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Assessing Energy Business Cases Implemented in the North Sea Region and Strategy Recommendations

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ABSTRACT

e-harbours is a unique European project that was set out to identify viable energy business cases on the exploitation of energy flexibility, which optimise their operations to match energy demand and supply while taking account of the additional volatility in supply caused by renewable energy sources, improve energy efficiency, and reduce dependence on fossil fuels. In this paper, we propose an integrated multi-criteria decision analysis based framework to assess the relative performance of 21 energy business cases, which implemented different demand-side management strategies. Our proposed methodology has the ability to address complex problems involving multiple conflicting interests from various stakeholders, different forms of data, and different fuzzy and crisp relations. We find that business cases based on contract optimisation and offering reserve capacity were ranked relatively high, while those based on trading on the wholesale market or hybrid approaches fared less well. Despite finding viable pilot business cases, *e-harbours* found that there was little enthusiasm among industrial partners to scale up the pilots. Consequently, EU governments should consider offering attractive incentive programmes for industry engagement in achieving their objectives in reducing greenhouse gas emissions, improving energy supply security, diversifying energy supplies, and improving Europe's industrial competitiveness.

Keywords: Smart energy, Demand-side management; Energy flexibility; North Sea Region; Harbours

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1. Introduction

1.1 Motivation

The promotion of renewable energies is a key pillar of the European Commission's broader energy and climate objectives of reducing greenhouse gas emissions, improving energy supply security, diversifying energy supplies, and improving Europe's industrial competitiveness. However, the intermittency of renewable energy has introduced additional volatility into the management of energy grids, leading to an increasing challenge around balancing energy supply and demand through traditional *supply-side management*. The deregulation of electricity markets along with the advances in information and communication technologies (ICTs) have encouraged various stakeholders (e.g., policy makers, energy companies and grid operators) to look increasingly at opportunities presented by *demand side management* (DSM). DSM is typically achieved through economic incentives along with energy storage technologies with the aim of flattening peaks and troughs in demand to help reduce load volatility and stress on the grid infrastructure, reduce the volume of the expensive standby capacity required, and create capacity to absorb excess renewable production to feed it back into the grid at times when there is demand. In practice, DSM allows end-users to adjust electricity consumption in response to market signals and is often considered as an efficient way to reduce energy costs and greenhouse gas emissions, improve system reliability and operational security [1, 2].

Despite many advantages of DSM, it has had limited widespread usage to date [3, 4]. The main barriers include low awareness of DSM programmes in promoting energy, carbon, and cost reductions, the lack of compelling business cases to demonstrate how one can exploit flexibility within their systems to persuade both businesses and households to invest in the necessary infrastructure or alter established consumption practices [5, 6].

1.2 Scope

Most empirical studies tend to measure the effectiveness of DSM programmes via simple cost-benefit analysis (CBA) or in terms of carbon reduction. For example, [7] assessed the potential for cost reductions by considering a future German power system with a variable renewable energy share of 70% of the total energy supplied scenario. [8] investigated the potential for DSM to match the energy demand for a domestic dishwasher with available renewable energy supply to reduce cost and greenhouse gas emissions from thermal generation. [9] developed a techno-economic methodology to evaluate three capacity-based DSM business cases for from domestic and commercial end-users. [4] compared the performance of various DSM programmes (i.e., short term operating reserve, triad, fast reserve and smart meter roll-out) based their ability on carbon savings.

Governments and municipalities are keen for end-users to implement DSM. However, the capital costs associated with DSM technology and/or the organisational disruption required to alter established operational practices are significant barriers potentially for large industrial energy users. Energy companies also need to see some benefit in encouraging their customers to consume less energy. Consequently, it is likely that the most effective DSM interventions – in terms of energy management – will not be the most attractive ones for all stakeholders. It is arguably more important identify *deliverable* interventions that are acceptable to all stakeholders rather than those with the best CBA or which are best at mitigating carbon emissions. It is also important to compare very different types of isolation. Typically, the merits of technical interventions are considered by engineers, while the potential of market are considered by economists. Previous studies have rarely sought to compare technical and financial instruments using common criteria. A methodology is therefore required that can consider – systematically – the often divergent perspectives of all stakeholders who are potentially involved in delivering DSM interventions and a range of disparate interventions ranging from engineering to financial management.

1.3 Contributions

In this study, we use an integrated multi-criteria decision analysis (MCDA)-based framework to assess the relative performance of different DSM strategies. Our methodology explicitly takes different stakeholders' perspectives into account. Moreover, it allows us to evaluate the effectiveness of DSM strategies under multiple criteria and with data in different forms. For example, some criteria are measured on monetary scale (e.g., additional investment cost, additional running costs), while a discrete scale can be used for those factors that are difficult to quantify in monetary values (e.g., technical transferability, stakeholders' attitudes). In addition, we allow for fuzzy relations for some criteria instead of crisp relations, by considering the magnitudes of differences so that small differences in performance would not matter in discriminating between DSM programmes. Our proposed approach is a generic framework and as such could be applied to assess any DSM programmes.

The methodology was developed as part of *e-harbours*, a European Interreg 4b North Sea Region funded project. Our model was applied to 21 *e-harbours DSM business cases* piloted across five European countries. By focusing on a motives, attitudes and decision making of end-users, stakeholders and experts – rather than merely the pure technical or financial aspects of DSM – the paper makes a new contribution to the field. The paper also compares and accesses a range of different pilot interventions (e.g., engineering investments, operational changes, contract optimisation and market trading). We also discuss how flexibility might more effectively be exploited within operations ranging from large industrial businesses, to small businesses, to private users in real applications and we conclude by making some practical points on the need for government and policy makers to take the lead on the large scale implementation of DSM.

1.4 Outline

The paper is organized as follows. Section 2 discusses the key approaches for managing the electricity supply-demand balance, and provides information on the *e-harbours* partners and their business cases. Section 3 describes the proposed MCDA-based framework. In section 4, we present and discuss our empirical results. Section 5 discusses policy recommendations. Section 6 concludes the paper.

2. Demand side management and energy business cases

2.1. Common approaches to maintaining the electricity network equilibrium

Running an electricity system reliably requires energy supply and demand to be balanced in real time. This balance is not necessarily easy to achieve, as both supply and demand levels can change rapidly and unexpectedly due to many reasons, such as generation outages, transmission and distribution line outages, and sudden load changes [1,5]. The traditional approach to maintain the network equilibrium is to vary electricity supply to match fluctuations in demand. However, with the increasing penetration of renewable energy sources (e.g., wind and PV) and the liberalisation of electricity markets, new uncertainties have been introduced into the energy system [10,11]. The geography of renewable energy production (e.g., wind, PV energy) provides one challenge for energy companies and grid managers. The grid is designed to transfer energy from a handful of central generation points outwards. Feeding renewables into the grid causes uncertainty of supply and – given that wind renewables in particular are often generated in remote, rural or island communities, renewable energy also places a strain on the transmission infrastructure in parts of the grid that are not designed for heavy input loads [12,13]. Thus, the intermittency of renewables creates problems for grid operators, in terms of the need to have expensive power generation capacity on standby. In some countries, this creates opportunities for third party power balancing companies, who make a large amount of money out of matching increasing unpredictable energy supply with demand (increasing costs for large energy consumers), while an excess of renewable off-peak times creates market anomalies, with negative energy markets (where suppliers have to pay consumers to use energy), which have been experienced in Belgium and Germany, set to become more widespread [14].

Against this background, there has been increasing interest amongst policy makers and energy companies in the possibilities offered by DSM [15]. The deregulation of electricity markets along with the advances in ICTs has encouraged more active DSM programmes that aims at influencing end-users' behavioural and consumption patterns of energy use [16,17].

2.2. Demand side management strategies

Energy consumers can only change their behaviour if they have a degree of flexibility in their energy consumption. DSM therefore relies on the identification and capturing of flexibility within energy systems. However, in order for the flexibility to be exploited, there has to be a viable business case so that an organization or individual can benefit from a return on capital or the opportunity cost of making an operational change. We review three major strategies that have been put into practice: 1) contract optimisation; 2) wholesale market; and 3) offer reserve capital.

Through *contract optimisation*, consumers aim to shift energy consumption to off-peak hours when unit costs are less expensive. This can be achieved through incentive-based and price-based initiatives. Incentive-based initiatives include direct load control programmes and interruptible load programmes, through which utilities companies have the ability to remotely control the power consumption of consumers' appliances by switching them on or off remotely that participating customers receive payment credits or discounted tariffs [18,19]. Previous research has demonstrated while direct load control has been successful in reducing peak-time energy consumption, consumers were uncomfortable with yielding control of their appliances to utility companies [20,21]. Price-based programmes are a less direct control mechanism, whereby customers are incentivized to shift consumption from peak to off-peak times via a differentiated pricing structure. Typical approaches include Time-of-Use pricing, Critical-Peak pricing, Peak-Time Rebate pricing, Real-Time pricing, and Inclining Block Rate pricing – see [1,5,6] for more details on these pricing schemes. Previous work has indicated that price-based programmes are relatively effective in reducing peak load and capturing flexibility in energy systems [22,23].

By *trading in wholesale markets*, large scale energy users can reduce their energy costs, generate revenues from selling electricity produced locally, or hedge against the potentially costly risks posed by divergence from an organization's predicted energy demand. One emerging smart energy innovation is for groups of smaller consumers to club together to form a collective entity (known as virtual power plants) with a large enough trading volume to overcome wholesale market entry barriers and to share entrance fees, annual subscription fees, and trading costs [24]. Examples of previous work include [25] developed an agent based model to optimise price bidding for energy market traders, generating significant cost savings for participants. [26] compared the effectiveness for trading electricity from the day-ahead electricity wholesale market using the social welfare with the industrial load reduction models.

By *offering reserve capacity*, a typically large energy consumer will enter into an agreement to provide pre-specified load adjustments, either increasing energy demand during times of surplus supply, or decreasing demand at peak times, for example, when there is little wind energy being generated [27]. In general, the reserve payment mechanism comprises two parts: the reserve capacity price for the reserve capacity allocated, and the deployed reserve price, which is the payment for the energy delivered. Participants are subject to penalties if they fail to respond to a call from the grid operator for load adjustment [1,28]. Relevant studies include [29], who previously explored the economic implications of different contract durations in offering primary and secondary reserve capacity in Germany distinguishing between the respective requirements of the spot energy and reserve capacity markets. [30] developed a mathematical model to coordinate energy generation and reserve capacity energy consumption to better match supply and demand using reserve capacity.

In sum, DSM provides a variety of programmes which offer incentives to end-users to adjust their amount and/or timing of electricity consumption. It must be noted, however, that a prerequisite for the successful implementation of these approaches is the presence of flexibility within local energy systems.

2.3. e-harbours' partners and their proposed energy business cases

Funded by the EU Interreg IVB North Sea Region, the *e-harbours* project set out to identify viable business cases predicated on the exploitation of energy flexibility. In order to help increase the volume of renewable energy, improve energy efficiency and reduce dependence on fossil fuels in harbour regions. *e-harbours* comprised partners from five North Sea Region countries: Belgium, Germany, the Netherlands, Sweden and the UK. The project identified 21 energy business cases that implemented a range of DSM strategies including contract optimisation, trading on the wholesale market, offering reserve capacity, and hybrid strategies. These business cases showed how one might exploit flexibility within its facilities ranging from small commercial and residential users, medium commercial and industrial users, to large commercial and industrial users [31] – see Appendix A for details.

Over half of the business cases identified were based around *contract optimisation*, ranging from recharging fleets of vehicles and boats at off-peak times, in Zaanstad and Amsterdam, respectively, through heavy industrial processes (such as sludge treatment in Antwerp and flexible management of reefer units[1] in Hamburg), to the use of smart homes to regenerate harbour regions in Malmo. For a number of harbours, business cases could be

[1] A reefer (also known as refrigerated container), is an intermodal container used in intermodal freight transport that is refrigerated for the transportation of temperature sensitive cargo.

identified from *contract optimisation* and *trading in the wholesale market*, for example, the flexible use of large storage facilities in both Antwerp and Hamburg and the energy management strategies pursued by the Municipality of Zanstaad. In these cases, it would be possible to capitalize on the inherent flexibility within the energy system through two different routes. Three business cases were identified which involved *offering reserve capacity*. Two of these were identified at a large chemical plant in Hamburg harbour, through the utilization of a Combined Heat and Power plant, potentially in harness with new electric heaters (see Business Cases 15 and 16 in Appendix A). The third case for reserve capacity existed at three cold storage warehouses in Antwerp, where there was potential for all three types of business cases (Antwerp 2a, 2b and 2c). Finally, three cold storage warehouses located in the Port of Hamburg were assessed separately under a hybrid strategy of contract optimisation and trading on the wholesale market (see Business Cases 17-19 in Appendix A).

3. A multi-criteria framework for assessing energy business cases

In seeking to assess the relative performance of our smart energy business cases, we use an MCDA-based framework methodology. This involves a three-stage process; namely, data and preference gathering; selection of an MCDA model; and formulation of recommendations. These stages are described in details hereafter.

Stage 1: Data and preference gathering

As mentioned earlier, one of the key challenges in assessing energy business cases is to identify and use criteria which have credibility among, and reflect the differing perspectives of, a potentially diverse group of harbour stakeholders. The first part of this process involved performing a *stakeholder analysis* to identify all the relevant parties who have a vested interest in our energy business cases.

The assessment criteria was developed and weighted during the duration of the first three years of the *e-harbours* project (2010-2013). To generate, refine, and precisely define a list of assessment criteria, we conducted 8 *workshops* and *interviewed* 12 energy flexibility experts. To assign weights to the assessment criteria, we subsequently administrated a questionnaire survey to energy stakeholders involved with the e-harbour business cases, yielding 42 completed questionnaires.

A *Delphi method* along with an elimination-by-aspects heuristic to assist with agreeing on a common set of criteria that considered to be important in evaluating the different business cases and related strategies. The choice of this method was motivated by some of its advantages such as avoiding self-censorship, offering the participants the flexibility to modify their views as they learn from others, and avoiding negative group influences such as dominating members. In sum, this process resulted in identifying a final list of 9 criteria and their corresponding measures, which are related to four dimensions; namely*; financial, environmental, technical,* and *social* (see Table 1 for details). The common approach to evaluate the relative performance of business cases would be the monetary value of the "flexibility" generated by each business case such as cost reductions [32,33]. However, each business case was specific to a particular harbour, in a particular county with its energy market and regulatory and legal systems. Thus, a business case might be viable in Belgium might not be transferable to Sweden or Germany. Consequently, it is important to compare different business cases not only using economic and financial factors, but also take into account 'local' factors such as wider transferability and the actual stakeholder interest in the case study and wider aspirations such as the ability of the initiative to save CO2 and generate jobs and wealth creation.

A number of methods could be used to generate weights for each criterion (e.g., Direct Rating method, Max100, Min100, Point Allocation method, Simos' cards method, and the Analytic Hierarchy Process). For our application, we opted for a *Point Allocation method*, in which criteria are rated relative to each other by distributing 100 points between them to reflect their relative importance. Such choice is motivated by its simplicity from a user's perspective. We have obtained two sets of weights: 1) one with preferences on financial dimensions to reflect commercially motivated stakeholders' preferences; 2) the other with preferences on social and environmental dimensions to reflect socially and environmentally motivated stakeholders. In our analysis, we used an equal weighting scheme as a benchmark to check how sensitive or robust rankings of strategies are to decision makers' preferences.

As noted above, final *questionnaire* was distributed to our industrial partners to collect business cases specific data on the measures of the final set of performance criteria, where the financial dimension is measured with additional investment cost, additional running cost, and flexibility (i.e., percentage saving in the total energy bill before and after the intervention); the environmental dimension is measured by CO_2 emissions (i.e., percentage saving in CO_2 emissions before and after the intervention); the technical dimension is measured by the technical transferability, organizational transferability, and legislative transferability; and the social dimension is measured by the stakeholders' interest, and wealth and job creation.

Note that our energy cases involved firms with different energy needs and different sizes – although size does not actually matter and even when it does, it is reflected in the energy needs of the company. Therefore, we adjusted some of the above mentioned measures accordingly. To be more specific, as flexibility and CO_2 emissions are relative measures expressed in percentage terms, there is no need to adjust them for energy needs. Also, as technical transferability, organizational transferability, legislative transferability, stakeholders' interest, and wealth and job creation are measured qualitatively by a score on a scale of 1 to 9 provided by our partners, in order to adjust them for energy needs, we asked the respondents to take account of the magnitude of their energy needs; therefore, they are energy needs adjusted. Finally, additional investment cost and additional running cost are adjusted for energy needs by dividing them by the total energy bill.

Stage 2: Selection of the MCDA method

In this study, we use the integrated Preference Ranking Organization Method for Enrichment Evaluation (PROMETHEE) II method. PROMETHEE II is an outranking method capable of accommodating conflicting criteria, if any, as well as any mix of quantitative and qualitative measures of such criteria when evaluating alternatives. The basic principle of PROMETHEE II is based on pair-wise comparisons of alternatives on each criterion, where a criterion could either be maximized or minimized. The main steps of the integrated PROMETHEE II method can be summarized as follows:

Step 1: Compute weights or relative importance coefficients of *m* criteria, say w_j, by using the *point allocation method*. Then, calculate the weight of each criterion j, say $\overline{w}_j$, as follows, where *K* denotes the total number of decision makers:

$$\overline{w}_j = \frac{1}{K}\sum_{j=1}^{K} w_j \tag{1}$$

Step 2: For each criterion j, we choose the preference function P_j as follows:

$$P_j(d_j) = \begin{cases} 0 & \text{IF } d_j \le \iota_j \\ \dfrac{d_j - \iota_j}{\pi_j - \iota_j} & \text{IF } \iota_j \prec d_j \le \pi_j \\ 1 & \text{IF } d_j \succ \pi_j \end{cases} \tag{2}$$

where d_j denotes the difference in performance with respect to criterion j between a pair of competing energy business cases; ι_j is the indifference threshold and any difference smaller or equal to this threshold is considered as negligible by the decision maker; π_j is the preference threshold and implies strict preference; any difference in-between implies hesitation, and we assign a score accordingly [34]. Note that, we use pseudo-criteria for quantitative measures and true-criteria for qualitative measures. A true criterion provides an absolute discriminating power: that is, any difference matters, regardless of its magnitude; while a quasi-criterion provides a non-absolute or nuanced discriminating power, in that differences within a small range are not meaningful, which involves the use of a single threshold, and a pseudo-criterion provides a non-absolute discriminating power, in that differences below a first threshold imply indifference, above a second threshold imply strict preference, and in between imply hesitation.

Step 3: For each criterion j, we use the appropriate threshold elicitation method to determine indifference and preference thresholds as functions of the range of values of the corresponding measure, as follows:

$$\iota_j = \alpha_j \times \left(\underset{a \in A}{maximum} \left\{ g_j(a) \right\} - \underset{a \in A}{minimum} \left\{ g_j(a) \right\} \right); \alpha_j \in (0,1) \tag{3}$$

$$\pi_j = \beta_j \times \left(\underset{a \in A}{maximum} \left\{ g_j(a) \right\} - \underset{a \in A}{minimum} \left\{ g_j(a) \right\} \right); \beta_j \in (0,1) \tag{4}$$

where *A* denotes the set of energy business cases. Note that α_j and β_j reflect percentages of the range of values taken by criterion j that would lead to indifference and preference situations, respectively. Given the nature of our application and the range of the values taken by the energy needs-adjusted measures of the quantitative criteria under consideration, the values of α_j and β_j for flexibility, additional investment cost, additional running cost, and CO_2 savings are set to 0.01 and 0.05, respectively. For the qualitative criteria (i.e., organizational transferability, legislative transferability, technical transferability, stakeholders interest, and jobs and wealth creation), α_j and β_j are both set to 0, because of the choice of true-criteria for the type of discriminating power to use.

Step 4. Compute preference indices for each pair of alternatives, as follows:

$$P(\mathrm{a},\mathrm{b}) = \sum_{j=1}^{m} w_j \cdot P_j(\mathrm{a},\mathrm{b}); \; P(\mathrm{b},\mathrm{a}) = \sum_{j=1}^{m} w_j \cdot P_j(\mathrm{b},\mathrm{a}) \tag{5}$$

where $P(\mathrm{a},\mathrm{b})$ is the aggregated preference index and expresses to what extent *a* is preferred to *b* over all the criteria; while $P(\mathrm{b},\mathrm{a})$ expresses to what extent *b* is preferred to *a*.

Step 5. Compute the positive and negative outranking flows for each alternative, say $\phi^{+}(a)$ and $\phi^{-}(a)$ respectively, as follows:

$$\phi^{+}(a) = \frac{1}{n-1}\sum_{b \in A \setminus \{a\}} P(a,b); \; \phi^{-}(a) = \frac{1}{n-1}\sum_{b \in A \setminus \{a\}} P(b,a) \tag{6}$$

Step 6. Compute the net outranking flow for each alternative:

$$\phi(a) = \phi^{+}(a) - \phi^{-}(a) \tag{7}$$

Step 7. Use the net outranking flows computed in the previous step to define a binary outranking relation, say S, as follows:

$$a \; S \; b \Leftrightarrow \phi(a) \geq \phi(b) \tag{8}$$

Stage 3: Recommendations – see section 5.

In the next section, we will use the methodology described above to analyse energy business cases.

4. EMPIRICAL RESULTS

4.1 Mono-criterion rankings

In this performance evaluation exercise, we consider 21 energy business cases assessed against nine criterial: additional investment cost, additional running cost, flexibility, CO_2 emissions, technical transferability, organizational transferability, legislative transferability, stakeholders' interest, and job and wealth creation. Table 2 reports the unidimensional rankings based on each of the criteria set out, where business cases are ranked from the best to the worst, using the relevant measures. These unidimensional rankings are useful in finding out whether a business case performs well on a particular aspect or performance criterion. For example, Malmo smart homes (10) is ranked the best according to the flexibility criterion, which suggests that the smart homes business case has the best ability to adapt to changes in energy supply and its cost compared to other energy business cases. This performance may be explained by the fact that residents can more easily postpone and/or vary energy consumption of smart appliances as compared to other industrial users where there are strict regulations or production requirements. This finding is important and providing another reasoning for policy makers to provide the appropriate incentives to encourage small commercial and residential end-users to participant, as they comprise a significant portion of total energy demand (e.g., 36% in the UK) [35]. According to the CO_2 savings, Hamburg cold storage warehouse (17) is the best option compared to other business cases. Therefore, these unidimensional rankings are useful for those decision makers who are interested in forming their decisions (e.g., investment choices) primarily based on certain criteria.

However, we find that the unidimensional rankings tend to suggest different rankings, based on different criteria; for example, although Malmo Smart Homes (10) offers the most flexibility, this business case generates quite average CO_2 savings; whereas 17 reduces the most emissions, it offers low level of flexibility as compared to others. Thus, decision makers would not be able to make an informed decision as to which business case performs best when taking all criteria into account. In addition, most of these unidimensional rankings have too many ties, which is not surprising given that many business cases have similar technical requirements and social benefits. In order to mitigate mixed performance results and reduce the number of ties, a single ranking that takes account of multiple criteria is required. This is provided via the MCDA framework (see Tables 3 to 5).

4.2 Multi-criteria rankings with preferences on financial dimensions

First, we analyse our findings from commercially motivated stakeholders (e.g., industrial partners) that privilege financial aspects over the remaining aspects in prioritizing what makes a strong business case. This resulted in the following weight vector (0.21; 0.20; 0.15; 0.07; 0.07; 0.06; 0.06; 0.06; 0.11). Table 3 provides the multi-criteria rankings produced by the integrated PROMETHEE II with this weight vector. We find that the multi-criteria rankings produced a single ranking of each business case and the rankings obtained from PROMETHEE II are different from the unidimensional ones. In fact, not only do these rankings take multiple criteria into account, but also they utilize pseudo-criteria and indifference and preference thresholds that shape the preference function. As noted above, PROMTHEE II provides the net outranking flow, which is the balance between positive and negative outranking flows, where a positive outranking flow of a business case indicates the extent to which it outranks other business cases, whereas a negative outranking flow of a business case indicates the extent to which it is outranked by other business cases. Obviously, the higher the net flow, the better the business case performs. We find that the business case on a company based in the port of Antwerp whose main activities are de-watering and recycling of sludge (1) is ranked the first, with the highest net outranking flow ϕ of 0.2452, whereas the cold storage warehouse in Hamburg harbour (18) is ranked the last with the lowest ϕ of -0.3308.

Regarding to the multi-criteria rankings, our results reveal that *contract optimisation* is one of the most effective strategies for exploring flexibility as suggested by the higher rankings of the business cases that make use of contract optimisation – appear frequently in top 7 across in Table 3. This is not surprising as contract optimisation strategy usually requires little time or investment/capital costs, and such a strategy is easily transferable from country to country, and its implementation involves little or no bureaucracy or legislative barriers.

Second, *offering reserve capacity* is another lucrative option as suggested by the rankings of business cases 15 and 16 on a chemical plant in Hamburg Harbour, and business cases 6 on chemical plant in Antwerp. Although earnings from the provision of reserve capacity can be very attractive, its implementation is not feasible for everyone because of the nature of its requirements. In order to participate in the reserve capacity market, each facility has to pass a pre-qualification procedure to verify that the facility is capable of delivering a pre-specified reserve capacity according to the rules and regulations. In addition, the benefits for entering to the reserve capacity market depend on the flexibility of their consumption, market prices of electricity and reserve service, and the frequency of required demand changes [27].

Third, *trading on wholesale energy markets* scores relatively well as suggested by its average rankings. Although the implementation of this strategy requires some technical knowledge of markets and/or agglomeration of small users, it is possible to reduce energy costs and promote off-peak energy usage without the need to invest in capital cost or to disrupt the core business. The results confirm that it is relatively easy to do so in the Dutch energy market. In fact, currently though even large industrial plants, with daily consumption of roughly more than 720 MW/day, tend to purchase only 15% of their energy from a wholesale market. Therefore, there is substantial potential to capture flexibility from wholesale trading across the industrial users in Europe, and traders need to be aware the rules and regulations across the wholesale market in different countries.

In contrast to the common perception that a *hybrid energy strategy* would do well, three cold storage warehouses located in the Port of Hamburg used a hybrid strategy (17, 18 and 19), where contract optimisation is typically combined with trading on the wholesale market, performed relatively poorly which suggest that hybrid strategies could either be expensive to implement as they involve relatively high investment and running costs, or the business cases using them lack sufficient flexibility to exploit their potential.

In sum, we find that top business cases can be identified within different industries and size, indicating that the underlying strategies can be found across a range of activities. In addition, we performed an additional analysis to find out why some business cases work well under a specific energy strategy while others work poorly – see Appendix B. We find that whether a particular energy strategy works or not would depend on different factors such as the level of investment and running costs, the specific application and the nature of the business and, more importantly, the scope for finding flexibility in the system.

4.3 Multi-criteria rankings with different weighting schema

In this section, we consider another scenario that specifically reflects the preferences of socially and environmentally motivated stakeholders (e.g., members of government bodies, and environmental groups). We obtained the following weighting scheme (0.15; 0.12; 0.08; 0.20; 0.03; 0.05; 0.07; 0.11; 0.19) corresponding to the additional investment cost, additional running cost, flexibility, CO_2 emissions, technical transferability, organizational transferability, legislative transferability, stakeholders' interest, and job and wealth creation criteria, respectively. Table 4 reports the multi-criteria rankings based on municipalities' and politicians' preferences. We have noticed some changes in rankings for the best performing business cases. For example, the Amsterdam electric boat business case (3) becomes the highest rated, its ranking improved when social and environmental criteria are assigned higher weights; Antwerp de-watering and recycling of sludge (1) dropped from being the top ranked business case to fifth place. Note that the rankings of the worst performing business cases have not changed by altering preferences.

In order to check to what extent the preference of decision makers will affect the results reported earlier, we consider a neutral scenario in which we assume that each criterion is equally important; thus, the weighting vector is simply (0.11; 0.11; 0.11; 0.11; 0.11; 0.11; 0.11; 0.11; 0.11). Table 5 provides the rankings based on an equal weighting scheme. We find that by altering the weights to an equal weighting scheme, the rankings of the best and worst performing business cases did not change much.

In sum, our multi-criteria rankings obtained from different weighting schema can be used to guide decision making. For example, socially and environmentally oriented rankings could be used by the government to guide its funding priorities and to provide the appropriate incentives for implementing its policies, whereas commercially oriented rankings could be used by businesses and users to guide their energy technology and investment choices.

5. Discussions and policy recommendations

This study used an integrated MCDA methodology, which allowed us to compare and assess a range of DSM business cases, ranging from contract optimisation, market trading and offer reserve capacity. This has generated some important insights into demand side flexibility and whether businesses and consumers can generate a return attempting to capture the flexibility inherent in many energy systems.

The results demonstrate that environmental benefits and social responsibility are essential in assessing energy business cases. Large harbours tend to perform better as compared to the small harbours, housing and electric transport. This may be explained by the fact that the energy demand for large harbours is high (with annual energy costs of millions of euros a year), and the implementation of smart energy business cases can save from 5-15% of their total energy bills. As such, making changes to business process and operations – or even investing in technology should – in theory - generate a healthy return.

Yet, despite finding viable business cases in all harbours, *e-harbours* found that there was little enthusiasm among industrial partners to scale up the pilots. One reason is that, energy costs, while high, often represent a relatively small proportion of the total operating costs of large industrial plants, so there is limited incentive to invest in technology and deviate from the core business operation in order to reduce their total operating costs. Furthermore, there have been no major blackouts/shortages or power quality issues, so there are no perceived risks to the business from interruption to supply, and thus little urgency to invest in or introduce smart energy solutions to better match supply and demand. Moreover, there is little incentive within energy markets to encourage end-users to actively seek to balance more renewable energy into the grid. Current energy markets are not able to reward the exploitation of the flexibility, partly because there is an increasing imbalance between base prices and levies on energy such as taxes, distribution and transport fees, subsidies, and other "contributions", which form an increasing part of the overall energy price. For example, in the Netherlands, there is a trend towards higher taxes on energy tariffs at the expense of variable base pricing to reduce the difference between peak and off peak energy consumption. In addition, with relatively little money to be made and no perceived threat, there is often a high level of scepticism, inertia and resistance to change among management, diminishing the chances that a harbour business will actively exploit a potential business case around energy flexibility. As such, the technology and business cases might work, but reluctance and resistance within organizations are perhaps the biggest challenge to exploiting flexibility.

Consequently, governments and policy makers need to think about designing attractive incentives (e.g., grants / public funding, tax incentives, pricing schema, regulatory levels) to drive both businesses (large and small) and individual consumers of energy (households) to change their behaviour and engage in offering or using smart energy concepts. For instance, although initial costs may be incurred prior to participating in a particular demand-side program, policymakers may find it appropriate to invest in technology rebate programmes, using ratepayer or benefits funds, to defray some of the participating customers' initial costs [36]. Note that the success of a DSM program depends heavily on customer education. Therefore, prior to deploying any DSM program, it is important to educate eligible end-users about the potential benefits of the program [37-39]. In addition, the regulations governing reserve capacity are also very stringent and a legacy of traditional, pre-renewable supply side power generation. In order to make the maximum utilisation of this DSM, it is recommended that the regulations must be relaxed to reflect contemporary modern energy mixes [40].

One notable finding was how well electric mobility performed when we value social and environmental dimensions higher – see Table 4. Using a number of electric vessels as part of smart energy systems appears to make sound business sense, and partners in Amsterdam have demonstrated that this can be done at a small scale. With the numbers of electric vehicles rising steadily across Europe, this is one potential source of flexibility that might be relatively easy to exploit. The *e-harbours* project has thus added further evidence to the potential for 'virtual power plants' to make a practical contribution to local and regional energy systems, and national and local governments could further facilitate this by supporting and subsidizing the development of private energy networks and enabling "prosumers" to exchange energy. While the basic production price of energy is relatively low across Europe, additional taxes and fees are rising sharply and now make up the larger component of the energy bill. Therefore, governments should encourage the development of "private energy networks", as they can deliver renewable energy to local communities of residential and/or industrial consumers while reducing the amount of network taxes that have to be paid for using the national grid.

6. CONCLUSION

With increasing volumes of renewable requiring to be balanced into the energy mix, policy makers and energy producers require Demand Side Management to balance energy generation and demand. Despite the study identifying viable DSM business case – which exploit the flexibility inherent in most harbour energy systems there was little appetite among large consumers to turn business case into industrial practice. The findings therefore supports previous work undertaken by [41] who characterise that present state of DSM as a chicken and egg situation, where policy maker and consumer wait for the other to take the initiative for energy management and balancing the grid. The main barriers include the relatively low energy cost savings in relation to the overall operating costs; institutional inertia and scepticism and an unwillingness to move outside core business; and a lack of perceived threat to the energy supply and energy markets that are not set up to exploit flexibility or renewable energy.

In this paper, we proposed an integrated multi-criteria decision analysis (MCDA)-based framework to compare and evaluate a diverse group of DSM businesses. As such, the work adds to the body of knowledge on the potential benefits and applicability, and the continued barriers to the wider adoption of DSM. We have also used a wide range of criteria, and different forms of data and relations (e.g., both fuzzy and crisp), to assess and compare the business cases and to reflect the multiple interests and priorities of a wide range of stakeholder. This is in contrast to conventional cost benefit analysis which typically focuses on the economic benefits at the expense of other factors like the environment, technological and legal transferability and legislative barriers.

Our main findings suggest the most attractive business cases are those which are non-disruptive, low costs contract optimisation. Strategies such as offering reserve capacity and trading on the wholesale energy market are also potentially lucrative, whereas hybrid energy strategies performed relatively poorly. There is a great deal of exploitable flexibility in large industrial harbour operations. The study also highlights the potential flexibility offered by agglomerating the storage capacity of large clusters of electric vessels or vehicles. Nevertheless, in order to capture the potentially lucrative flexibility apparent in harbour and other large scale energy systems, policy makers need to create more attractive incentives to encourage businesses and individual consumers to change their behaviour and to take advantages of the commercial opportunities around the exploitation of energy flexibility. One example identifies would involve the freeing up of stringent reserve capacity markets to allow clusters of domestic and other users to enter this market.

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Table 1: Description of criteria used in evaluating business cases

	Criteria	Definition
Financial	**Additional Investment Cost**	Additional investment required to implement an intervention over business as usual (BAU) scenario, such as technology, specialist services, advice and consultancy, construction of physical structures and buildings, capital costs associated with the design and implementation of a smart grid including infrastructure and software to support it.
	Additional Running Cost	This criterion consists of both operation and maintenance costs required over BAU. The operation cost includes additional employees' wages and additional products and services' costs for operating the energy system, whereas the maintenance cost includes the additional costs of preventive maintenance to avoid any system failures.
	Flexibility	Refers to the ability of the system to adapt to changes in energy supply and its cost. This criterion is measured by the percentage saving in the total energy bill before and after the intervention, which is computed using the energy mix and their costs for each energy business case prior to the intervention in 2010 and after the intervention in 2013.
Environ mental	**Carbon Dioxide (CO_2) Emissions savings**	Measured by the net CO_2 emissions savings prior to the intervention in 2010 and after the intervention in 2013, which is computed using the energy mix and their corresponding levels of CO_2 emissions for each business case. Note that the levels of CO_2 emissions for each business case are computed based on the average CO_2 emissions per kg per kilowatt for specific types of energies and for specific countries, provided by Covenant of Mayors for most EU countries and by DERFRA for UK.
Technical	**Technical Transferability**	Refers to the extent to which a particular business case could be technically transferred for use in a different environment. Decision makers were invited to identify the technical hurdles transferability might face (e.g., technical challenges or operating issues), and potential technical opportunities (e.g., shared technology or operating systems, potential market size, low costs). This criterion is measured qualitatively by a score on a scale of 1 to 9 provided by decision makers, where 1 corresponds to having little or no technical potential to be replicated elsewhere, and 9 corresponds to having very high technical transferability to other environments.
	Organisational Transferability	Refers to the extent to which a particular business case could be transferred in a different organization. Decision makers were invited to identify the organizational hurdles transferability might face (e.g., organizational constraints or barriers to adoption including resistance to change, complexity of change, lack of required resources), and potential organizational opportunities (e.g., familiarity with technology). This criterion is measured in a similar way to technical transferability.
	Legislative Transferability	Refers to the extent to which a particular business case could be legally transferred for use in a different environment. Decision makers were invited to identify legal hurdles transferability might face (e.g., electricity regulation of the energy market, energy trade agreements), and potential opportunities (e.g., deregulation of electricity market). This criterion is measured in a similar way to technical transferability.
Social	**Stakeholders' Interest**	An overview of the opinions related to interventions by the local stakeholders (e.g., harbour authorities, utility companies, and local authorities) regarding the energy business cases. If stakeholders are interested in and value the intervention, then it is more likely to be fully implemented and to realise its potential benefits. This criterion is measured on a qualitative 9-point ordinal scale.
	Wealth and Job Creation	Refers to the extent to which the implementation of an energy business case would generate wealth and jobs. This criterion is also measured on a qualitative 9-point ordinal scale.

Table 2: Unidimensional rankings of energy business cases by performance criterion

	Criterion	Rank from Best to Worst
Financial	**Flexibility**	10→3→13→14→2→16→1→11→19→7→12→15→8→17→18→20→5&6→4→9→21
	Additional Investment Cost	6→4→5→15→20→1→19→7→11→16→8→12→17→18→9→2&3&13&14→10→21
	Net Running Cost	6→4→5→20→15→16→9→7→1→11→21→10→8→12→17→19→2&3&13&14→18
Environmental	**CO2 Savings**	17→16→3→14→15→21→20→2→18→19→10→9→11→7→12→1→8→5→4→6→13
Technical	**Organizational Transferability**	21→7&8&11&12→9&13&14&17&18&19→1&2&3&4&5&6→19&15&16→20
	Legislative Transferability	9→4&5&6→1&7&8&11&12&15&16&17&18&19→2&3&10&21→13&14&20
	Technical Transferability	10&21→1&2&3&4&5&6&7&8&9&10&11&12&13&14&17&18&19&20→16→15
Social	**Stakeholders' Interest**	10&21→13&14&15&16→2&3&4&5&6&7&8&11&12→1&9&17&18&19&20
	Wealth and Job Creation	21→1→2&3&4&5&6&9→7&8&11&12→10&13&14→15&16→17&18&19&20

Note: [1]Antwerp_1; [2]Amsterdam_a; [3]Amsterdam_b; [4]Antwerp_2a; [5]Antwerp_2b; [6]Antwerp_2c; [7]Antwerp_3a; [8]Antwerp_3b; [9]Malmo_1; [10]Malmo_2; [11]Antwerp_4a; [12]Antwerp_4b; [13]Zanstaad_a; [14]Zanstaad_b; [15]Hamburg_1a; [16]Hamburg_1b; [17]Hamburg_3a; [18]Hamburg_3b; [19]Hamburg_3c; [20]Hamburg_2; [21]Scalloway.

Table 3: Multi-criteria Rankings with preferences on financial dimensions

Rank	Business case	Phi	Rank	Business case	Phi	Rank	Business case	Phi
1	1*	0.2452	8	4*	0.1597	15	2*	-0.0937
2	11*	0.2050	9	3**	0.0104	16	20*	-0.0938
3	15***	0.2040	10	8**	-0.0335	17	21*	-0.1128
4	16***	0.1859	11	12**	-0.0416	18	13*	-0.1575
5	7*	0.1750	12	19****	-0.0603	19	9*	-0.1584
6	6***	0.1651	13	10*	-0.0784	20	17****	-0.2602
7	5**	0.1624	14	14**	-0.0917	21	18****	-0.3308

Note: [1]Antwerp_1; [2]Amsterdam_a; [3]Amsterdam_b; [4]Antwerp_2a; [5]Antwerp_2b; [6]Antwerp_2c; [7]Antwerp_3a; [8]Antwerp_3b; [9]Malmo_1; [10]Malmo_2; [11]Antwerp_4a; [12]Antwerp_4b; [13]Zanstaad_a; [14]Zanstaad_b; [15]Hamburg_1a; [16]Hamburg_1b; [17]Hamburg_3a; [18]Hamburg_3b; [19]Hamburg_3c; [20]Hamburg_2; [21]Scalloway.

*Contract optimisation; **Trading on wholesale market; ***Offer Reserve Capacity; ****Hybrid strategy

Table 4: Multi-criteria Rankings produced with preferences on social and environmental dimensions

Rank	Business case	Phi	Rank	Business case	Phi	Rank	Business case	Phi
1	3**	0.2263	8	5**	0.0732	15	12**	-0.1041
2	16***	0.2169	9	4*	0.0713	16	13*	-0.1543
3	15***	0.1915	10	2*	0.0627	17	19****	-0.1733
4	21*	0.1808	11	14**	0.0514	18	9*	-0.1743
5	1*	0.1417	12	7*	0.0221	19	20*	-0.1871
6	11*	0.0791	13	10*	-0.0545	20	17****	-0.1935
7	6***	0.0746	14	8**	-0.1039	21	18****	-0.2467

Note: [1]Antwerp_1; [2]Amsterdam_a; [3]Amsterdam_b; [4]Antwerp_2a; [5]Antwerp_2b; [6]Antwerp_2c; [7]Antwerp_3a; [8]Antwerp_3b; [9]Malmo_1; [10]Malmo_2; [11]Antwerp_4a; [12]Antwerp_4b; [13]Zanstaad_a; [14]Zanstaad_b; [15]Hamburg_1a; [16]Hamburg_1b; [17]Hamburg_3a; [18] Hamburg_3b; [19] Hamburg_3c; [20] Hamburg_2; [21]Scalloway.

*Contract optimisation; **Trading on wholesale market; ***Offer Reserve Capacity; ****Hybrid strategy

Table 5: Multi-criteria Rankings produced by equal weighting scheme

Rank	Business case	Phi	Rank	Business case	Phi	Rank	Business case	Phi
1	11*	0.2224	8	16***	0.0814	15	2*	-0.1017
2	21*	0.1794	9	1*	0.0794	16	19****	-0.1124
3	6***	0.1505	10	8**	0.0144	17	10*	-0.1236
4	5**	0.1487	11	12**	0.0046	18	13*	-0.1643
5	4*	0.1473	12	3**	-0.0027	19	17****	-0.2211
6	15***	0.147	13	14**	-0.0513	20	18****	-0.2282
7	7*	0.1392	14	9*	-0.0568	21	20*	-0.2521

Note: [1]Antwerp_1; [2]Amsterdam_a; [3]Amsterdam_b; [4]Antwerp_2a; [5]Antwerp_2b; [6]Antwerp_2c; [7]Antwerp_3a; [8]Antwerp_3b; [9]Malmo_1; [10]Malmo_2; [11]Antwerp_4a; [12]Antwerp_4b; [13]Zanstaad_a; [14]Zanstaad_b; [15]Hamburg_1a; [16]Hamburg_1b; [17]Hamburg_3a; [18]Hamburg_3b; [19]Hamburg_3c; [20]Hamburg_2; [21]Scalloway.

*Contract optimisation; **Trading on wholesale market; ***Offer Reserve Capacity; ****Hybrid strategy

Appendix A: Description of Partners and Their Business cases*

Partners and Places for holding the business cases	The opportunity	Business case descriptions	Name & Type of Strategies	Index & Energy consumption level **
Municipality of Amsterdam, Amsterdam	Amsterdam has 250 commercial electric cruise and rental boats and 14,000 leisure. The recharging demand from these boats could be agglomerated into a number of discrete energy consuming entities or virtual power plants.	1. **Amsterdam "Local"**: A fleet of boats at the same geographical location was studied to assess the potential of for contract optimisation to encourage owners to charge boats at off peak times when there is excess local renewables available.	**Amsterdam_1:** Contract Optimisation	2 - Medium
		2. **Amsterdam "Cluster"**: A fleet of boats at many locations in the Netherlands considered as a "virtual" cluster, which is authorized to trade on the wholesale market on behalf of its pool of customers. The optimisation of the battery-charging process was based on the wholesale market strategy so that boats charge their batteries only when there is cheap electricity selling at the wholesale market as well as when there are excess local renewables available.	**Amsterdam_2:** Wholesale market	3 - Medium
Antwerp Harbour & research organization	High energy consumption among the industrial complexes at the harbour of Antwerp, and the potential for identifying operational flexibility. Industrial operations examined included de-watering and recycling of sludge facilities; chemicals and plastics production facilities; and cooling and freezing facilities.	1. **Antwerp1**: The port of Antwerp is located on the River Scheldt which connects to the North Sea. The nature of its location requires continuous dredging of the river and in the docks to provide ships with more draught access to the port. A couple of recently built facilities have the ability to store sludge for weeks and their pump installation, which is responsible for the transport of the sludge between their locations, has a significant overcapacity. The combination of large buffers and overcapacity are the ingredients for flexibility.	**Antwerp_1:** Contract Optimisation	1 - Medium
		2. **Antwerp2**: A world player in the production of chemicals and innovative plastics has one of its facilities located in the port of Antwerp. Its production process is sizable and its electrical energy consumption is considered stable and predictable. The flexibility of such a process could be achieved with no extra operational costs by controlling power consumption within a range of -6% to +4% for a significant amount of time without affecting the production process. The flexibility of this facility was assessed under three different strategies: *contract optimisation*, *trading on wholesale market*, and *offer reserve capacity*.	**Antwerp_2a:** Contract Optimisation; **Antwerp_2b:** Wholesale Market; **Antwerp_2c**: Offer Reserve Capacity;	4 - Large 5 - Large 6 - Large
		3. **Antwerp3: A** logistics company offers handling and storage services of various goods has a temperature-controlled warehouse located at the	**Antwerp_3a**: Contract	7 - Medium

		port of Antwerp, which provides flexible chamber storage at a range of temperatures ranging from deep freezing right through to ambient. The flexibility of this facility is achieved by adjusting the temperature of the cooling and freezing process between its lowest and highest allowable temperature band. The flexibility of this storage facility is assessed under two strategies: *contract optimisation*, and *trading on the wholesale market*.	Optimisation; **Antwerp_3b**: Wholesale Market;	 8 - Small
		4. **Antwerp4: Another** logistics company offers handling and storage services for various goods has a fresh division based at the port of Antwerp, which focuses on the storage and distribution of temperature-controlled perishable products. The flexibility of this facility is assessed under two different strategies: *contract optimisation*, and *trading on the wholesale market.*	**Antwerp_4a**: Contract Optimisation; **Antwerp_4b**: Wholesale Market	11 - Small 12 - Small
City of Malmo, Malmo	Opportunities presented by the regeneration of the Western and Northern harbours in the City of Malmo, Sweden Two case studies examined. Smart houses and the potential of using heat and biogas to complement electricity in meeting energy demand in the Northern Harbour.	1. **Northern Harbour**: A collaboration initiative between the City of Malmo and two large producers of electricity, heat, and biogas (EON and Sysav), to provide the Northern Harbour in Malmo with a mix of energies to meet its growing needs. The focus of the case study was to find excess heat and renewable heat for the district heating grid, and make use of renewable energies when they are cheap and available. 2. **Smart Homes**: Eight smartly-designed rental apartments in the residential area of West Harbour in Malmo. These apartments are equipped with the latest technology to improve energy efficiency and to generate and make use of renewable energies such as smart grids, solar collectors, photovoltaics and own wind mill. Smart homes residents have the flexibility to adapt energy use on a 24 hours basis. The strategy is to use renewable energies when they are cheap and available.	**Malmo_1:** Contact Optimisation **Malmo_2:** Contact Optimisation	9 - Large 10 - Small
Hamburg Applied University, Hamburg	The opportunity for identifying smart energy among a range of harbour operations such as chemical production, cold storage, and container operations.	1. **Chemical Plant Company**: This business case is concerned with operating a production plant in the Hamburg Harbour, where a broad range of semi-finished goods are produced. Heat at the facility was traditionally produced by large gas-fired boilers. In order to meet the heat demand more efficiently, they have recently installed a large gas-power combined heat and power (CHP) plant to cover a large share of the heat demand. During most of the year, the CHP plant produces more electricity than the company's consumption, which makes this industrial property a net power producer, from a grid point of view. The flexibility can be achieved by the provision of negative reserve capacity; to be more specific, the following two scenarios are considered: (a) CHP is switched off whenever there is surplus of energy in the grid and gas-	**Hamburg_1a:** Offer Reserve Capacity; **Hamburg_1b**: Offer Reserve Capacity	15 - Large 16 - Large

		fired boilers are turned on to ease up the load of the grid, and (b) when CHP is turned off, electric heaters (to be installed) are temporarily turned on to ease up the load of the grid instead of gas boilers.		
		2. **Container Terminal**: A large container terminal with a yearly cargo capacity of 2-3 million twenty-foot equivalent unit in the port of Hamburg. Refrigerated containers, also called reefers, are used in the global transport chain for storing chilled or frozen foods. Reefers are equipped with electrical on-board cooling units, which are connected to the ship's energy supply when on a ship or are plugged into the electrical grid when at the terminal. These reefers are very well insulated, as they have to maintain their temperature level for several hours, even if not connected to the grid, for example, during road transport or loading/unloading at the terminal. The flexibility of this initiative is assessed under a contract optimisation strategy; that is, cooling devices are switched off for a certain amount of time when the price is high, or cooled down on purpose at times of high availability of electricity.	**Hamburg_2:** Contract Optimisation	20 - Large
		3. **Cold Storage Warehouses:** Three cold storage warehouses located in the Port of Hamburg, which are cooled by vapor-compression refrigeration using electric compressors. Power consumption can be controlled in response to energy price and availability. The flexibility of each cold storage warehouse is assessed separately under a *hybrid strategy* of contract optimisation and trading on the wholesale market. Note that flexibility is made possible because of the good insulation of cold storage warehouses and the large mass of cargo stored; to be more specific, temperatures within a warehouse will only rise slowly if a compressor operation is interrupted.	**Hamburg_3a, 3b, & 3c**: Hybrid strategy	7 - Medium 18 - Small 19 - Medium
Municipality of Zanstaad, Netherland	The potential of electric car recharging as part of a Municipality's smart energy strategy	**ReloadIT:** A smart grid application has been developed and deployed by the Dutch company *EnergyGo*, and it takes into account the weather forecast and the travel profiling information. Flexibility can be achieved by charging electric car batteries when local renewable energies (i.e., solar, wind) are available or when the energy tariffs are low, so as to guarantee that the state of charge of each electric car is sufficient for the next planned journey. The flexibility of this initiative is assessed under a contract optimisation strategy and a trading on the wholesale market strategy, respectively, and by making use of renewable energies when they are cheap and available.	**Zanstaad _ a**: Contract Optimisation; **Zanstaad _b**: Wholesale Market	13 - Small 14 - Small
Pure Energy Centre,	The potential of exploiting energy flexibility and promoting	**Scalloway:** Scalloway Harbour is an important Scottish fishing harbour situated on the west side of the Shetland Islands. It is the third largest	**Scalloway**: Contract	21 - Medium

Scalloway	energy efficiency in small harbour operations .	harbour in the Shetlands. Its energy demand is high due to the refrigeration and fish processing plants contained within the harbour area, along with transportation, heating systems, net cleaning and shore power for marine vessels whilst in the harbour. The aim of this business case is twofold. The Pure Energy Centre has installed a multitude of advanced data loggers along with the latest weather station system to understand energy consumption and to look into a number of options to improve demand-side management, on one hand, and to increase the uptake of renewable energy in the harbour area by integrating the existing energy network with a smart grid, on the other hand.	Optimisation

* Note that, due to a non-disclosure agreement, the full name, precise data on the company and the detailed strategies implemented in the Antwerp and Hamburg business cases may not be published.

** We have classified the energy business cases into three categories depending on their energy consumption: 1) small commercial & residential users; 2) medium commercial & industrial users; 3) large commercial & industrial users.

Appendix B: Decompose the global net flow

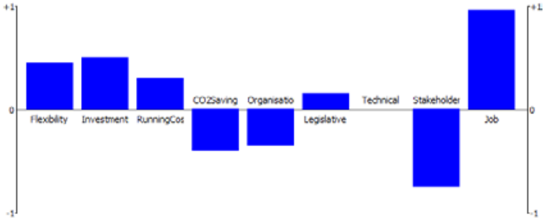
Further analysis was carried out to find out why some business cases work well under a specific energy strategy while others work poorly. In sum, we decomposed the global net flow of each business case into single criterion net flows; i.e., $\phi_j(.)$:

$$\phi_j(a) = \frac{1}{n-1} \sum_{b \in A \setminus \{a\}} \left[p_j(a,b) - p_j(b,a) \right] \qquad (9)$$

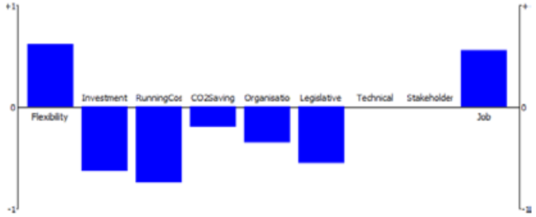
and analysed them – the set of all the single criterion net flows of a business case is referred to as its profile. Table 4 shows the profiles of the 21 business cases under consideration and allows us to find out how a business case is outranking or outranked by all other business cases on each criterion. A closer look at the signs and magnitudes of single criterion net flows for each business case suggests that there are major differences between business cases on different criteria, which uncover the reasons behind the higher and lower ranked business cases. In fact, the top ranked business cases tend to have more positive single criterion net flows than negative ones and the magnitudes of the positive single criterion net flows are higher than the magnitudes of the negative ones; to be more specific, the sum of the positive single criterion net flows is higher than the sum of the negative single criterion net flows. Note, for example, that business cases 7 and 11 all have $\phi_j(.) \geq 0$ for all criteria except the CO_2 emissions criterion, as compared to the remaining business cases, which have $\phi_j(.) < 0$ for very many criteria. In addition, the magnitudes of the positive $\phi_j(.)$ on most criteria are higher for the top ranked 7 business cases, as compared to the remaining 14 business cases.

Table B: Profiles of Individual Business cases

[1]Antwerp_1

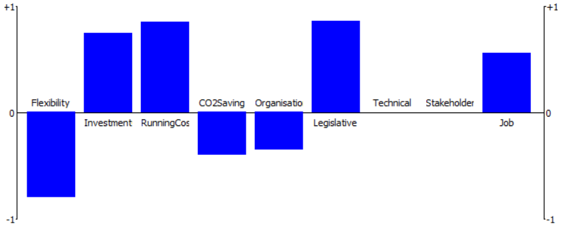


[2] Amsterdam_a

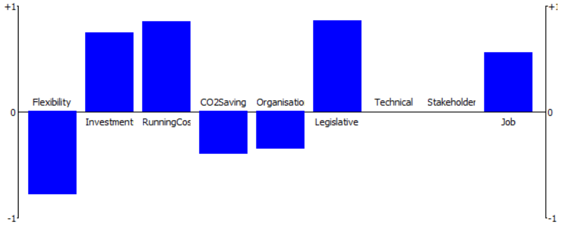


[3]Amsterdam_b

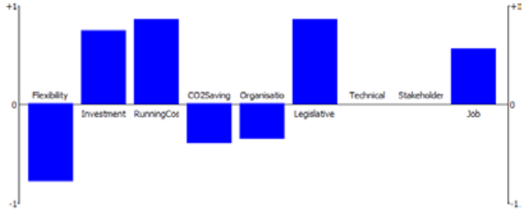
[4]Antwerp_2a



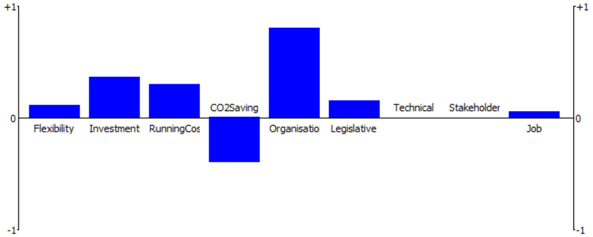
[5]Antwerp_2b



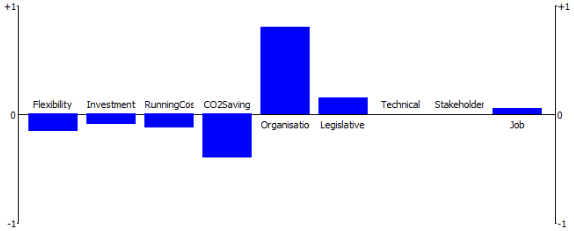
[6]Antwerp_3



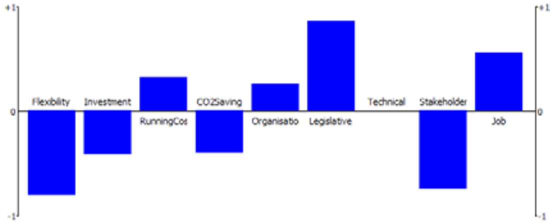
[7]Antwerp_3a



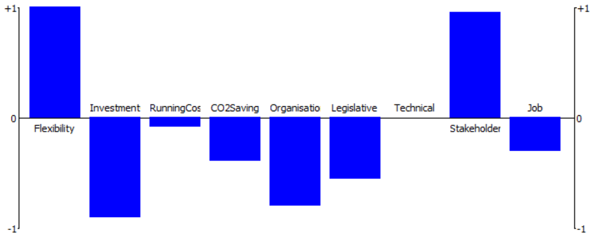
[8]Antwerp_3b



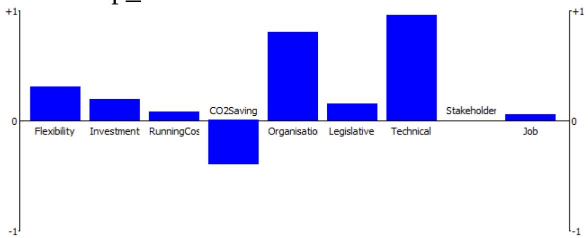
[9]Malmo_1



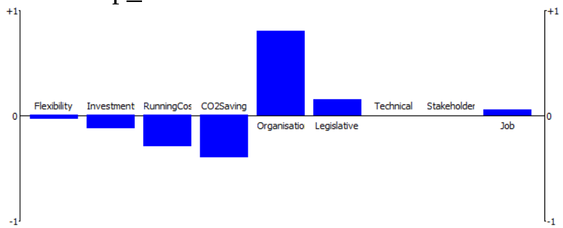
[10]Malmo_2



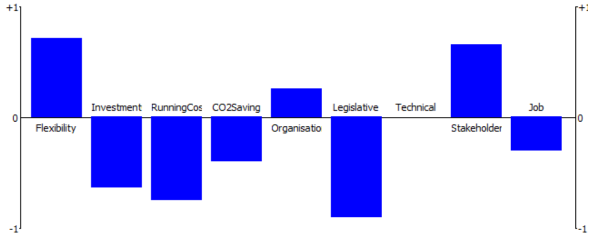
[11]Antwerp_4a



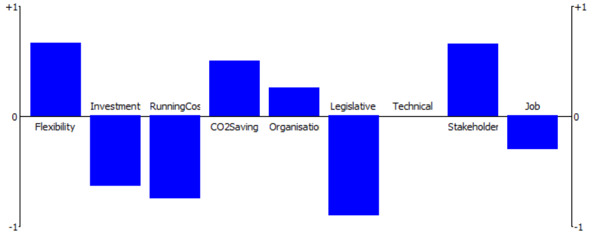
[12]Antwerp_4b



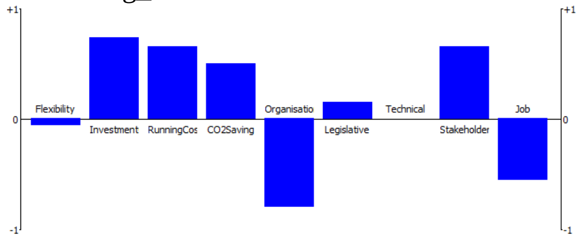
13 Zanstaad_a



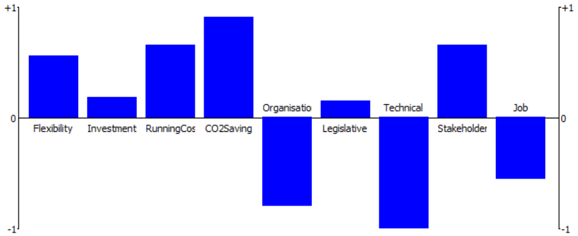
14 Zanstaad_b



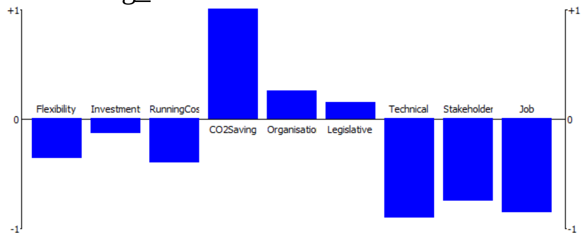
15 Hamburg_1a



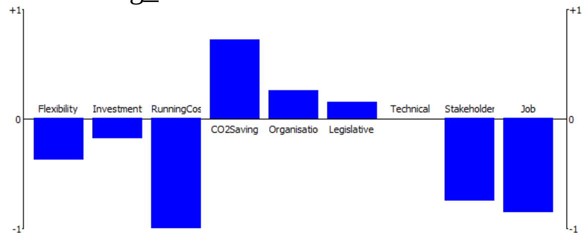
16 Hamburg_1b



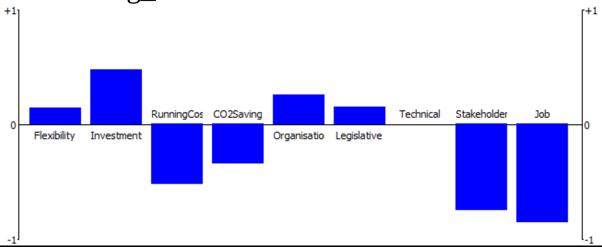
17 Hamburg_3a



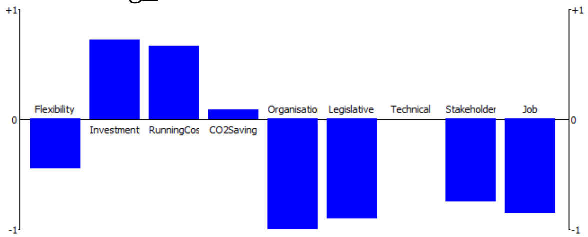
18 Hamburg_3b



19 Hamburg_3c



20 Hamburg_2



21 Scalloway