT import is quite expensive
- ✓ HT export price slightly lower than NT import price
- ✓ NT export gives only low financial revenue.

[1] Example for Germany: http://upload.wikimedia.org/wikipedia/commons/7/7a/Lastprofil_VDEW_H0_Winter.png

Thus one evident element of optimization is shifting HT import to times of NT export. Total daily import and total daily export values are the limits for this optimization process.

Figure 13:
Exemplary visualisation of the relation between generation, import, load and export for the Day and Night Tariff time blocks (shown as energy per tariff for one day and one night tariff period). All parameters have been chosen arbitrarily and imply no real energies.

For the analysis of the maximum optimization result export, load and import might be considered as flexible parameters. In the example shown a part of the load during the day tariff is shifted towards the night tariff time (thus avoiding import), where it is covered by a part of the export energy.

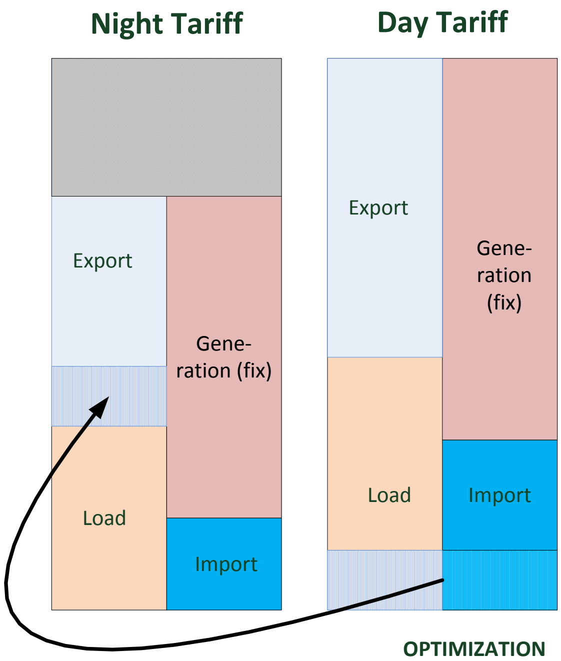


Figure 13 illustrates the options and approach for the optimisation of the energy management. There are three variables for optimization: export, import and load. The current investigation presumes that there is only one sort of electrical generator involved: wind turbines. Thus the generation at a certain time is a given value that could not be changed by the optimizer. The theoretical option of intentional lowering of the wind turbines' output has no actual meaning in the given context.

The figure also visualizes constraints for the optimization procedure. Such constraints are:

- Local generation is fixed and must not be changed by optimization routines.
- Export + load must equal generation plus import
- Export must not exceed generation.
- Import must not exceed load (as long as no storage is involved)
- The daily total load must be served on a daily basis by generation and import.

The last constraint implies full flexibility of the consumers regarding shifting their loads during the day, but no energy savings in total. This assumption is based on the results of the inventory of the current communities' loads and consumer behaviour, showing a below-average electricity consumption and high existing awareness of people regarding of an efficient use of energy in their community. For future simulations this criterion could be changed easily.

The intention of this evaluation is to determine the **maximum** potential for the increase of self-consumption or the financial balance. Of course it is illusive to assume unlimited shifting of loads within the day, especially in a situation of a high continuous base load. Further social and technical evaluations need to determine parameters to integrate a realistic flexibility for load shifting. Nevertheless this evaluation of the maximum benefit sets an upper limit for the costs for the investment and operation of the ORIGIN energy management system, if considered from the economical point of view only.

As mentioned at the beginning, optimization could aim at either increase of self-consumption or financial optimization. The first approach implies that there is no need to “touch” consumption during times where the load can be served locally by wind generation. Thus this optimization approach is less intrusive that the other option. Strict financial optimization could require load increase even above the momentary wind generation (thus increasing the momentary level of self-supply) in order to avoid expensive electricity imports during other times.

Figure 14 illustrates this situation. Because generation exceeds load only the exported energy can be used for energy management measures when optimizing self-consumption. For financial optimization all the load could be increased or decreased freely even if higher import or export would result from this. (The evaluation will show that in many cases both approaches lead to the same optimization result. For practical relevance the optimization of self-consumption might be preferable because of higher transparency for the final consumers.)

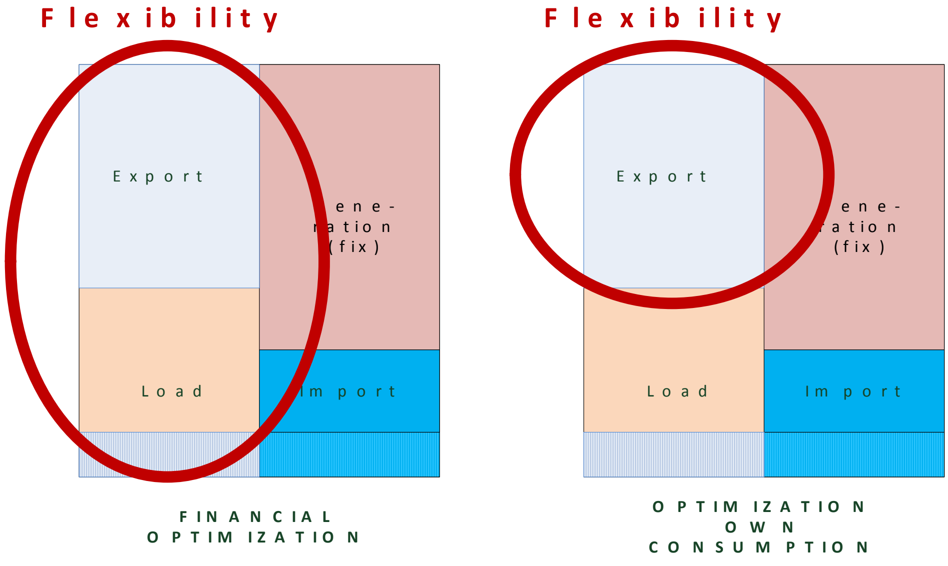


Figure 14: Comparison between financial optimization and optimization to increase self-consumption

2.2.3 Results of optimization approaches

As explained, April 2014 had been chosen for the first evaluation of the optimization potential. The mathematical optimization has been realised by formulating a linear optimization problem and applying a LP Simplex engine operating under Excel.

Figure 15 shows for illustration self-consumption, total load and wind generation before optimization. Table 2 summarizes the optimization results for both financial optimization and optimization to increase the self-consumption.

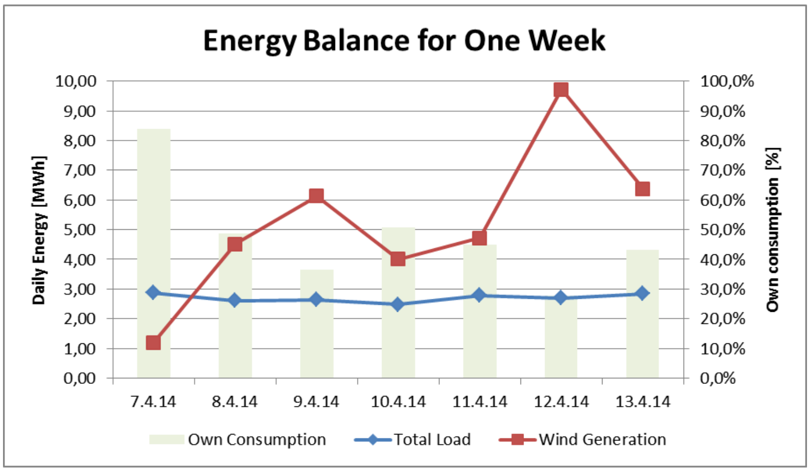


Figure 15: Self-consumption, total load and wind generation for one week starting 07 April 2014 without optimization.

Table 2: Optimization results for one week in April 2014 with the optimization targets „self-consumption“ and „financial optimization“. All financial values are given in British Pounds.

	07.04.2014	08.04.2014	09.04.2014	10.04.2014	11.04.2014	12.04.2014	13.04.2014
Current yield	-142,25	87,62	139,33	54,11	63,82	307,57	154,99
Own Consumption	83,79%	48,84%	36,49%	50,82%	45,06%	27,70%	43,12%
Optimised self consumption	-102,82	94,17	156,70	67,92	88,51	307,57	157,28
Own Consumption	100,00%	57,59%	43,00%	62,09%	59,08%	27,70%	44,70%
Financial optimization	-102,82	94,17	170,27	74,52	94,75	323,77	173,09
Own Consumption	100,00%	57,59%	43,00%	62,09%	59,08%	27,70%	44,70%

As can be seen in Table 2 a significant increase of self-consumption, calculated as the ratio between (generation-export)/(generation), could be reached, being the same for both optimization approaches. The financial result is different for some of the days, being partly significantly higher after financial optimization. One of those days is April 13 with about 16 £ difference.

Table 3: Changes of energy flows due to the different approaches for optimization for 13. April 2014

13.04.14	Before optimization	Optimized self-consumption	Financial optimization
Wind Export NT Time [kWh]	1.606,3	1.505,5	0,0
Wind Export HT Time [kWh]	2.019,7	2.019,7	3.525,3
Import NT Time [kWh]	100,3	0,0	0,0
Import HT Time [kWh]	0,4	0,0	0,0
Load NT Time [kWh]	1.205,9	1.206,4	2.711,9
Load HT Time [kWh]	1.643,8	1.643,4	137,8

Table 3 explains this situation. The table shows all relevant energy flows before and after optimization. Before optimization a rather low import volume can be seen showing a rather high percentage of wind energy to cover the load (because of significantly higher wind generation the self-consumption of wind is only 43%). Thus there is no flexibility for significantly increasing daily self-consumption while maintaining momentary self-consumption.

Financial optimization, however, makes drastic changes to the consumption strategy. It shifts most of the consumption to the NT time fully consuming wind generation, while achieving a significant increase in wind export during the HT time with higher revenues from wind export. This rather extreme scenario shows the ambivalent situation of the operator of the ORIGIN EMS to select a proper optimization mode: earn maximal money or limit the impact on the final consumers.

The monthly evaluation for April 2014 shows that days like April 13 are rather exceptions and for most days the difference in the optimization results between both approaches is small or zero. The financial result of the optimization for the whole month of April 2014 is shown in Table 4.

Table 4: Total financial result (Export – Import) for April 2014 and financial success of optimization for the two optimization strategies. Negative values of „Total“ mean payments to the SSE company while negative values for „change“ mean lowering of payments.

	Total [GBP]	Change [GBP]
Current yield	-1783,15	0,00
Own Consumption	74,17%	
Optimised self consumption	-861,72	-921,43
Own Consumption	84,87%	
Financial optimization	-787,79	-995,36
Own Consumption	84,87%	

After deducting the payments for wind energy export the Findhorn Community (represented by FWP) pays about 1783 Pound to the supplier of electricity SSE. After optimising self-consumption of wind generation the payments are lowered by 921 Pounds leading to a total of 862 Pound. After financial optimization only a most increase of savings can be observed being another 74 Pound. Taking into account that strict financial optimization might require drastic behavioural changes of the final consumers it might be assumed that the optimization for maximal self-consumption might be the proper choice.

Assuming the same order of magnitude of savings for the whole year (which still needs to be verified) the total yearly benefit of an ORIGIN EMS will be in the order of magnitude of 11.000 Pound (strict financial optimization would lead to 12.000 Pound). Note, that these values are upper limits requiring full flexibility of the final consumers!

2.2.4 Summary

A first evaluation of the economic benefits of energy management has been carried out for April 2014. Two different optimisation strategies (increase of self-consumption of wind energy and strict economic optimization) were implemented and the optimization problem was solved using a LP Simplex engine. The results shows significant potential for savings in the order of magnitude of 11.000 Pounds per year for improved self-consumption with only modest additional savings potential of 1.000 Pounds for strict financial optimization. Since the latter implies partly drastic behavioural changes of the final consumers the optimization strategy focussing on self-consumption currently seems to be a preferable approach for the ORIGIN energy management system. The savings indicate the upper limit for the investment and operation costs for the energy management system implementing the optimization strategies into practice.

2.2.5 Conclusions

The evaluation has demonstrated the possible maximisation of revenues in a multi tariff import / export financial situation.

The evaluation is illustrative only but highlights the opportunity presented by variable tariffs from grid operators. These tariffs need to be established over a significantly longer period than is currently the case for Findhorn but the current availability of long term import only 'white meter' tariffs in the UK suggest that this may be possible.

The extent to which load shifting is possible was assumed to be 100% shift-ability within a daily period, this is highly unlikely to be realised in the current system. It could be facilitated by the introduction of electrical storage, but in this case the technical and financial performance of the storage system would have to be factored into the calculations.

Were longer term tariff arrangements secured then these could be input to the community level models created in WP6 and factored into future scenario planning as described in D6.1 and section 1 of this report.

3. General guidance on how to identify most appropriate energy technical and financial market options for Communities.

This section presents a more generic step by step guide into the multiple facets to be considered in planning for future renewable energy systems in Communities.

At a first glance, energy supply in communities with preference to the use of local resources seems an easy task: motivate every community member to invest in some distributed generation (DG) like wind or thermal collectors and use as much as possible of the energy produced. Yet a second thinking leads to a number of questions showing the shortcoming of such a simplified approach:

- Which (natural) resources could be utilized at which location with maximum benefit (PV ⇔ Wind ⇔ Heat ⇔ Biomass ⇔ …)?
- Which technology should be applied for exploitation of a single resource?
- Which technical and economic benefits result from scaling such solutions (meaning: would it make sense to install a larger PV generator instead of lots of smaller ones)?
- How to exploit synergy potential generated by combining complementary technologies?
- Would it bring benefits to jointly (on a community level) "consume" the energy produced by all of the generation units operated by community members (e.g. by creating new load profiles more adjusted to the generation profiles)?
- Would it even make sense to transfer responsibility for (major) investments and operation of DG generation to educated specialists, which on behalf of the community develop and realise an economically and technically optimized concept of local energy supply? What would have to be the criteria and approach for such a decision making process?

Because of the huge variety of community structures (ranging from small isolated communities in rural environment to city-like communities with high population density) a simple "cookbook" for finding the optimum solution can't be written. Nevertheless a number of technical and non-technical criteria can be formulated that need to be considered when developing energy supply concepts for communities or assessing existing solutions. Besides technical and economic criteria one special aspect must be taken into account in any case: what do the people of the community want, how much are they willing (and able) to adjust their personal behaviour to what is expected to become the "energy market model" for the community.

Within this work we will summarize technical and non-technical criteria and exemplary discuss the application of those criteria to the most common energy generation and provision options. Technologies being addressed are wind generation, photovoltaics, small co-generation units (CHP), heat pumps and biomass heaters. Electricity purchase from the grid and export of locally produced electricity will be mentioned in this context as well.

The criteria to be discussed in detail are:

- Local consumption profile and supply needs
- community and individual "philosophies" regarding energy generation and supply
- local natural resources,
- technical potential
- flexibility and storage options of applicable technologies
- local non-technical resources (skills, finances, regulations, …)
- scalability and implications of scaling
- Cost and yield parameters
- interoperability of technologies
- interfacing between local systems and global/national supply options (e.g. grid)
- other aspects

These variables especially the specific financial situations that apply in each country, for each technology, and for different scales of deployment, which are re-negotiated with power companies periodically, and subject to varying Governmental incentive schemes, make specific advice for each community with regards to current market options problematic. However it is possible to provide general guidance on the main factors that should be considered in planning Community level Renewable Energy Systems.

3.1 Criteria for local prioritization of energy supply option

This section will elaborate criteria being important in the decision making process for prioritizing different energy supply options. The challenge for the decision maker is to find all the relevant questions to be answered to start answering those questions by making a first "educated guess", before (costly) professional planning work will step in. So the next sections will often end with a collection of questions and an explanation of how to give first answers to the question.

It needs to be pointed out that any technical figures given in this context are only rough estimations with no claim for completeness or correctness, these need to be checked for the specifics of the situation.

3.1.1 Local consumption profile and supply needs

Key Question:
What power does our community need (type, quantity, profiles)?

The general energetic demand for communities includes different types of energy, mainly electrical energy (mostly 230 V/ 400 V AC for the household loads, 10 kV for larger industrial loads), thermal energy (heating, cooling) and mechanical energy (transportation, manufacturing). The following discussion will primarily focus on electricity supply, yet overlapping aspects will be mentioned when being relevant. This is especially the case in situations where heating energy can be provided by electrical heaters combined with different heat generation technologies.

The most basic information for determining local electrical load profiles would be a time series giving total load at the grid transformer(s) supplying the community, preferably with quarter-hourly resolution. If such data are available for a whole year, conclusions can be drawn both on the energy consumption (MWh) during relevant time intervals and the maximum and minimum power demand (MW) for several periods. (Figure 16).

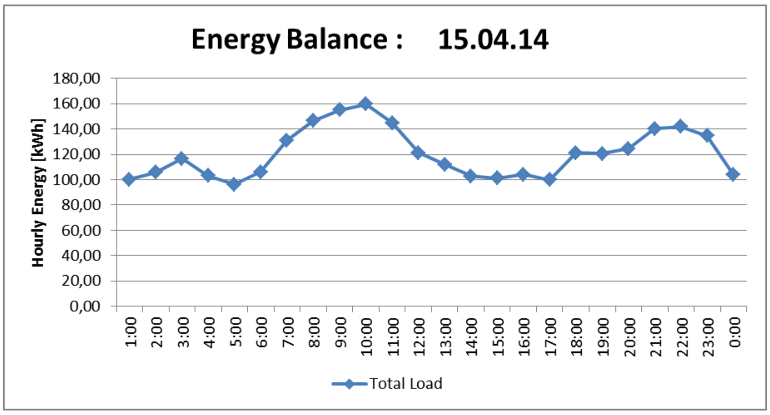


Figure 16: Total electrical load for the ORIGIN community Findhorn for one Tuesday in April 2014. The load profile shows consumption maxima in the morning and evening hours and a relatively high base load of nearly 100 kW. For more details please refer to the ORIGIN technical reports.

Unfortunately, utilities only occasionally install advanced metering equipment at their connection points and often limit their engagement to the determination of meter readings needed for billing purpose. In such cases, total energy demand profiles need to be estimated by determining the consumption profiles of the typical consumer groups in the community and the upscaling of normalized consumption profiles according to the annual consumption and the relative shares of the consumer groups.

For assigning consumption profiles to groups of customers it makes sense to differentiate between private consumers, commercial consumers and other medium size loads (like community amenities), and industrial consumers. For larger industrial loads the individual load profiles are mostly known, since time resolved load measurements need to be done for balancing and billing purposes. Those data are available at the local utility/grid operator, access for third parties will mostly be limited due to privacy and data protection matters. Nevertheless, for planning energy supply options for communities detailed load profiles of industrial load are essential to know.

For small and medium size consumers a number of approaches for classification and assignment to so-called “standardized load profiles” exist. The idea behind is that a larger number of representatives of a certain consumer class will always have typical load profiles even though the individual load profiles will vary. The standardised load profiles are data sets with normalized load data, often on a quarter-hourly resolution basis. To deduce real load profiles for a community, those standardised load profiles need to be scaled up by the annual power demand of the consumers forming the corresponding load classes.

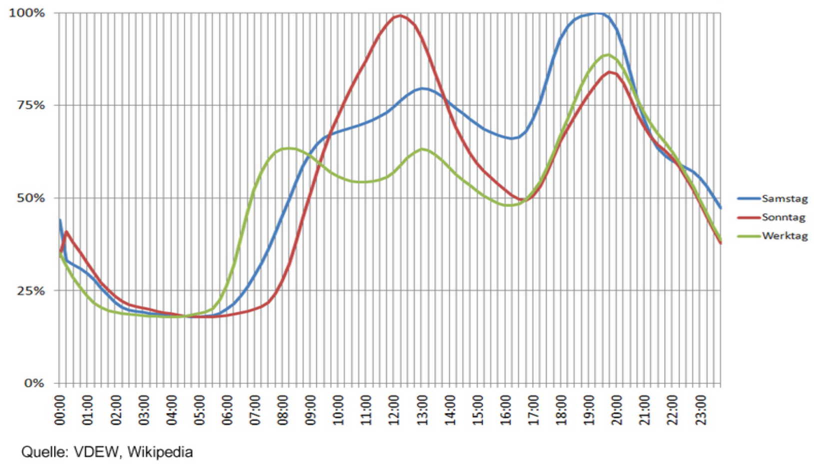


Figure 17: Standardised load profile H0 for household customers for different types of days during winter time. [Source: Wikipedia, based on data by German VDEW]

To mention one example: In Germany such standardised load profiles are defined by the local grid operators based on the Electricity Network Access Regulation[2]. Typical groups of consumers are trade, households, agriculture, continuous load customers, interruptible customers and electrical storage heaters. Grid operators are free to define new and more adjusted standardised load profiles for customer groups. Figure 17 shows as an example the expected load variation for household loads in wintertime for weekdays, Saturday and Sunday. There is a distinct load maximum at the late afternoon hours and a varying load maximum during noon. Standardised algorithms allow transforming those type days to each single day in one year.

The most perfect way to determine community consumption profiles for the different customers of course is to measure them. If concrete data are available or monitoring actions are feasible, those data should be the basis for tailoring the energy supply concept of the community.

After having quantified the historic and typical load profiles estimations about the general development of the community should be asked. The discussion of aspects like

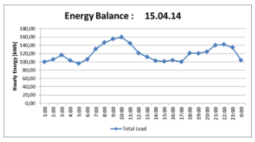
- future number of dwellings in the community
- plans for changes in the heat supply system or public services
- new or refurbished industrial or commercial users

should lead to a conclusion about systematic changes in the energy supply requirements during the upcoming years.

Besides the electrical consumption profiles, thermal load profiles are of special interest in most cases because of their frequent linking to electrical loads (either by using cogeneration units or

[2] Bundesministerium der Justiz, *Verordnung über den Zugang zu Elektrizitätsversorgungsnetzen (Stromnetzzugangsverordnung - StromNZV),* BGBl. I S. 1002 (Germany), 2012.

electrical heating systems). Because of the multitude of possible constellations it is not so easy to use standardised heat load profiles as it is being done for the electricity supply. Standards like EN 12831 (Heating systems in buildings – method for calculation of the design heat load) give complex calculation schemes requiring detailed knowledge about a number of building parameters. As for electrical loads, measurements and historic data are the best options for determining thermal load profiles. Innovative energy supply concepts of communities should explicitly consider flexibilities in the load and generation profiles. Flexibilities for consumption are either aspects of behavioural changes of customers (e.g. adjust consumption to flexible tariffs) or technical means (e.g. peak load limitation by energy management systems). Those aspects will be further discussed in section 2.4.

Question to clarify	**Way to answer**	**Note**
Electrical load profiles		
Total consumption of the community for different time intervals (hour, day, week, month, season) Both energy (MWh) and power (MW)!	• Measurements at the integration points (e.g. transformer to MV grid) • Accumulation of consumption profiles for all relevant groups of consumers	Example Findhorn: yearly aggregated electricity consumption: 7,000 MWh/a, higher resolution profiles available 
Total consumption of individual groups of consumers	• Individual measurement for all or some of the consumers • Use of standardised load profiles or load profile generation tools depending on a few input parameters	Example Findhorn: load profiles for subgroups of dwellings, trade buildings, commercial and community buildings, public services
Other load profiles		
Thermal load profiles	• Individual measurements • Estimations on the basis of simulations or use of load assessment tools.	Thermal demand profiles for heating of houses and other heat loads.
Water load profiles	• Measurements or estimations.	Pumped water supply (e.g. drinking water, irrigation) might set requirements for electricity consumption

3.1.2 Community philosophy and needs

Key Question:
What is our 'Community way' of producing / procuring energy?

In parallel to the determination of the "hard facts" (like load profiles etc.) about the energy supply requirements of a community it is necessary to evaluate the communities' philosophy regarding peoples' expectations and commitments with respect to different energy supply options. There are four major aspects to be investigated:

- Financial aspects for the community and the individuals
- Aspects of "local" energy supply and level of autonomy wanted
- Aspects of "greenness" of the electricity supply (independent from the local aspect)
- Individual engagement vs. community engagement.

Especially in communities with high environmental dedication a number of electricity supply options will not be relevant for them not fitting to the lifestyle of the community. Another sensitive aspect might be the use of local resources (e.g. wood) for energy supply purposes, since a reasonable compromise needs to be found between self-supply and the preservation of the local environment.

Caution should be given to an underestimation of the financial aspects. For concepts with a high level of autonomy and a high share of local RES generation risks and chances need to be communicated to the community in an adequate and transparent way to allow people to come to an educated assessment. Impacts regarding environmental parameters (e.g. CO_2-emissions) should be communicated realistically.

Question to clarify	**Way to answer**	**Notes**
Community philosophy and needs		
What are the preferences and limits the community members see for different alternatives of energy supply	Ask community people for the importance of • financial aspects • relevance of "local" supply • importance of greenness • level of requested individual involvement	Example Findhorn: • high relevance of self supply by RES generation, but no full autonomy requested • major engagament via joint community efforts (e.g. by investing in new wind turbines) • solutions should not lead to untypiccaly high electricity prices.

3.1.3 Local natural resources and technical potential

Key Question:
What resources exist in our Community?

Within the scope of the ORIGIN project only renewable and environmentally friendly local resources are considered; local resources of conventional fuels (oil, natural gas) will not be discussed. With this assumption the following natural resources of energy are assessed:

a) Water
b) Solar Irradiation (both for thermal and photovoltaic applications)
c) Wind
d) Biomass, biofuels
e) Environmental heat (ground, air)

For a first rough assessment of the technical potentials, the questions given in the table below should be answered.

Knowing the natural resources it is possible to make a first rough estimation about the technology specific technical generation potential. For more accurate forecasts simulations and elaborated calculations need to be done, but for a first comparison of supply options thumb estimations might be reasonable. In any case the determination of the technical potential will be the more accurate the more single environmental and technology data are available.

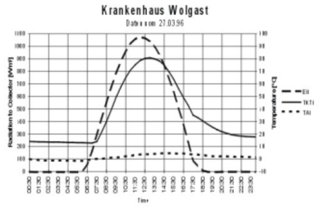
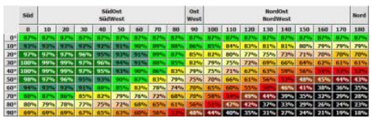
The aspect of interoperability of different technologies is of special importance for heat generation systems, where often conventional and non-conventional systems are combined, together with storage units. Those systems have binding supply tasks to fulfil and any lack of e.g. solar heat production needs to be compensated by either stored heat or by conventional heat generation.

So for deciding about the investment in generation technologies like heat pumps, solar heaters or even wood pellet heaters it is necessary to clarify:

- What is the supply task to be served?
- What other technologies are available or planned?
- Can the foreseen/existing technological systems be combined and serve a joint distribution system?
- What are the extra costs for this technology combination, what effort is needed for operation management and optimisation?

Relevant parameters	Way to determine / estimate	Notes
Water => Hydropower (river)		
INPUT DATA		
Flow speed of river	• Measure, e.g. using a winged wheel sensor or applying the "Acoustic Doppler Current Profiler" method • Indirect determination from water volume and cross section • use data from regional authorities	Flow speed might vary during different seasons!
River power	• Calculate from density ρ (abt. 1000 kg/m3), applicable cross section A and flow speed v like: $P = \frac{1}{2} \cdot \rho \cdot A \cdot v^3$	
Efficiency of hydro turbine	80 - 95% (KAPLAN-Turbines)	Check manufacturer data for other types of turbines
Efficiency of electrical generator	η is about 90%	Check manufacturer data for more precise figures
OUTPUT DATA		
Electric power	Calculate from $P = \frac{1}{2} \cdot \rho \cdot \pi \cdot r^2 \cdot v^3 \cdot \eta_{ges}$ with "r" being the turbine diameter (density ρ, flow speed v, efficiency η).	Foresee buffer areas between turbine and ground/riverside

Water => Pumped-storage power plant		
INPUT DATA		
Available water volume	Measure storage volume Vp	
Difference in height	Calculate δh from different altitudes	
Round-trip efficiency	η is about 81%	Check manufacturer data for more precise figures
OUTPUT DATA		
Usable electric power	Calculate from $E_{el} = \eta \cdot Vp \cdot \rho \cdot g \cdot \delta h$ with ρ being the density of water and g = 9,81 m/s² (efficiency η, volume Vp, height difference δh)	

Solar Irradiation => Photovoltaics		
INPUT DATA		
Area under irradiation	• Available land area • Available roof area	Roof areas should face to South, West or East orientation might be options as well
Specific irradiation	Go to weather service and procure data, look at meteorological data, use available local measurements or make own measurement	Clarify typical daily, monthly and yearly irradiation volumes being as much site specific as possible
Energy potential	Multiply available areas by specific irradiation	Use realistic figures regarding usable areas
Irradiation profile	If possible, procure time series of data. This would allow to calculate generation profiles with alike time resolution.	 Example:
Other helpful data	• Temperature profiles • Aspects of shading and soiling • Typical roof inclination	Use these data to estimate relevant losses compared to the “ideal” generation volumes.
OUTPUT DATA		
• Generation profiles (daily, monthly, seasonally) • Generation totals (hour, day, month, year)	Assume PV generator area and multiply irradiation values (kW/m^2) by area and by 19% module efficiency and by 90% BOS efficiency. Lower by 10% during hot periods. Use additional information available (like given in the note). [standard silicon PV modules assumed]	There are a number of resources in the internet allowing assessing PV output depending from orientation and tilt angle of the modules. For example see here: www.photovoltaik-web.de/ dacheignung/dachausrichtung.html 

It is important to understand that actual energy outputs vary significantly from year to year depending on the solar irradiation situation.

Wind energy => Wind turbines

Yield estimation

Exact estimations of local wind energy potentials are rather difficult because of the high dependence from the properties of the geographic location, orography, the surface properties and the problem to measure the vertical wind profile needed to assign wind speeds to different hub heights for the wind turbines. An alternative for good estimations is given by using the European Wind Atlas and applying some common software like the "Wind Atlas Analysis and Application Program WAsP" (see http://www.wasp.dk for more details). Doing it yourself, however, requires some special expertise.

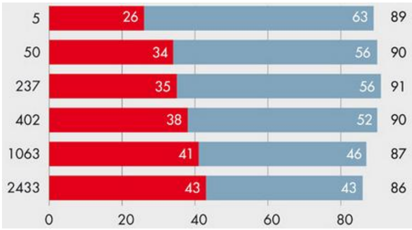
For some countries internet tools exist that allow estimation of wind power and theoretical electrical energy on the basis of available wind data (wind maps) and some simple parameters characterizing the ground profile. Examples:

Germany:
http://www.renewable-energy-concepts.com/german/windenergie/wind-basiswissen/kalkulator-windkraft-berechnen.html

UK:
http://www.reuk.co.uk/Real-Time-Wind-Speed-Map.htm together with
http://www.reuk.co.uk/Calculate-kWh-Generated-by-Wind-Turbine.htm
or
http://www.vgenergy.co.uk/energy-calculator/

It is important to understand that actual energy outputs vary significantly from year to year depending on the wind situation.

Relevant parameters	Way to determine / estimate	Notes
Biomass, biofuels => Co-generation units (CHP)		
INPUT DATA		
Types of biomass / biofuel being available	Clarify availability of biogenic fuels, like • Wood (waste wood, wood cropping) • Energy plants (oil plants, straw, sugar plants, …) • Waste from wood/plant industry • Other organic waste (e.g. from homes) • Liquid fuels (bio-ethanol, plant oil, …) • Gaseous fuels (digester gas, bio-methane, SNG (synthetic natural gas)	Some of the primary resources (like wastes from households) need secondary treatment (e.g. fermentation) before being useful as bio-fuel for CHP units or other applications. It needs to be clarified on a case-by-case basis what investments and running costs are required for these processing tasks.
Quantification of bio-resources	Assess the available quantities per time period using historic production data or reasonable estimations, e.g. litres per day or tons per month. Concrete estimation approaches need to be elaborated site and resource specific.	Always clarify the current use of those resources, since energetic use will have to compete with the “old” utilization. Be aware that availability of some of the resources might vary depending on external parameters (e.g. annual precipitation)
Estimation of energy content	Mostly the biofuels will be just burned, so the calorific value is a good indicator for the energy content. There are tables with calorific values and energy densities	In some cases the energy output can be approximated directly from geographical and cultivation inputs. Example:

	available in the internet (e.g. www.biomassenergycentre.org.uk) Wood chips have a calorific value of 3,5 kWh/kg and an energy density of 870 kWh/m³.	1 hectare of wheat straw will deliver roughly 13 MWh per year. See: www.biomassenergycentre.org.uk
Efficiency of CHP	CHP generate heat and electricity, some of the energy gets lost. The total efficiency is between 80% to 90%, the electrical efficiency is between 25% and 40%. Larger CHP have higher electrical efficiencies.	Check manufacturer data for more precise figures  Graphic: electrical efficiency (red), thermal efficiency (grey), total efficiency (figures right) depending on CHP power in kW (Source: www.asue.de)
OUTPUT DATA		
Electric power	Multiply energy content of the biomass resource by electrical efficiency of the CHP. Add up for reasonable time intervals.	
Thermal power	Multiply energy content of the biomass resource by thermal efficiency of the CHP. Add up for reasonable time intervals.	Note, that the use of CHP only makes sense in situations where both thermal and electrical power can be used.

Heat Pump

INPUT DATA AND OUTPUT

A heat pump provides heat energy from a source of heat to a destination called a "heat sink". A heat pump uses some amount of external power to accomplish the work of transferring energy from the heat source to the heat sink. Typical heat pumps provide thermal energy of 4 to 5 times the electrical energy consumed.

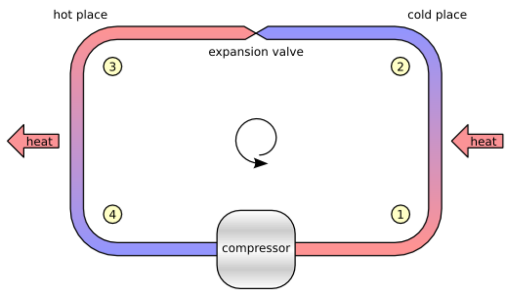


Figure: Scheme of working principal for heat pumps (source: Wikimedia Commons, Jleedev)

Different to the other technologies the energetic potential of heat pumps normally is not restricted by environmental conditions but depends on the size of the collector area or type of the probe located in a drilling hole to the ground. By adjusting collector size and type the thermal energy drawn from air or soil can be adjusted to the needs of the thermal loads.

Heat pumps need electrical compressors for their operation. Operation of heat pumps is especially interesting for situations where cheap electricity and large temperature differences between hot and cold medium are available. So any combinations of solar systems with heat pumps can be interesting options.

Note, that different sources of heat allow different efficiencies, with air having the lowest and water the highest efficiency. The power for heat extraction from soil using collectors is between 10 W/m² (dry sandy soil) and 35 W/m² (soil with ground water). Using geothermal probes one could achieve between 20 W/m (bad soil) and 70 W/m (rock with high thermal conductivity).

Heat pumps are manufactured in a broad range of nominal power between kW and MW ranges.

Detailed information can be found at the webpages of the larger heat pump manufacturers, e.g. www.viessmann.com.

3.1.4 Flexibility and storage options

Key Question:
How do we match consumption and generation in our Community?

One important aspect for the evaluation of different technical options for local energy supply is the opportunity to adjust generation/energy supply to consumption profiles and/or to store generated energy for some time. This question is of special importance for situations where communities seek a high level of self-sufficiency or want to offer system services requiring flexibility options. Assessing flexibility aspects for the considered technologies helps to identify most economic and tailored solutions.

Technology	Flexibility/storage	Notes
Hydro Power (river)	Running river hydro power normally has no options for power control (except cases where water flow control is possible) and storage.	Because of not being relevant for the ORIGIN project, water reservoirs are not considered in this survey. If available, they are an excellent option to adjust water flow and corresponding electricity production.
Pumped-storage power plant	This technology is fully flexible for storing and producing power amounts within the technical specifications and storage volume. If periodically larger amounts of cheap electricity are available hydro pumped storage is a good option if being available.	Mostly only relevant when already being available. Building new storage systems leads to a multitude of problems, involving environmental and economic aspects.

Solar Irradiation / Photovoltaics	No flexibility in generation, full consumption during generation advisable. Most common storage option: batteries (lead-acid or lithium). Storage is still expensive (20cent€ per kWh) and with efficiency loss (up to 10% energy loss). Heat production during excess times might be an alternative option. There is a small flexibility to match consumption and demand by choosing special orientations of the PV modules. East/West orientation of PV modules shifts maximum production to earlier/later time of the day, but lowers the total output.	Electric vehicles might be an option for flexible use of PV generation in future. Also storage systems used for other purposes (e.g. backup power supplies) could be used.
Wind Energy	Wind turbines have no flexibility or storage options (except forced power down situations).	As for PV systems, small battery systems might be an option for storing excess energy from smaller size decentralised wind turbines.
Heat Pump	Heat pumps are a technology with excellent flexibility regarding the electrical and thermal parameters. Because of either the thermal inertia of the thermal loads themselves or the common use of thermal storage systems operation schedules for heat pumps can be adjusted with high flexibility. This could be used for at least two purposes: increase local electrical consumption of locally produced excess energy, and make use of variable electricity tariffs.	Because of their high flexibility heat pumps could also be used to provide system services to the electricity grid. In certain technical concepts they can be combined with solar-thermal systems for achieving overall high heat generation efficiency.

Biomass CHP	CHP units offer flexible plant operation, if heat generation can be adjusted to flexibility needs. Because of frequently used thermal storage systems or high thermal inertia of the heat loads (e.g. heating systems of homes) CHP often offer an excellent flexibility regarding the generation of electricity and thus be able to compensate short-term fluctuations of other RES.	Flexibility restrictions might result from the inflow of biogenic fuels. So CHP driven by biogas generated locally (e.g. sewage water plants) need to consume the biogas almost instantaneously if no relevant gas storage is available.
Batteries	Even though not being a technology specifically linked to the natural resources summarized in the previous chapter it is worth considering availability or procurement of electrical battery systems. They could easily be combined with each of the generation technologies mentioned and improve flexibility depending from size and power. As of today investments in electrical batteries mostly do not pay-off with the sole use for increasing flexibility and self-consumption. Significant price reductions are expected for the upcoming years.	It is worth clarifying if battery systems already exist in the community. Larger batteries could be expected for emergency power backup installations or for electric cars (EV). Storing excess electricity in a pool of EV cars and feeding this energy back to the grid if needed will be one option for the “intelligent” multipurpose use of EV batteries in future.

3.1.5 Local non-technical factors

Key Question:
What are other drivers and hurdles for our community energy system?

When comparing different local energy supply options it is worth discussing the (potential) role of local actors and especially find out local “factors” being supportive or obstructive regarding one or the other technical options. The following table might give just some ideas about how such “factors” might look like.

Factor	Impact
Local reconstruction planning	Useful impact: if a community is planning to rebuild or extent infrastructure that might be a good opportunity for integrating measures for new energy supply options. Examples: rebuilding streets might easily allow to install new / enforced electric cables needed to connect new distributed generation or to build/extent local heat distribution systems in order to connect so much heat customers that investing into innovative heat generation technology would be reasonable.
Local craftsmen (especially if already under community contract)	Useful impact: Cost efficient operation and maintenance of the technology, high level of dedication of local personnel,
Land protection laws prohibiting combustion of wood etc.	Obstruction: Combustion of biomass or biofuel might be prohibited in that community
Restrictive architectural laws	Obstruction: PV on buildings might be not allowed or forbidden, also other technologies changing the appearance of buildings or sites might be difficult to realise.
Local competition	Generating energy with new and innovative technologies might create situations of competition with old established supply structures. Certainly this is less relevant for electricity (which is mostly delivered by central power plants up till now) but could be an actual problem for heat generation and distribution. Example: the installation of new heat pump systems might be prohibited if the house is connected to a local heat distribution network.

3.1.6 Scalability and implications of scaling

Key Question:
How flexible is our community in designing the energy supply in the future?

Aspects of scalability might become relevant in a number of situations:

- the community wants to make only limited investments at one time but steadily continue their engagement in future (i.e., extend the installations)
- the requirements (e.g. load profiles) are expected to change on a medium-term perspective
- after steady quantitative accumulation of generation capacity, at a certain point new qualitative options open up (e.g. investment in dedicated storage systems become relevant).

Therefore it is worth to clarify, if up- or downscaling of the technologies under consideration would be an option and what limitations or chances would be linked to such changes.

Resource	Aspects about scalability
Hydropower (river)	Hydropower installations are normally not scalable because of often using the full hydro potential energy at a certain location. Sometimes cascading of power stations might be possible, also repowering of engines might be a rare option.
Pumped-storage power plant	Normally such installations are not scalable. In rare cases there might be options of repowering the turbines/pumps, which certainly will be quite expensive.
Solar Irradiation / Photovoltaics	PV installations could easily be extended if sufficient space is available. Combination of different types of modules and different module orientations is possible. Installation of a number of smaller inverters is preferable for easier scaling. Replacements of BOS components, wires and transformers might become necessary after reaching certain power levels. Because of manageable single components PV installations can be relocated if necessary. Note that under certain regulatory schemes certain modifications to the systems installed might result in the expiry of permissions for grid coupling or feed-it tariff options.
Wind Energy	There is a number of options for rescaling wind energy installations. Currently the most frequent option is repowering, meaning the replacement of the whole active parts of a wind turbine by new ones. This trend is driven by the enormous progress in wind system technology resulting in much higher yields and efficiencies compared to former years. Given sufficient ground area the total number of single wind turbines could be increased at a certain location. Grid connection infrastructure might need extension in that case. It should be taken in mind that in wind parks there is a wind shading effect of the single turbines with each other leading to lowered efficiencies for the whole park when installing new turbines. Different from Photovoltaics the extension / repowering of wind parks is rather costly.
Heat Pump	In most cases heat pumps will supply local thermal loads and will be technically designed in a proper way. In such cases there is no reason for extension or rescaling. On a community perspective it is worth considering the stepwise installation of new heat pumps for houses with decentralised heat provision and no heat pumps, solar thermal systems or local CHP up till now.

Biomass CHP	CHP are not easily scalable, upscaling just involves the purchasing of additional CHP units. Because of efficiency aspects it is mostly not advisable to invest in a larger number of smaller CHP even though there are some aspects in favour of such solutions (easier part load operation, availability after CHP failures). Upscaling of the use of excess biomass fuels for heating purposes is easily achievable by additional burners operated in parallel to existing CHP.

3.1.7 Cost and yield parameters

Key Question:
Can our Community afford the energy supply system it would like to build up?

Financial cost and yield aspects play an important role for the prioritization of supply options. Detailed technical planning actions are normally necessary to calculate a reliable cost-/benefit ratio. Local geographic and natural conditions play a most decisive role regarding the costs, so it is fairly impossible to define rue-of-thumb values for some of the technologies. In any case, as a first step, it is necessary to summarize, which factors determine costs and financial benefits for any investment.

Major cost parameters common to all the technologies are:

Investment and installation costs:

- Main active generation part (wind turbine, PV modules, water turbine etc.)
- Power electronics to couple the generation part to the grid (e.g. inverters or converters)
- Wiring and other secondary BOS components (including safety equipment, monitoring equipment, communication)
- Labour for mounting and commissioning
- Fee for grid connection and allowance

Operation costs:

- Maintenance and repair work
- ongoing fees (like fees for allowances)
- running metering and communication costs
- insurances

Income:

- revenues from electricity sales to third parties, including export fees for excess energy
- electricity fees from local single customers
- savings from own consumption to avoid energy purchases
- additional earnings from the provision of system services, if applicable

The next table will show a few major cost elements for the different technologies in order to illustrate the order of magnitude for the costs of the different technologies.

Resource	Cost figures
Hydropower (river)	Investment costs for smaller run-of-the-river power plants in the power range between 70 kW and 1000 kW are between 8.500 Euro and 10.000 Euro per kW installed, electricity costs can be estimated in the range between 3 to 8 cent €/kWh for larger and 10 to 20 cent€/kWh for smaller installations. Significant external costs can be relevant, e.g. for water management, land management or fish stock. An example showing detailed cost parameters for a 100 kW power plant can be found here: http://www.energie.ch/wasserkraft. Investment costs in this example are in total 1 Mio. Euro, yearly costs are about 70.000 Euro (including depreciation). In some EU countries hydropower might receive feed-in payments (Germany up to more than 12 cent€/kWh for small installations).
Pumped-storage power plant	As explained above, investment in pumped-storage power plants will certainly be an option in exceptional cases only. Therefore no cost details will be given here. The full costs for storing one kilowatt-hour for one day are in between 3 to 5 cent€/kWh, so the duration of storage directly determines the overall costs. It should be noted that in the past pumped-storage power plants were one of the few technologies able to react extremely fast to varying power demand requests (e.g. for balancing energy). With an increasing number of new flexible technologies this market advantage is getting partly lost.

Photovoltaics	The total price of a PV rooftop-system including inverter, wiring, mounting system, grid connection now is in the range of 8,500 Euro for a 5 kWp system. The annual costs are assumed to be about 2% of investment costs (including insurances). The price for PV systems has been decreasing rapidly during the last years. For installations in the near future one could assume about 1,500 €/kWp roof mounted installations (ready to use) with this price decreasing for large installations. The full costs price per kWh depends strongly on the irradiation conditions at the installation site and is in the order of a magnitude of 10 cent €/kWh considering 20 years of operation. Real operation times for the PV generator are expected to exceed the 20 years significantly with only the power electronics needing replacement after some time. Costs for large free-standing PV plants can be significantly lower down to 1,000 €/kWp depending on the availability of cheap modules. In some EU countries PV power might receive feed-in payments (Germany currently up to 12,47 cent€/kWh for small roof-top systems).
Wind Energy	Only onshore wind generation will be considered in the following. Investment costs for ready-to-use small wind generators (kW range) are in the range between 3,000 € to 10,000 € per kW nominal power, costs for larger wind generators in the MW range are down to 1,400 € per kW. The larger the system is, the lower are the specific investment costs. The full cost energy price for small wind turbines in central Europe is in the range of 25 cent €/kWh, for large installations between 4 and 10 cent €/kWh (assuming 20 years of operation). Operation and maintenance costs are about 12% to 15% of the annual turnover with increasing tendency during the years because of technical attrition.

Heat Pump	Costs for heat pumps depend strongly on technology and size. Heat pumps tailored for the heat supply of living houses (8-9 kW heating power) are in the range between 8,500 € to 12,000 € for the system plus costs for opening up the heat source between 200 € (air heat collectors) and 6,000 € (wells for accessing ground water). The operational costs are determined by the electricity purchase (living house: 400-800 € per year). The profitability of investments in heat pumps depends very much on the electricity price, the price for alternative heat supply options and the annual performance factor (measure for the efficiency of the heat pump). Especially in situations with high costs for conventional energy sources (oil, gas) and an existing need for replacement of the heating system heat pumps are an economically attractive option.
Biomass CHP	CHP costs involve investment (micro size: up to 15,000 €/kW, medium size: 4,000€/kW, larger systems: below 2,000€/kW), operation costs (costs for the biofuels) and operation and maintenance costs (small CHP: 2.5 to 3.0 cent(€)/kWh, larger CHP: 1.5 to 2.0 cent(€)/kWh). Additional costs need to be considered if a processing or storing of the biofuels becomes necessary (e.g. investment in gas tanks). Financial funding is given for investors in high efficient CHP in some countries. This could either be grants for the investment costs or feed-in payments for electricity from the biomass CHP (Germany, 2015: up to even 23.73 cent(€)/kWh for CHP running on biogas generated from liquid manure). Also tax alleviations might become relevant. The profitability of CHP depends strongly on the need for heat delivery and the costs for competing heat generation technologies.
Batteries	Investment costs are the most relevant aspects for batteries, O&M is negligible. As of today a rough price estimation is 200 €/kWh for lead-acid batteries (without BOS!), 800 – 1,000 €/kWh for lithium-ion-batteries. Because of BOS costs, the limited battery life time and the dependence on battery operation, cost figures per kWh stored electricity are more informative, being 25 cent(€)/kWh and above today. Some battery manufactures announce drastic price reductions recently, so Tesla announced a 10 kWh battery with less than 20 cent(€)/kWh stored energy. Note, that depending on the case of application additional costs for energy management systems are to be considered.

3.1.8 Interfacing to regional / national supply

Key Question:
How does our community want to interface with the 'rest or the world'?

During the evaluation of local energy supply options the interfacing to regional or even nation supply systems (both electrical and thermal) needs to be discussed because of two quite different reasons:

- There might be regulations governing the parallel operation of the public infrastructure and the local energy generation options. So, as an example, there are very strict restrictions for operating thermal home systems in a number of German communities in cases where local heat supply grids are available.
- Connection to regional / national supply systems might offer good chances to increase financial profitability of local systems or simplify technical installations (e.g. by achieving balancing via the public grid).

The aspects to be clarified are very case specific. In the following only a few examples of aspects will be explained more in detail.

Some of the energy supply options, like wind or hydro power, are often located on the outskirts of communities or at some geographic distance with poor or no electricity grid infrastructure nearby. It needs to be clarified who is responsible (and has to pay) for any needed grid extension, which could become a serious cost aspect. It also should be clarified after which time period connection to the grid actually could be achieved since some grid operators have limited capacities for the planning and engineering tasks. For larger hydropower installations and pumped hydro the provision of grid system services should be considered (because of their high power and excellent control options). In any case it should be clarified, if grid operators are obliged to connect the systems to the public grid and if any feed-in tariffs or by-back price will be paid by the grid operator.

A full disconnection from the public electricity grid might be possible (islanding operation), but requires a number of technical conditions. So the total local generation must be sufficient to supply the local loads and flexibility options (like batteries or controllable loads) are needed to match generation (with will be fluctuating when using RES technologies) and varying consumption. Fall-back solutions are needed in case of serious technical defects like broken generators or unexpected external influences (e.g. long periods with zero wind power generation). Local generation equipment must be suited for islanding mode with single large generators operating as "network formers".

In some countries / areas there exist rules prohibiting the operation of own electrical / thermal supply systems independent from the central supply structure. This is especially the case in communities with heat supply grids or areas with small grid operators / energy suppliers (especially on islands). In such cases it needs to be clarified in advance what technical options are feasible and if possible solid agreements should be made with the local authorities.

In case of electrical distributed generators connected to the public grid a large number of technical requirements have to be met. Usually equipment providers will sell only devices and components being compatible to standards and regulations. There is, however, one aspect investors and planners of new installations should be aware of. Due to the significantly increasing shares of distributed RES feeding electricity in the distribution grids and replacing increasingly large central power plants, energy flows in the grids change significantly and the number of current providers of system services decreases. This leads to the necessity of adjusted grid operation schemes and modification of rules as well as regulations to allow seamless integration of the new generation technologies. In some cases this might lead to the need of technical modification of existing installations and in some cases even unexpected financial losses. So, for example, in Germany operators of existing PV installations (above some power limit) were forced to install control and communication equipment to existing PV systems allowing the grid operator to determine and influence power output needed.

3.1.9 Other aspects

Key Question:
Anything else to consider?

There are always a large number of site specific aspects that are important for identifying the most reasonable energy supply option. A typical "other aspect" is the community members' attitude regarding the optical and architectural integration of the technical units into the total picture of their community. While nearby wind turbines are acceptable for some communities, other will strictly forbid such installations for noise and visual interference. One typical problem is linked to questions of cabling and the discussion of installing either (cheap) overhead-lines or (expensive, but invisible) underground cabling for new larger generators. Also matters of natural protection could become relevant for the construction and operation of large power generators, like the existence of protected animal species at or near the building place.

Another aspect with potential relevance for innovative energy supply schemes is the need for monitoring and communication systems in order to match demand and supply properly and to find the technical and economic maximum for the energy supply system. By monitoring the status of all components and transferring lots of data to a central energy management system so called "smart grid operation will become feasible". This, however, leads to a large stock of data allowing to "spy" into the behaviour of energy customers and (hypothetically) infringing their privacy. This matter should be treated as early as possible in the planning process for introducing new energy supply options. The best way to prevent corresponding conflicts is a maximum in transparency about the way of using of the data and a high level of safeguarding and data protection measures. One technical challenge in this context might be the solution for collecting data from single houses being integrated into intelligent energy measures. In some cases tenants are quite reluctant against wireless communication systems because of expected health interference. Again early and professional information might help, in some cases the systems need to be designed in a way avoiding WiFi communication.

Immediate involvement of community members is an efficient leverage for realising new energy supply projects in communities. Besides early and detailed information of community member it might give high trust, if local specialists can be involved. Also chances to manufacture parts of the installations locally (as could be done for some solar collectors) might be important.

A completely different aspect is the attitude towards self-sufficiency and independence from centralised supply infrastructure. Quite often community members have the strong desire to fully supply themselves with locally generated energy and to use their local resources for their own purpose. This leads into a high level of engagement and a high willingness to adjust personal behaviour to the availability profiles of local energy resources. Nevertheless, both from economic and environmental perspectives it could be advantageous to cooperate with other communities and share resources and needs jointly. Joint energy supply projects could collect a critical mass of investment capital for larger generation technologies (like wind parks), could level out fluctuations both in demand and generation (thus avoiding expensive balancing measures) and might enable communities to participate markets for grid and system services when achieving required minimum power limits. Doing this will require clarifications, for what services a physical linking of the supply grids / generation units of the communities would be required, or where virtual balancing groups can be formed adding up the communities' resources.

3.2 Criteria Weighting

The intention of this section is to give decision makers and community planners a number of criteria and aspects to consider when planning to extend or refurbish the energy supply of their community, allowing them to understand a number of options and to make a rough balancing of the pros and cons of different approaches. A number of options have been described in Chapter 2 and often after considering all these aspects some of the options could be ruled out at a very early stage of discussion. For the supply options still under consideration it is necessary to weight their relevance and decide on reasonable compromises. Certainly this procedure has to be done individually for each case.

A very rough method for first assessment is shown in the following (exemplary) tables. There are a number of knock-out criteria, which could lead to final rejection of any technology without further investigation. Following this a number of "normal criteria" should be collected that are important for the community. They should be assessed regarding the degree of importance for the community members and the level of fulfilling by the selected technology. Using these criteria parameters a "total ranking indicator" can be calculated, multiplying the total of the "importance" values by the total of the "technology assessment" values. This ranking parameter can be determined for each supply options and finally compared with each other.

Criteria and figures in the tables are just very simplified examples with criteria far from completeness. Most certainly the technological solution needs to be specified more in detail before preparing the table. So "Photovoltaics" will have to be split into roof-mounted and freestanding installation and perhaps could be distinguished between different classes of nominal power (especially with comparison to the power demand of the community).

		Importance	Technology assessment
Knock-out-criteria	Grid connection allowed		Fulfilled
	Suitable land or roof area available		Fulfilled
Normal criteria	Irradiation situation	5 (very high)	4 (good)
	Acceptance in Community	5 (very high)	5 (very good)
	Costs of the systems	3 (moderate)	2 (rather high)
	Controllability of generation	2 (low)	1 (very bad)
	Flexibility for extension	3 (moderate)	5 (very good)
Knockout criteria met: YES **Total ranking (Total of Importance x Technology assessment): 68**			

		Importance	Technology assessment
Knock-out-criteria	Grid connection allowed		Fulfilled
	Suitable land or roof area available		Fulfilled
Normal criteria	Wind speed situation	5 (very high)	3 (fair)
	Acceptance in Community	5 (very high)	3 (medium)
	Costs of the systems	3 (moderate)	2 (rather high)
	Controllability of generation	2 (low)	1 (very bad)
	Flexibility for extension	3 (moderate)	3 (medium)
Knockout criteria met: YES **Total ranking (Total of Importance x Technology assessment): 47**			

		Importance	Technology assessment
Knock-out-criteria	Availability of river		Fulfilled
	Allowance for modification of river		Not Fulfilled
Normal criteria	Not relevant		
Knockout criteria met: NO **Total ranking (Total of Importance x Technology assessment): 0**			

The planner should be aware that especially cost parameters need detailed specification because of different aspects of “low costs” and “high costs”. For communities wanting to spend a limited absolute budget the “total costs” for the investment are a most important parameter being almost a knock-out criterion. For communities with some flexibility about the available budget the “specific costs per power (kW, kWh)” will be more important. For most generation technologies the specific costs are much lower for larger units and it is worth considering investing into somewhat larger units in such cases if the specific costs for the whole installation would be much lower.

There is some interdependence between some of the parameters which restricts figures for technology assessment in some cases. So if choosing "efficiency" as one criterion (which might be the case for thinking about heat pumps) a broad range of different unit types and technologies are available differing significantly in efficiency, but at the same time differing in price. Demanding a very high efficiency would mean accepting high unit prices in that case inevitably.

Special community requirements should be written on top of the tables. Such as "100% self-sufficiency", which would lead to especially high ranking of the achievable energy output and the seasonal generation profiles. A combination with storage systems might become necessary in such cases and could influence the ranking decisions significantly.

At the end ranking of the different technological concepts can be compared and solutions with highest ranking should be evaluated in more detail.

3.3 Postscript

The first step for considering actions to improve or refurbish the energy supply system of communities is a very rough assessment of requirements, options and limitations. For this start no expensive expert opinion is needed but some basic insight into the existing technological options coupled with some rule of thumb evaluations might give a surprisingly reasonable assessment of potential options and their pros and cons. Of course any following planning process would require professional engineering.

The present report was written to give guidance and some basic information for this step 1 evaluation. It shows the way of thinking and summarizes questions to ask. Technical data in the report are rough indications only and the authors neither claim correctness nor completeness of data. Because of rapid technological and manufacturing progress cost especially cost figures will quickly be obsolete, they also vary from country to country significantly. What will retain is the methodology to prioritise energy supply options for communities. This methodology has a simple basic approach:

What do we want to achieve?

What natural resources to we have?

What financial/material resources are we ready to spend?

What technology fits us best?

Who can help us for implementation?

The latter aspect had not been addressed in this report since it depends very much on the concrete planning and the local situation. Most certainly professionals and concerned trades could be found by the help of the internet or by contacting other communities already engaging in such energy supply options.

Quite often there will not be one technology able to serve all needs but a combination of a number of combined technologies could be the best solution with respect to efficiency and economics. In such situation it could be worth considering the implementation of an energy management system scheduling and optimizing the operation of each flexible component and allowing to define the individual optimization criteria as to the needs of the community members. The ORIGIN system is one existing option to realize such an innovative approach. Detailed information about the ORIGIN system and contact information is given at the webpage http://www.origin-energy.eu/ .

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