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# Assessing the Overall Life Cycle Impact of Home Energy Management Systems

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## Abstract

An ever-increasing body of research explores the effectiveness of Home Energy Management systems (HEMS) in achieving energy savings. To date, however, the overall life cycle impact of the HEMS itself has not been taken into account. Thus, no assessment has been made whether the amount of energy saved ( $e_{\text{saved}}$ ) outweighs the energy needed for production, use and disposal ( $e_{\text{invested}}$ ). To determine whether  $e_{\text{saved}} > e_{\text{invested}}$ , a lifecycle assessment was conducted comparing three HEMS in six usage scenarios. The results show that the impact is dependent on the type of HEMS, and that the benefits do not always outweigh the (environmental) costs.

## Keywords:

Home energy management system (HEMS), life cycle assessment (LCA), feedback, household energy consumption, smart meter

## 1 INTRODUCTION

Home energy management systems (HEMS) are defined as intermediary devices that can visualize, monitor and/or manage domestic gas and/or electricity consumption [1]. Their main purpose is to give users direct and accessible insight into their energy consumption. This makes them different from smart meters, which are predominantly intended for automatic two-way communication of energy data between the gas or electricity supplier and homes. Smart meters generally need HEMS to give users the intended feedback and insight. [2, 3]

HEMS are being given increasing attention both in academia and in commercial enterprises and are much advertised and promoted as 'high potentials' for domestic energy savings. Studies have indeed reported positive results up to 10% or even 20% savings, at least in the short term [4, 5], but in the mid to long-term studies it was found that HEMS are less effective [1, 6, 7].

While savings of 5 to 15% [8] in electricity or gas consumption can sound impressive, this is not a complete picture for a number of reasons. Savings are regularly not achieved on the total energy consumption of a home but rather a part of it. So, for example, savings were only achieved for the gas or electricity consumption of one appliance [5, 9], or for overall electricity consumption but not for heating or gas [1] or vice versa [6]. Currently, there is little evidence to guarantee that these same savings can be achieved for other appliances or types of energy.

A second reason why the stated savings present an incomplete picture is that studies tend to report on the resulting direct energy reductions within the home. In such studies, the achieved savings are usually calculated in the following manner: a number of households are selected, pre-trial baseline consumption measurements are made and/or control group(s) are selected, the HEMS are installed and the meters read (or the consumption data is tracked), and, after a specified period of time, the meters are read again and the HEMS uninstalled. The two (or more) readings are subtracted from each other,

possibly corrected for seasonal influences and compared to the baseline or control group measurement. This is an important assessment. However, it should not be the last or only. In the strictest sense of the word, these 'savings' are not all savings. Energy is needed to produce, use and dispose of the HEMS. HEMS need hardware to measure the consumption of appliances and/or energy types. More hardware will likely mean that more energy is needed to produce and/or run the HEMS. When this energy is subtracted, the net energy savings become apparent. This is a more accurate depiction of the effectiveness of HEMS.

A third reason is that the savings are calculated over a limited period of time. However, the period after the intervention has ended presents a number of uncertainties. Care should be taken when extrapolating the savings to the period after the intervention. There is evidence that the achieved savings decrease over time [1, 6], and that not everyone manages to save with a HEMS [1]. Additionally, there is risk that HEMS become obsolete before their technical lifespan has ended [4]. Taking these factors into consideration, a holistic approach becomes essential. Only then can it be assessed if the benefits outweigh the costs. Therefore a holistic view is advocated by taking the overall life cycle impact of the HEMS itself into account. This is currently not a standard approach. Only one study could be found where the overall life cycle impact was analyzed and reported. This was for a HEMS intended to conserve water [10].

## 2 OBJECTIVE

This paper aims to give a more complete picture of the overall effectiveness of HEMS. Consideration should be given to the overall life cycle impact of HEMS and not only to the direct energy savings that can be achieved. In other words, a trade-off needs to be made between the energy needed for production, use and disposal of the device versus the amount of energy saved within the home by using it. When the savings achieved through

HEMS are only sustained for a short period, it is hard to break even with the amount of energy invested.

Effectiveness was defined by van Dam et al.,[1] as the extent to which users can maintain significant energy savings over prolonged periods (>4 months). This definition is not sufficient for this article as the meaning of the words 'energy savings' need to be more specifically defined. A distinction needs to be made between *net*, *direct* and *indirect* energy savings. In literature implementing HEMS, 'energy savings' usually refer to *direct* energy savings on gas and/or electricity, depending on the type of energy the HEMS targets. Spillover effects to other forms of energy or savings on *indirect* energy consumption (i.e. energy embedded in the production, transportation and disposal of consumer goods such as fruit, ready-made meals, etc.) are difficult to measure and attribute to a particular intervention. As such, they are less studied, with a few exceptions [11]. Within this article, the focus is on positive *net* energy savings where  $e_{\text{saved}} > e_{\text{invested}}$ . So, within the stated definition of effectiveness, the words 'energy savings' refer to a positive outcome of the equation: *Direct* energy savings through use of the HEMS minus the energy invested in the HEMS itself.

The objectives of this case study were firstly to assess whether the environmental benefits of HEMS outweigh the environmental costs and in doing so effectively contribute to household energy savings. As this is time-dependent an additional objective is to determine after what time a breakeven point can be achieved where  $e_{\text{invested}} = e_{\text{saved}}$  and whether it is realistic that this will be achieved during the economic and technical lifespan of a HEMS. The final objective is to evaluate whether the HEMS are economically viable for households and what the payback is.

Based on previously conducted life cycle assessment studies (LCAs), and HEMS usage tests from previous studies, we had certain expectations. Because 'simple' HEMS (e.g., HEMS with few parts or with small displays rather than LCD (touch) screens) are relatively low-tech products, we thought that these would have a positive net energy balance. In contrast, as our experience from running trials with HEMS showed that the energy consumption of more complex HEMS was not optimal and that duplicate peripheral devices were sometimes implemented as part of the setup of the HEMS, we thought it highly questionable that the net energy savings would be positive in these cases.

### 3 SETUP AND METHOD

To assess the impact of the production, use and disposal of HEMS on the overall effectiveness of HEMS, three HEMS were analyzed using cumulative energy demand (CED) and eco-costs indicators. For the use phase of the HEMS, a number of scenarios were developed for the potential energy savings. The three HEMS were chosen due to their diverse nature and as a representation of the different types of HEMS available on the market. The HEMS were an energy monitor, a multifunctional HEMS and an energy manager.

#### 3.1 Description of the three HEMS

The energy monitor is a small, straightforward, dedicated device that gives real-time feedback on overall electricity consumption within the home. Figure 1 gives a schematic visualization of the setup of the energy monitor.

The energy monitor consists of a sensor, a transmitting unit, and a display. The sensor and transmitting unit are attached to the electricity meter and are battery powered by 2 AA batteries. The transmitting unit sends a radio

signal to the display, which is plugged into a socket. The display unit uses 1W and the batteries in the transmitting unit last six to twelve months depending on the frequency with which the signal is transmitted. There is an accompanying website with a step-by-step plan and advice for saving energy.

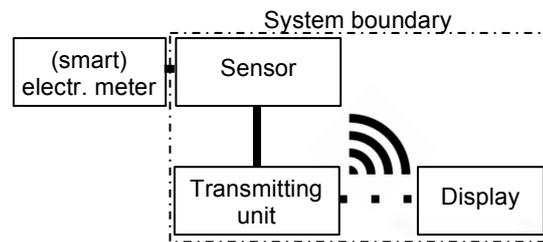


Figure 1: Schematic visualization of the setup of the energy monitor.

The second HEMS, the multifunctional HEMS, gives historical, and in certain configurations real-time, feedback on overall gas and electricity consumption. The device, a touch-screen, doubles as a programmable thermostat and can also provide up-to-date weather and traffic information. Figure 2 gives a schematic visualization of the setup of the energy monitor.

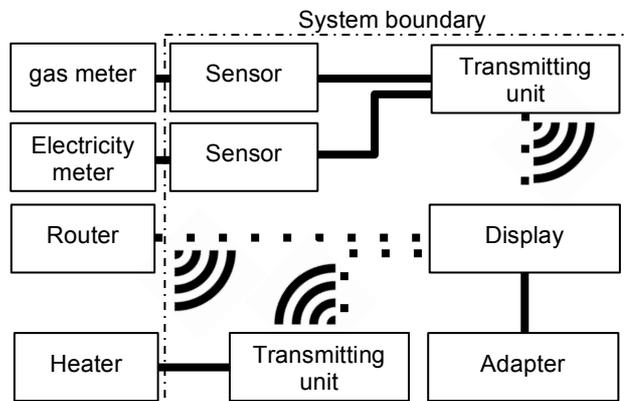


Figure 2: Schematic visualization of the setup of the multifunctional HEMS.

The system consists of an 8" touch screen, two sensors for, respectively, the gas and electricity meter, two transmitting units for, respectively, the meters and the heater (i.e. furnace for the central heating system), an adapter and, depending on the house, 0-3 repeaters (to increase the signal strength of the wireless communication between transmitting unit(s) and the display). Communication between the different parts happens by means of z-wave but a wireless router also needs to be present in the home for two-way communications outside the home. It is estimated by the manufacturer that the multifunctional HEMS uses 56 kWh per year, equivalent to using the display 14 minutes per day. An accompanying website is also present where more information on the energy bill and energy savings advice can be found.

In a later, improved version of this multifunctional HEMS, the energy consumption was optimized by changing the transformers present in most units to switching adapters, reducing the size of the 8" display to a 7" display, wiring the display to the heater and omitting the need for an additional Wi-Fi router (asides from the one assumed to be present within the home). The new configuration uses an average of 44kWh per year under normal use of the display. Switching adapters are currently becoming the norm in almost all appliances and therefore the new configuration is more comparable to the HEMS currently coming to the market. Based on what was known of the

new configuration, the eco-costs and CED of the new multifunctional HEMS were calculated and presented next to the results of the old configuration.

The third HEMS, the energy manager, gives real-time and historical feedback on the electricity consumption of individual appliances. The provided software can be used to manage if and when the connected appliances consume electricity. (Figure 3).

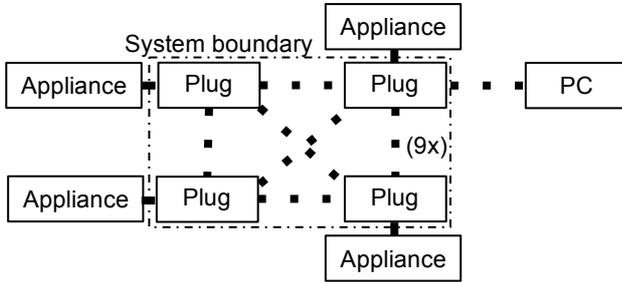


Figure 3: Schematic visualization of the setup of the energy manager.

The system consists of individual plugs in a Zigbee mesh network. The plugs of the appliances are inserted into the plugs of the energy manager, which are inserted into the wall sockets. One plug is wired to transmit the data from all plugs to a USB stick inserted in a participants' personal computer. For this study a set of nine plugs is sampled (only four are visualized in Figure 3) which use 3,6W when all connected appliances are switched off *via the software* and 9,9W when all are 'on' *according to the software*. It is estimated by the manufacturer that the nominal consumption is 43 kWh per year, equivalent to all connected appliances being switched off 19 hours a day. If the energy manager is only used to monitor consumption, it would use 87 kWh per year.

### 3.2 Description of the savings scenarios

This section presents a calculation for the net energy savings. For the energy consumption of households, the rounded off Dutch averages of 3500 kWh and 1600 m<sup>3</sup> of gas [12] were used which equals 12600 MJe plus 52,800 MJth of energy per year. An increase in electricity consumption of 1,5% per year was included. To estimate the electricity and gas prices, a number of Dutch energy comparison websites for consumers were consulted and an average distilled at 0,22 €/kWh and 0.65€/m<sup>3</sup>. Rises in the price of energy were not taken into consideration.

Based on literature, scenarios were developed for the potential savings. As the savings in literature vary for different studies [8, 13], it was decided to create six savings scenarios (Figure 4). The duration of use (i.e. the use-phase) was set to five years as it was assumed that this was within the technical life span of these HEMS. In these scenarios hypothetically 2, 4, 6, 8, or 10% savings were achieved by introducing a HEMS in comparison to the pre-intervention baseline consumption. Consecutively these savings on baseline consumption were maintained in the following five years. So no fallback or additional savings in the consecutive years was assumed. For reference, 7% savings in gas is equivalent to reducing the thermostat settings 1 °C [14]. 10% savings in electricity is equivalent to replacing four to five 60W incandescent light bulbs with CFL bulbs or reducing 62,5% or all of the standby consumption of appliances [15, pg. 395-397]. So technically the mentioned savings scenarios are attainable for households.

In actuality however, it is more likely that households will fall back to their old consumption patterns (to a certain extent) [1, 6]. Therefore a 'fallback' scenario was also developed in which for the first half year (gas and

electricity) savings of 8% were achieved, the consecutive year savings reduced to 4%, after which households fell back to their old consumption levels for half a year. For the remaining 3 years, the gas consumption remained constant at 0%, while the *electricity* use resumed to follow the national trend by increasing 1,5% per year [12].

As all three HEMS gave feedback on electricity consumption, but only the multifunctional HEMS gave feedback on gas consumption, the hypothetical savings were only calculated for the type of energy households received feedback on. This was done because there is currently little evidence to calculate a potential spillover effect to other forms of energy consumption.

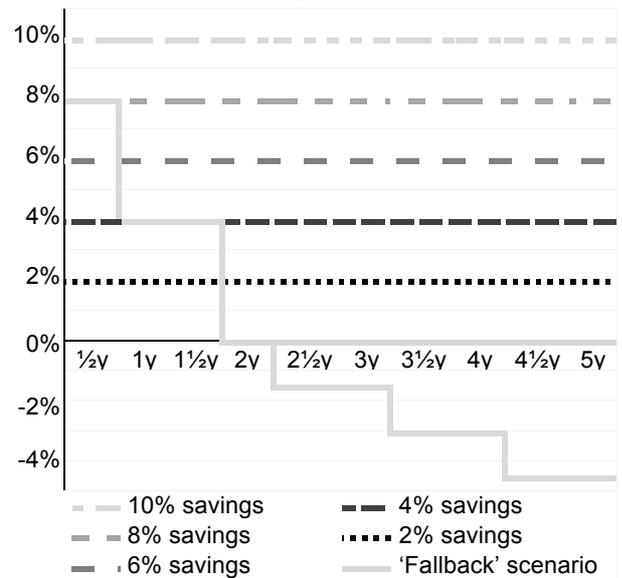


Figure 4: 6 Savings scenarios over a 5-year period in comparison to pre-intervention baseline consumption.

For the energy manager, the situation is complex as the potential savings are achieved with a set of individual plugs. Energy consumption feedback for a single appliance is a fraction of the total energy consumption of a home. Savings with a HEMS intended for one appliance would, on the basis hereof, only make a small dent in the total energy consumption of a home. However, disaggregated feedback is believed to be more effective than aggregated [16], but more hardware is needed to deliver the feedback from a number of individual appliances. Extrapolating the savings to a percentage of the total electricity consumption is difficult because this is dependent on many variables. The energy consumption of individual appliances can vary widely and the possibilities to save are dependent on the type of appliance. Additionally, the behavior related consumption for individual appliances can vary strongly. The calculation would therefore become too hypothetical. As such, the savings scenarios were left the same as with the other two HEMS and were calculated on the basis of the overall electricity consumption. However, consideration should be given to these issues when viewing the results.

### 3.3 Ecoinvent

Using the Ecoinvent database [17] the eco-costs, cumulative energy demand (CED) and economic payback time for each HEMS were calculated. These two single indicators were chosen because the CED gives an accurate depiction of the energy invested versus the energy saved, the main objective of this paper. However the drawback of this indicator is that it focuses too singularly on energy and aspects such as toxicity and disposal are not accurately depicted. Therefore the eco-

costs indicator was also chosen to assess the environmental burden.

All three HEMS were disassembled and weighed or measured. The printed wiring boards (PWB) were weighed after removal of connectors and copper transformers. The type of PWB was compared to the PWB's in Ecoinvent and the most similar PWB selected, in this case the PWB for a laptop mainboard. For the display, the standard 17" display in Ecoinvent was used and the value scaled to compensate for the smaller area of the 8" display. A number of assumptions were made. It was assumed that all parts were produced in China while assembly took place in Europe. It was assumed that all PWB's were lead free. The lifespan of the battery used in the energy monitor was set to one year.

#### 4 RESULTS

This following section presents the results from the eco-cost and CED calculations. First the eco-costs and CED of the HEMS are presented (Table 1) after which the CED will be used in the scenarios to calculate at which point in time the energy saved exceeds the energy invested.

	Energy monitor	Multif. HEMS	Multif. HEMS new	Energy manager
CED prod+disp	231MJ	1535 MJ	1176 MJ	1285 MJ
CED use phase	534 MJ	3389 MJ	2676 MJ	2639 MJ
<b>Total CED</b>	<b>765 MJ</b>	<b>4924 MJ</b>	<b>3852 MJ</b>	<b>3924 MJ</b>
Eco-costs prod+disp	€4.44	€33.91	€26.09	€24.75
Eco-costs use phase	€4.62	€29.38	€23.19	€22.87
<b>Total Eco-costs</b>	<b>€9.07</b>	<b>€63.28</b>	<b>€49.28</b>	<b>€47.62</b>

Table 1: CED and Eco-cost calculations for production, use and disposal, calculated over 5 years.

Table 1 shows that when calculating the CED over a five-year period, the use phase is more energy intensive than the production phase. The disposal phase is by far the least important. However, the eco-cost indicator gives more weight to the production and disposal phase. The results show that the overall impact is dependent on the type of HEMS. It also shows that the improvements to the multifunctional HEMS make significant impact for the use phase as well as the production and disposal phases. The CED and eco-costs are reduced by more than 22%.

Using the six scenarios from Figure 4, Table 2 shows the breakeven point for each scenario and HEMS respectively. The energy needed for production and disposal was used as negative starting point. Then for each consecutive half year, the CED of the home was calculated based on the total electricity (and gas) consumed (including the electricity needed to run the HEMS) with, dependent on the scenario, a subtraction for the energy saved through the use of the HEMS. This was then compared to the CED for 'business as usual' i.e. no HEMS was installed, no energy was saved and the electricity consumption followed the national trend. When the CED in the scenarios was less than 'business as usual', the net energy savings were considered positive and a '+' was noted. When the CED was more than 'business as usual', due to the energy needed for production, use, or disposal of the HEMS, a '-' was noted. The 'multifunctional HEMS new' is not displayed because

the results were identical, with exception for the 2% scenario where the breakeven point was a ½ year earlier.

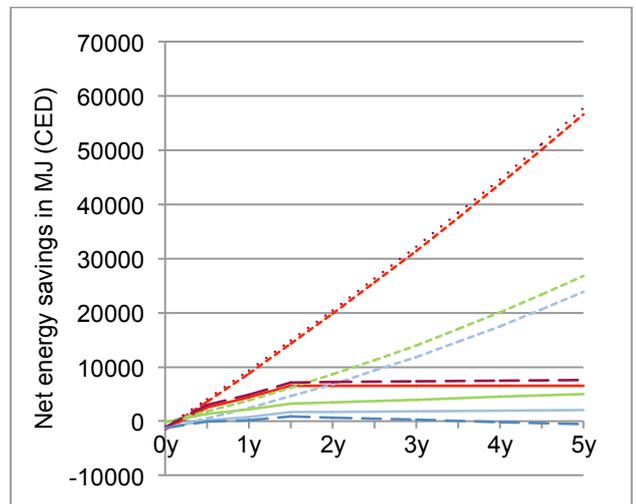
	'fallback'						'fallback'						'fallback'					
	2%	4%	6%	8%	10%	fallback'	2%	4%	6%	8%	10%	fallback'	2%	4%	6%	8%	10%	
0y	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-	
½y	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	
1y	+	+	+	+	+	+	-	-	-	-	-	-	-	-	-	-	-	
1½y	+	+	+	+	+	+	+	+	+	+	+	-	-	-	-	-	-	
2y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
2½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
3y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
3½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
4y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
4½y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
5y	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	+	
	Energy monitor						Multifunctional HEMS (old)						Energy manager					

Table 2: Breakeven point for CED of 3 HEMS calculated for 6 scenarios.

The results show that all HEMS break even within two years for all scenarios. The simplest HEMS, in this case the energy monitor, quickly reaches a break-even point even with small savings. These are positive outcomes.

Table 2, however, also shows that as soon as the HEMS is more technically complex and the duration of use is short or the achieved savings are small, the benefits do not always outweigh the environmental costs. The more elaborate HEMS (i.e. large displays, multiple plugs or adapters, take longer to attain a break-even point.

To visualize the potential amount of net energy savings that can be achieved, Figure 5 gives a graphic visualization of Table 2 with the inclusion of the old and new version of the multifunctional HEMS.



—	Fallback energy monitor
- - -	10% savings energy monitor
—	Fallback multifunctional HEMS
- - -	10% savings multifunctional HEMS
· · · · ·	Fallback multifunctional HEMS new
· · · · ·	10% savings multifunctional HEMS new
—	Fallback energy manager
- - -	10% savings energy manager
- - -	Fallback energy manager when consuming 1.1W

Figure 5: Net Energy savings in MJ for 3 (+1) HEMS for the 'fallback' and 10% scenario over 5 years.

Only two of the six scenarios are displayed for each of the three HEMS to visualize the difference: The best-case scenario with 10% savings and the fallback scenario. On paper, the Multifunctional HEMS (old and new) has the potential to achieve the greatest net energy savings in the 10% scenario due to the fact that it targets both gas and electricity. The energy monitor and energy manager only target electricity and as such their potential is less than half. In comparison, the potential net energy savings in the fallback scenario are marginal.

The flattening in the curves of the fallback scenario is caused by the electricity consumption of the HEMS's themselves and the fallback in savings. While the similarity between the curves of the old and new version of the multifunctional HEMS seem to suggest that the energy consumption of the HEMS itself is not important, the following example shows the contrary. Figure 5 displays an additional fallback line for the energy manager in which the plugs consume 1.1W continuously, i.e. 87kWh per year, rather than 43kWh. This is a real possibility in the case that households only use the HEMS to monitor the energy consumption of appliances but do not switch them off via the energy manager. Here, the line dips back under 0 after 3½ years, meaning that the energy manager does not break even any more.

The previous results have focused on the environmental costs, and this next paragraph will shortly discuss the economic costs in Table 3.

	'Fallback'	2%	4%	6%	8%	10%
Energy monitor	-€5	€81	€158	€235	€312	€389
Multif. HEMS	-€199	-€93	€88	€269	€450	€631
Multif. HEMS new	-€186	-€80	€101	€282	€463	€644
Energy manager	-€239	-€153	-€76	€1	€78	€155

Table 3: Economic profit in euros after 5 years for the 3 (+1) HEMS for the 6 scenarios.

While Table 2 showed that there were environmental benefits for all HEMS within two years at the most, the economic benefits are not positive even after five years for a number of scenarios. Notably, no HEMS are profitable in the fallback scenario, and only the energy monitor is profitable in the 2% scenario. With the energy manager it is the most difficult to achieve a positive return on investment, due to the high price tag and the fact that it only targets electricity consumption. While a negative return on investment may defeat the purpose for which households buy a HEMS, from an environmental perspective this is not necessarily a negative outcome: It can prevent a rebound effect where households invest the saved money in other energy intense products or services.

## 5 DISCUSSION

A life cycle analysis always contains a number of assumptions and as such there is always a relatively large margin of error. The comparison of the three HEMS was hindered because they are in effect three distinctly different products with, from an LCA point of view, distinctly different components. In particular the differences in printed wiring boards and displays made it more difficult to compare, and possibly increased the margin of error.

There is a reasonable risk that the HEMS will become obsolete before their technical lifespan has ended. The scenarios have the basic assumption that the HEMS are used by its owner for five years, or at least consume

energy during that period. It is however possible that at a given point in time, the owner consciously or unconsciously discontinues the use of the HEMS, and that he or she consecutively cuts the power to the HEMS or lets the battery die. If households consecutively still manage to sustain their savings without receiving any more feedback, the lines in Figure 5 would be steeper. However, there are strong indications [1, 6] that a certain amount of fallback will occur, resulting in a flattening or even negative bend of the lines.

It is not known if a spillover effect can be achieved where savings in a different type of (indirect) energy other than the one that is targeted can be achieved. There is little evidence available on spillover effects, but it is possible that this will occur. In such a scenario, a HEMS can be more profitable.

The calculations in this article are only based on the physical HEMS itself within the system boundaries as shown in Figures 1,2 and 3 on pages 2-3. However, there are two issues concerning these system boundaries that should be taken into consideration when viewing the results. First of all, the peripheral devices outside the system boundaries are essential for the functioning of the HEMS mentioned in this article and need to be present. The HEMS will not work without respectively a (smart) meter, router, or PC. These peripheral devices also have embedded energy and use electricity to function. While it can be argued that in some cases the energy would be consumed anyways, this will not hold true in all cases.

Secondly, nowadays it is commonly advocated or, in certain countries, legislated to implement a smart meter alongside a HEMS [18]. The calculations in this paper exclude the LCA of a smart meter. For the discussion on net energy savings *within* the home and simply on the basis of the technical complexity of a smart meter in comparison to a HEMS, a strong note of warning should be given as to whether implementing smart meters is environmentally beneficial. However, there is another side to this coin. There is a wider discussion taking place concerning the implementation of smart metering, and savings within the home is but one of reasons for which smart meters are being advocated. Smart meters are often regarded as part of smart grid developments. Smart grids focus on peaking shifting, e.g., through dynamic pricing schemes. This process employs smart meters together with HEMS that provide real-time pricing, which intends to give consumers the incentive to reduce electricity use during high-priced peak periods. The calculations within this paper were based on net energy savings within the home that can be achieved by means of a HEMS. In contrast, the environmental benefit of a smart grid is in the creation of more evenly distributed grid-loads. Research from 1987 implementing HEMS with pricing schemes has shown that the overall consumption is not reduced but rather shifts to periods with cheaper electricity [19], implying that smart grid systems mainly lead to different energy usage behavior (and not necessarily to energy conservation). This makes the calculations of the environmental benefits far more complex and outside the scope of this paper.

## 6 CONCLUSION

Referring back to the objectives as stated in chapter 2, all three HEMS can theoretically achieve net energy savings and a positive return on investment within their technical lifespans. However, particularly for the energy manager, substantial energy reductions need to be achieved before the HEMS becomes economically (and environmentally) viable. The chances that net savings will actually be

achieved are dependent on a number of factors into which there is currently too little insight. It is unclear how many of these HEMS will still be in use after five years. It is also unknown how the savings of households will progress in the course of five years, as this has not been documented in research up to now. Additionally savings over such a period are difficult to calculate and to trace back to a particular intervention.

The reservations that were voiced in chapter 2, concerning whether there would be a positive impact for more complex HEMS, were not confirmed. The more complex HEMS also have positive environmental results after 5 years. However, the results from the multifunctional HEMS and energy manager do still show that care should be taken that HEMS are not developed with unnecessarily elaborate parts or functionalities and that their own electricity consumption is minimized.

There are a number of conclusions that can be drawn for the individual HEMS based on the schematic visualization of the 3 HEMS in Figures and Tables 1,2 and 3 and the results in Figures 4 and 5.

The energy monitor is technically the simplest HEMS and dependent on the least amount of peripheral devices. Figure 5 shows the potential net energy savings that can be achieved are relatively high. However, the potential to use persuasive technology [20] or other behavior change strategies [21] are limited due to the type the display. Therefore, while the small display is positive for the CED, it could limit the actual potential to achieve net energy savings through behavior change.

The results in Table 1 for the new version of the multifunctional HEMS show that reducing the amount and size of parts and the HEMS' energy consumption has effects on the CED and eco-costs. However more is needed to prevent the line from flattening in the fallback scenario. This HEMS has the most potential on paper for net energy savings due to the inclusion of gas consumption. Heating is the main source of CO<sub>2</sub> emissions in homes in the northern hemisphere, yet few HEMS bring this across. It is however unknown if the multifunctional HEMS also has the most potential to effectuate behavior change and thereby create actual savings. This is likely dependent on the visualization of the feedback on the display.

A number of different paths could be taken to increase positive net energy savings of the Energy manager. It is a modular system and can be extended at will. Therefore one option could be to only implement plugs on 'high potential' appliances; those with high energy consumption and large feasible savings such as the pump for underfloor heating and close-in boilers. Another option would be to use a different marketing model, e.g. by leasing or renting them to households for a short period after which this can be repeated with a next household. This option can harness the effectiveness of disaggregated feedback [16] without the drawback of the extended energy consumption during the use phase. A third option would be to combine a very modest number of plugs from the energy manager with an energy monitor. This can be used for the incidental testing of the consumption of different devices and consecutively for the permanent management of the 'high potential' appliances while keeping tabs on the overall consumption.

Finally, In light of the uncertain long-term effects of HEMS it can be argued that these devices should not be developed as stand-alone, dedicated products, but should be integrated in existing products instead. Care should however be taken that the simplicity and accessibility [22] of the feedback is maintained. This is an important, yet

controversial issue. Integrating a HEMS in an app, TV page, or thermostat can arguably contribute to the HEMS functionalities being snowed under or forgotten amongst the rest of the functionalities or apps. In conclusion, it is important to weigh the different issues and find a balance that does justice to the odds that are at stake.

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