Environmental Efficiency Analysis of Swiss Acute Care Hospitals

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22. November 2021

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Abstract

Using a novel set of Global Warming Potential (GWP) data for hospitals in Switzerland. We estimate the environmental efficiency by stochastic frontier analysis and data envelopment analysis for the hospitals overall and 14 specific hospital areas. We find median efficiency of hospitals of at most 53.4 percent. The improvement potential for the Swiss acute care hospitals is estimated to be 136'669 t CO_2-eq based on a GWP weighted mean environmental efficiency of 69.3 over all hospitals. The areas with the highest potential are heating and electricity: a one percent increase in efficiency would reduce overall GWP by 0.60 and 0.58 percent, respectively.

Keywords

environmental impact, hospitals, efficiency analysis, eco efficiency, stochastic frontier analysis, data envelopment analysis, global warming potential, Swiss health care, Swiss hospitals

1. Introduction

Reducing the environmental impact of economic activities belongs to 17 United Nations Sustainable Development Goals (SDG). This can be achieved in a cost-efficient way by improving environmental efficiency – minimizing the use of environmental resources in a production process (Kuosmanen and Kortelainen, 2005). By looking at the environmental efficiency of firms or sectors the potential for improvement to environmental impact can be identified. With an average 5.5 percent proportion of the national carbon footprint in 2014 and on average 9 percent of GDP in OECD countries in 2016 (Pichler et al., 2019) the health care sector is both environmentally and economically relevant. Within the sector, hospitals are the main contributor to health care expenditure with a proportion of 33 percent in the U.S. in 2019 or 39 percent on average in the OECD (OECD, 2020).

Several studies have estimated the environmental impact of hospital services in terms of Global Warming Potential (GWP). A study for all OECD countries using expenditure categories by Pichler et al. (2019) finds that 29 percent of GWP of health services stems from hospitals. Studies for the U.S. (Eckelman & Sherman, 2016 and Chung & Meltzer, 2009) estimate the proportion of hospital care on total GWP of health services to be 36 percent and 39 percent, respectively. A study by the National Health Service (NHS) England used a combination of NHS data and standard conversion factors for carbon equivalent emissions together with environmentally extended input-output tables (EEIOT) to estimate a 6 percent proportion of hospital care of the national footprint in 2017 (SDU, 2018). For Switzerland a study used EEIOT to estimate a GWP of 8,290,000 tonnes CO_2-equivalent (t CO_2-eq) for the health care and social services sector. Pichler et al.'s (2019) estimate for Swiss hospitals suggests that 29 percent of GWP of health services stems from hospitals.

The environmental impact assessment in the above studies all use a top-down approach to assess the carbon footprint of hospitals or the health care sector. To our knowledge, the first study to apply a bottom-up approach to estimate the environmental impact for a sample of hospitals is Keller et al. (2021). They conducted comprehensive life cycle analysis (LCA) of 12 hospital areas for 33 Swiss acute care hospitals[1] in broad range of environmental impact

[1] An acute care hospital is a general hospital with an inpatient facility for acute somatic examination, treatment, and care of patients. In Switzerland the delimitation is based on the hospital typology of the SFSO (BFS, 2006). Acute care hospitals include all basic and tertiary care providers, specialty clinics for surgery, gynecology/neonatology, and pediatrics.

categories. They find that the drivers of environmental impact vary considerably among hospitals, indicating at a potential for environmental efficiency improvements.

The study of environmental efficiency has grown into a popular field of research in the past decades (Sueyoshi 2016). Different approaches have been developed to incorporate environmental detrimental effects or undesirable output into production efficiency study. One mode of distinction between the approaches is whether (1) the complete production of desirable and bad outputs is be modelled and evaluated or (2) if the model is limited to explaining the relation between the environmental outcomes with respect to the economic outcome (Lauwers, 2009). The first group of approaches propose solutions to the incorporation of decreasing undesirable output into standard production efficiency models that require output to increase. Dakpo et al., (2016) give an extensive overview of the different solutions applied and the methodical issues. The second approach "frontier eco efficiency" extends the concept of traditional eco-efficiency[2] by incorporating a parametric or non-parametric frontier analysis framework. The approach gives emphasis to the trade-off between economic and environmental aspects. As both economic outcome and environmental impact are functions of the physical inputs such as labor and capital, they are implicitly included (Kuosmanen and Kortelainen, 2005). Korhonen & Luptacik (2004) apply this method to estimate the environmental efficiency of powerplants with respect to local air pollutants. Kuosmanen & Kortelainen (2005) estimate environmental efficiency of air pollutants on local road transportation.

This paper contributes to existing literature by providing the first estimate of the environmental impact of the hospital sector based on bottom up LCA results. Building on these results the paper delivers the first estimates of the environmental efficiency of hospitals. This is achieved using the frontier eco efficiency approach, where hospital services are the output, and the environmental impact of the hospital is the input. The hospital services are measured using standardized hospital revenue. This allows us to incorporate all services (inpatient, outpatient and other) into a single measure that accounts for difference in service production efficiency. Input data is the environmental impact of hospitals measured in GWP and calculated by Keller et al. (2021) for a sample of 33 acute care hospitals. These data are used to calibrate a series of linear models that predict the environmental impact of acute care hospitals in 14 different areas.[3] Using administrative data from the Swiss hospital statistics, the GWP for 127 acute care hospitals is

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2 The concept was first publicized in Schmidheiny (1992) in cooperation with the World Business Council for Sustainable Development.
3 Keller et al. (2021) summarized a number of hospital areas with a small impact and therefore display the results for 12 instead of the 14 hospital areas available in their raw data and LCA calculations.

calculated. As these hospitals represent more than 99 percent of the acute care hospital revenues in Switzerland, the total GWP of the sector can be estimated. In 2018, it ran in at 444,861 t CO_2-eq.

Two different frontier analysis methods are used to estimate the environmental efficiency. For the reduced sample of 33 hospitals where Keller et al. (2021) calculated GWP and, therefore, the data quality is deemed to be good, data envelopment analysis (DEA) is used to estimate both the overall and 14 hospital area specific efficiencies (e.g. efficiency of heating or pharmaceuticals). For the full sample of 127 hospitals the stochastic frontier analysis (SFA) is applied as it can account for the estimation error present in the GWP data.

We find that the median efficiency of the hospitals in the full sample is 53.4 percent environmentally efficient. With a standard deviation of 23.7 percent, the variation in efficiency among hospitals is considerable. Combining the result for input-weighted mean efficiency with total GWP for the hospitals, we estimate an improvement potential of 136,669 t CO_2-eq for the sector. Applying DEA to the reduced sample of 33 hospitals we can identify the improvement potential in different hospitals areas. Heating and electricity exhibit the greatest potential in terms of the effect of efficiency improvement on total GWP of the 33 hospitals.

The paper is structured as follows: Section 2 contains all information on the data and method used. It explains how hospital revenue is standardized to get a single and comparable measure on hospital output; presents the environmental impact data used as input in the efficiency analysis; and also presents the two frontier estimation methods. Section 3 shows the results of the efficiency analysis. In section 4, we offer concluding remarks.

2. Data and Methods

Estimating efficiency requires data on inputs and outputs to be considered in the analysis. Our eco-efficiency approach to the estimation of the environmental efficiency is a single input and single output model (see section 2.3). We measure output of hospitals by their revenue corrected for differences in tariffs (see section 2.1). The input is environmental impact measured by the GWP (see section 2.2).

2.1. Data on hospital output

Hospitals provide a broad range of services beyond health care services in the narrow sense. Among them are initial- and continuing education, research, public health related services and other non-health related services. Previous efficiency studies of Swiss hospitals have either focused on inpatient services alone or included outpatient services additionally (see SDU, 2018, Rosko, 2001, Farsi & Filippini, 2008, Meyer, 2015). However, to assess the environmental efficiency and impact of hospitals, we need to consider these additional services as well.

One approach is based on implicit costs, but implicit cost as a proxy for output ignore the differences in efficiency between the hospitals. The cost would need to be adjusted for difference in factor prices between Swiss hospitals to allow a comparison. Calculating these factor price adjusted costs for every hospital service performed requires a lot of data on the cost structure that is not available. The other approach uses hospital revenue to measure total hospital output. Revenue here is defined as all forms of proceeds as well as direct contribution from municipalities, cantons, the federal government and corporations, trusts, and private individuals[4]. As all services hospitals provide entail an implicit cost that must be covered by some form of revenue, it implicitly is a suitable and feasible measure of output.

The main drawback of using hospital revenue as an output measure is that it includes inefficiencies and differences in operating costs: Tariff systems that determine the reimbursement of inpatient and outpatient health services consider the different operating cost at hospital and cantonal level, making it difficult to remove inefficiencies from operating cost. Also, the tariffs partly reflect the parties bargaining power. This adds additional noise to the data and complicates a comparison. To counter this, the revenues are standardized using the mean tariffs for Switzerland in 2018.

2.1.1. Tariffs in Swiss health care system

The Swiss health care system has four main tariff systems that determine proceeds for inpatient and outpatient care by health care providers.

1. Inpatient care is compensated on a case base. They depend on the cost weight of a specific diagnosis related group (DRG) and the base rate in a specific hospital, which is the price of treatment for a case with a cost weight of 1.

2. Outpatient care is compensated according to the number of tax points (TP also known as fee-for-service) assigned to a specific medical or technical service and the tax point value (TPV) applied i.e., the price charged per tax point. Tax points for these services are defined in the TARMED tariff system. Clinicians such as physiotherapists, occupational therapists and speech-language pathologists are also reimbursed for their outpatient services based on separate systems of tax points and tax point values.

[4] More precisely revenue includes all sums from positions 60-62 and 65-69 of the financial accounting system REKOLE®, the accounting system used by Swiss hospitals.

3. Inpatient rehabilitation is compensated based on daily rates.

4. Long-term care is reimbursed based on daily rates that depend on the level of care required by the patient.

The rates in the different tariff systems are the result or negotiations between service providers (hospitals, doctors, clinicians) and insurers.[5] The negotiated tariffs take into account the different operating costs of service providers, i.e. differences in capital and labor costs. For inpatient care, the negotiated base rate considers systematic differences in patient composition and hospital structure that are not adequately considered by the cost weight, e.g. the number of resident physicians or the operation of a recognized emergency room. Due to difficulties in calculating operating costs of hospitals, inefficiencies are also implicitly compensated by the negotiated base rate. The tax point values are the result of negotiations between services providers and insurers and cantonal approval as well. Laboratory services indeed are fixed at national level.

Our main source for tariff data is the «Einkaufsgemeinschaft HSK AG» (HSK), one of two large buying syndicates of Swiss health insurers that negotiate inpatient base rate for acute care and TPV for outpatient care (TPV_{out}) with the hospitals on behalf of the insurers.[6] This data lists the base rate and the date of validity for every service provider for the years 2012-2018. In the cases where tariffs change during a calendar year, we calculate the base rate for 2018 as a weighted average. TPV data for 2018 is available by canton and is matched to the service providers based on their location. The HSK data also includes the rehabilitation daily rates (DR_{rehab}) for hospitals with inpatient rehabilitation (19 of 156 acute care hospitals) and the base rate for inpatient psychiatric care (base $rate_{psych}$). The tariff for outpatient physiotherapy (TPV_{Physio}) is available from Physioswiss the Swiss Physiotherapy Association.[7] For long-term patients, only the daily rates depending on the levels of care can be obtained, but there is no information on the mean care level per service provider. Overall, tariff data is available for 144 of the 156 acute care hospitals in 2018.

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5 In cases where the two parties do not reach an agreement the government can impose a tariff rate.
6 Besides the two buying syndicates in some cases insurances negotiate directly with the hospitals.
7 The tariffs for other clinicians are not required as they are not differentiated in the revenue data. No adjustment is necessary for tariffs that are fixed on the national level.

Table 1. Summary statistics tariffs in CHF

Tariff	Mean	Min	Max	SD
Inpatient care (base rate$_{acute}$)	9,549.97	8,480.00	11,200.00	439.23
Outpatient care (TPV$_{out}$)	0.88	0.80	0.96	0.04
Inpatient rehabilitation (DRrehab)	733.44	520.00	1,575.00	199.75
Inpatient psychiatric care (base rate$_{psych}$)	723.22	630.00	915.00	92.47
Physiotherapy (TPV$_{physio}$)	1.02	0.94	1.11	0.06

Notes: N = 144 acute care hospitals with tariff data available.

Table 1 shows that tariffs exhibit considerable variation. While outpatient care and physiotherapy can only vary across cantons and daily rates for rehabilitation and base rate for psychiatric care only apply to a small number of hospitals in our sample, the base rate for inpatient care is relevant for all hospitals. It shows great variation across cantons and by hospital type (see Appendix Figure A.1). This underlines the argument that hospital proceeds should be adjusted for differences in tariffs to allow for a comparison in efficiencies.

2.1.2. Revenue in Swiss hospitals

The annual Swiss Federal Statistical Office (SFSO) hospital statistics collects accounting data for all Swiss hospitals and is the prime source of data on the proceeds in Swiss hospitals. The statistic categorizes revenue into account groups that reflect different sources of income. Proceeds from health services can further be differentiated by the three care types (outpatient, inpatient and long-term). The account groups include both direct proceeds from health services as well as financial income (rental income, capital interest income, other financial income), income from side operations (revenue from personnel and third-party services) and contributions and subsidies. The data is available for the four hospital activity types (acute care, psychiatry, rehabilitation/geriatrics, and gynecology/neonatology[8]). By summing the totals per revenue account group across the activity types we get the total revenue of each hospital in the data.

Total revenue for the 156 acute care hospitals in 2018 sums to CHF 25.21 billion across 13 accounting groups. This represents 83.2 percent of the Swiss hospital market. However, three acute care hospitals report revenue of together below CHF 1’000. This is very implausible; we consider it a data error and exclude these hospitals. Together with the

[8] This includes maternity houses as specialized clinics for childbirth.

availability of tariff data for the hospitals this reduces the sample to 141 hospitals. For the remaining 141 acute care hospitals in 2018 the most important revenue source is inpatient care which accounts for 63.7 percent of revenues. This is followed by outpatient care (25.4 percent) and revenue that cannot be attributed to a care type (10.3 percent). Long-term care is not relevant for the acute care hospital sector.[9] When looking at the source of income from the account group perspective, the groups with a revenue percentage higher than 5 percent represent nearly 96 percent of revenue and are the following:

- Revenue from medical, nursing, and therapeutic services for patients (60.42 percent)
- Other individual hospital services (20.62 percent)
- Individual medical services (8.12 percent)
- Contributions from Cantons (6.51 percent)

The first three accounting groups together comprise the revenue from health services and generate 89.1 percent of hospital revenues. As these revenues are determined by the tariff systems and therefore includes inefficiencies and other differences in operating costs, they need to be adjusted for these differences in tariffs. Revenue for other services provided by hospital is not subject to a tariff system. The services provided are either directly reimbursed by the users (e.g. parking, cafeteria, continuing education) or financed through contributions and subsidies (e.g. research, public health related services).

2.1.3. Standardized hospital revenue

The standardization of health care revenue is done by replacing the hospital or cantonal specific tariff with the national mean tariff. Depending on the accounting group, care type and activity type revenues are a function of different tariffs. Both “Revenue from medical, nursing and therapeutic services for patients” and “Individual medical services” are defined by TPV_{out} for outpatient care for all activity types but for inpatient care the relevant tariff varies by activity. For acute care and gynaecology/neonatology is the base $rate_{acute}$, the base $rate_{psychic}$ for psychiatry care. In rehabilitation/geriatrics the daily rates for rehabilitation are relevant. While in long term care reimbursement is based on daily rates that depend on the care (requirement) level of the patient. “Other individual hospital services” are

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[9] Appendix Table A.1. Amount & Proportions of Hospital revenue by accounting Group and Care Type in 2018. NotesAppendix Table A.1 in the shows the revenue proportions for all accounting groups and care types in 2018 for the 141 acute care hospitals.

functions of different TPV i.e. TPV_{out} for “thereof TARMED (TL)”, TPV_{physio} for “thereof physiotherapy” and the TPV for laboratory analysis (“thereof laboratory”). For the residual in this accounting group, it is unclear which tariff applies.[10]

Using the national means of the tariffs in the different accounting groups, care types and activity types we can standardize the revenues of the hospitals. The standardized revenue y_i for hospital i is given by

$$y_i = \sum_g \frac{revenue_{g,i}}{tariff_{g,i}} * mean\ tariff_g$$

where

$revenue_{g,i}$	is revenue of accounting group g for hospital i;
$tariff_{g,i}$	is the tariff that applies to accounting group g for hospital i. Where no tariff applies, it is set to one;
$mean\ tariff_g$	is the national arithmetic mean tariff of the tariff for accounting group g in hospital i.

Applying the above method allows us to standardize 99.8 percent of revenue hospital revenue from health services. Table 2 shows the proportions of revenue in an activity-care type combination that can be standardized. Inpatient care can be nearly completely standardized across all activity types. For outpatient care between 66.5 and 84.0 percent can be standardized. The large remainder stems mainly from residual in the accounting group “Other individual hospital services” where it is not clear if and what tariffs apply. In long term care only below 1 percent of revenues can be standardized. This is due to the lack of data on the average care requirement level at per hospital. As only 0.6 percent of revenue stems from long term care this inaccuracy is acceptable.

Table 2. Proportion of Revenue Standardized with Mean Tariffs

Activity Type	Outpatient	Inpatient	Long Term	Percentage of Total Revenue
Acute care	66.5%	98.0%	0.9%	85.1%
Gynecology / neonatology	72.4%	99.3%	-	0.1%
Psychiatry	84.0%	99.7%	-	1.8%
Rehabilitation / geriatrics	69.4%	99.1%	0.1%	2.7%
Percentage of Total Revenue	25.4%	63.7%	0.6%	-

Notes: N = 141; “Percentage of Total Revenue” shows the proportion of total revenue by care type or activity type.

[10] An overview of the mapping of tariffs and accounting groups by care type is given in **Fehler! Verweisquelle konnte nicht gefunden werden.** in the Appendix

Table 3 shows the summary statistics for standardized return by care type and overall. The median hospital has an outpatient revenue of CHF 18.13 million and an inpatient revenue that is three times as large at CHF 55.23 million. Long term is not present in the median acute care hospital and therefore there is no revenue attributed to it. The hospital with the largest revenue had proceeds of CHF 1,837.2 million in 2018.

Table 3. Summary statistics of standardized revenue of Swiss acute care hospitals (in mil. CHF) by care type in 2018.

Care type	Mean	Median	Min	Max	SD
Outpatient	44.82	18.13	-	383.23	76.42
Inpatient	108.83	55.23	0.05	802.50	157.98
Long term	1.04	-	-	31.07	4.19
Overall	171.34	74.59	0.05	1,837.20	291.69

Notes: N = 141.

2.2. Data on environmental impact

Environmental impact defines the effect of economic output on the environment. Its quantification is the first and indispensable step towards estimating the environmental efficiency of the Swiss hospitals. In our estimation of environmental efficiency hospitals, we consider it to be the sole input into the production of hospital services (see section 2.3).

2.2.1. National survey of acute care hospitals

The data to calculate the environmental impact is collected in a national survey of Swiss acute care hospitals. This survey was jointly developed by Keller et al. (2021) and this papers authors. All 156 Swiss acute care hospitals are contacted.

The questionnaire asks key data for 14 hospital areas: electricity, heating, catering, building infrastructure, laundry, water use, waste and wastewater, textiles, medical products, housekeeping products, paper use and printing, pharmaceuticals, electronic equipment, and large medical equipment. Keller et al. (2021) identified these environmentally relevant areas based on a screening LCA[11]. A detailed live cycle assessment was conducted in two partner hospitals – one a small hospital and one large university hospital – and served as a basis to select key variables

[11] A screening LCA is a "quick and simple analysis, evaluating the order of magnitude of each life cycle stage contribution" (Jolliet et al., 2016). Since an LCA is by nature an iterative process (ISO 2006), a less detailed first assessment to identify the environmentally relevant hospital areas can be conducted in the beginning.

available at the hospitals best suited to evaluate the environmental impact of each area. This environmental key data along with administrative data was then collected in the survey, split into four parts – (1) general key data, (2) infrastructure and resources, (3) food and consumables, and (4) electronic equipment. To keep barriers to response as low as possible, each part could be filled out independently, e.g. by different internal departments. The survey was sent out in June 2019 and collected data from 2018. As an incentive and thanks, the participating hospitals get a small report on their relative positioning regarding indicators on resource consumption, as well as their individual ecological footprint based on the LCA conducted by Keller et al. (2021) for all respondents (see below).

In total, 33 acute care hospitals completed the survey. At 54.5 percent the rate of return amongst tertiary medical care hospitals is significantly higher than for basic medical care hospitals at 10.3 percent. Among specialties hospitals only 5.5 percent responded to the survey. In total, the survey participants represent more than 60 percent of the Swiss hospital sector (62.8% measured by Full Time Equivalent (FTE) and 60.2% by the sectors' revenue).

2.2.2. Global Warming Potential

Life cycle assessment (LCA) has become the method of choice to quantify environmental impacts. It considers the full life cycle of a product or service, including all emissions and all resource use directly or indirectly caused by them. Using the data collected in the survey Keller et al. (2021) conduct bottom up LCA for each of the 33 survey participants. Environmental impact is calculated for individual environmental impact categories, called midpoint methods. One midpoint category widely used is the Global Warming Potential (GWP). GWP is the potential climatic effect of each greenhouse gas in the atmosphere. We use the method that evaluates the heat absorbed in the atmosphere for 100 years (IPCC, 2013), calculated as a multiple of the heat that would be absorbed by the same mass of carbon dioxide (CO2). The results are thus expressed in tonnes CO_2-equivalents. Keller et al. (2021) find the results eating, catering, and infrastructure turn out to be the most relevant areas for the average hospitals' climate impact. These three areas represent 57.2 percent of total environmental impact.

To increase the sample size beyond the 33 acute care hospitals with GWP calculated by Keller et al. (2021) and to get an idea of the total GWP by the Swiss hospital sector, we model relationship between environmental impact and the SFOS administrative hospital data available for all 156 acute care hospitals. The environmental impact in each of the 14 different areas is modelled separately. For five areas (housekeeping products, textiles, pharmaceuticals, large medical equipment, office supplies) GWP is modelled analogously to Keller et al. (2021) based on the mean environmental impact[12]. For all the others, we estimate a linear model without an intercept[13] by ordinary least squares (OLS). The models are of the following form:

$$y_k = \beta_1 x_{1,k} + \beta_2 x_{2,k} + \cdots + \varepsilon$$

where

- y_k is the environmental impact of each area k, except for electricity, where its consumption is modeled and subsequently multiplied by the environmental impact of the average local energy mix provided by the local electricity provider at the hospital's location;
- $x_{j,k}$ are the predictors j: either variables on the cost structure (input costs from financial accounting statistics) or variables that drive the underlying production function (staff numbers, inpatient days).

Table 4 shows the results for 9 linear models estimated. The models deliver very good fits. Except for heating, where the environmental impact heavily depends on the type of energy source and no additional information on the energy mix can be derived from secondary sources. However, it is important to remember that a good fit does not mean that the individual estimations for non-participant hospitals are reliable. Results are robust on average.

Using the coefficients estimates from the 9 models above we predict GWP per area for 94 hospitals that did not participate in the survey. The remaining acute care hospitals cannot be estimated due to incomplete or implausible secondary statistics. Combined with the calculated GWP for the remaining five areas the overall GWP per hospital is attained. Looking at the distribution of GWP per standardized revenue for the survey participants and non-participants, we see that they exhibit very similar statistical spread except for three outliers (see Figure 1).

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[12] GWP for housekeeping products and textiles is calculated using GWP per CHF of household expenditures; pharmaceuticals using GWP per CHF of spending on pharmaceuticals; Large medical equipment using GWP per large medical devices installed; paper use and print using GWP per FTE staff employed.

[13] The intercept is excluded as environmental impact without any resource consumption should not be assigned to hospital services.

Table 4. Results of CO2 Prediction Models

Predictors	Catering	Heating	Water	Waste and wastewater	Laundry	Building infrastructure	Medical products	Electr. equipment	Electricity
Food expenditure	0.00***								
	0.00								
Total Staff incl. affliated medical professionals (FTE))	0.15			0.12**	0.07***		0.07***		3743.3***
	(0.09)			(0.04)	(0.01)		(0.01)		(733.94)
Energy and water expenditure		0.00***	0.00***	0.00					0.77
		0.00	0.00	0.00					(0.46)
Total inpatient days			0.00						
			0.00						
Household expenditures					0.00				
					0.00				
Maintenance and repair expenditures						0.00			
						0.00			
Total Staff (FTE)						0.38***		0.10***	
						(0.07)		(0.01)	
Medical supply expenditures							0.00*		
							0.00		
Administrative and IT expenditures								0.00*	
								0.00	
Observations (N)	33	31	31	32	33	33	33	33	32
R^2 adjusted	0.952	0.545	0.94	0.937	0.952	0.939	0.956	0.98	0.979

Notes: * $p<0.05$ ** $p<0.01$ *** $p<0.001$

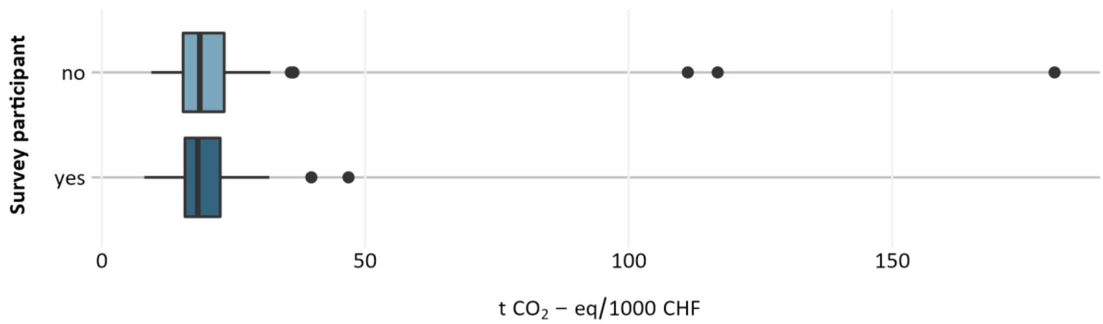

Figure 1. Environmental Impact Swiss Acute Care Hospitals. Notes: Boxplot where upper and lower hinges are first and third quartile, bar indicate the median and whiskers indicate the 1.5 times the interquartile range.

2.3. Method

The environmental efficiency of the Swiss acute care hospitals is estimated with a frontier eco efficiency approach as described by Lauwers (2009). Therefore, the focus lies on explaining the relationship between GWP (i.e. environmental impact) and standardized revenue (i.e. economic outcome) rather than estimating the entire efficiency of the complete production process for health services and the detrimental output environmental impact. Hence, GWP is the sole explicitly considered input in the analysis. However, other physical inputs such as labor and capital are included implicitly. The GWP is by construction a function of labor and capital. For instance, GWP of infrastructure is a function of energy reference area of the hospital and hospital staff. GWP of catering is a function of food expenditure and hospital staff. When using a parametric frontier analysis method such as SFA, we would face multicollinearity issues if the determinants of the GWP were included. Additionally, increasing the number of parameters to be estimated in an already small data set would lead to less accurate results.

The population for our analysis is the 156 acute care hospitals in Switzerland in 2018. For 14 no GWP data can be calculated. For 12 no revenue data is available. Three acute care hospitals have neither data available. This leaves 127 acute care hospitals that constitute the "full sample". Accurate GWP by hospital area are only available for the hospitals that participated in the national survey and, hence, supplied enough data for Keller et al. (2021) to conduct a comprehensive LCA for each hospital area. The 33 survey participant hospitals constitute this "reduced sample".

Table 5 shows the summary statistic for both GWP and standardized revenue of hospitals in full and the reduced sample. As expected, the mean and median are significantly higher in the reduced sample. This is due to the higher response rate in the survey by larger hospitals (see section 1).

Table 5. Summary statistics for GWP and standardized revenue by sample

Sample	Variable	Mean	Min	Max	Median	N
full	GWP	3,502.84	11.04	46,555.64	1,584.50	127
full	Standardized revenue	171.46	0.62	1,169.94	89.89	127
reduced	GWP	8,482.89	11.04	46,555.64	3,868.07	33
reduced	Standardized revenue	397.00	0.62	1,169.94	215.87	33

The environmental efficiency frontier is estimated using the two most common methods for efficiency analysis: the non-parametric DEA and the parametric SFA. We exploit the advantages of both frontier analysis methods to get a comprehensive picture of the environmental efficiency of Swiss hospitals with respect to the environmental inputs. The DEA fits a linear convex hull piece-by-piece. This means that no assumption on the functional form of the production function is required, and specification errors are, hence, not possible. In our application this is the main advantage over SFA where the rather small number of observations (127) excludes the use of a highly flexible production function such as translog due to the large number of parameters to be estimated. The disadvantage of the deterministic method DEA is that it does not allow for random data errors. This means that without high quality data, the efficiency estimates will be biased (Newhouse, 1994). As the environmental inputs for all hospitals except the 33 survey participants are modelled empirically, random errors are introduced into the data. Therefore, DEA is only applied to a reduced sample, i.e. the 33 survey participants' data.

Under the assumption that our modelling of the environmental impact for the non-participants of the survey introduces no systematical errors, SFA allows for unbiased estimates of the environmental efficiency despite measurement errors. Since biases are likely present in the full sample of acute care hospitals, these efficiencies are estimated with SFA.

The exact model specifications for each method are described in the following paragraphs.

2.3.1. Data envelopment analysis

DEA is a well-established non-parametric method for measuring the efficiency of decision-making units (i.e. hospitals). It was first proposed by Charnes et al., (1978) and has been used in thousands of research papers.[14] It is used both in the health sector to measure the performance of hospitals (see Steinmann et al., 2004) for an example

[14] A survey by Emrouznejad & Yang, (2018) finds over 10'000 journal articles which are DEA-related.

using Swiss hospitals) and to measure the environmental efficiency with respect to environmentally detrimental inputs for example in farming (Reinhard et al., 2000). Our base specification is a simple input-oriented DEA model with variable returns to scale (VRS). VRS is assumed because it is implausible to expect that all hospitals operate at optimal scale in the highly regulated Swiss health sector. The additional specification of constant returns to scale (CRS) is used to measure the possible long run environmental efficiency at optimal operational scale. The input-orientation also corresponds to a planning view where hospitals guarantee a certain level of services while minimizing resource use (Steinmann et al., 2004). The linear program to be solved for a hospital i is thus

$$\begin{aligned} &\min_{\theta,\lambda} \theta_i \\ &st. \\ &\boldsymbol{x}\lambda \leq \theta_i x_i \\ &\boldsymbol{y}\lambda \leq y_i \\ &\lambda \geq 0 \end{aligned}$$

where

- θ_i *is the efficiency score of observation* i *under evaluation,*
- $\boldsymbol{x}$ *is the 1 x N input vector, where N is the number of observations (*x_i *is input of observation* i*),*
- $\boldsymbol{y}$ *is the 1 x N vector of outputs (*y_i *is the output of observation* i*),*
- λ *is the N x 1 vector of weights pertaining to the observations.*

2.3.2. Stochastic frontier analysis

The SFA is the other well-established method for efficiency analysis. Developed independently by Aigner et al., (1977) and Meeusen & van Den Broeck, (1977), it incorporates a composed error term into frontier analysis allowing for both stochastic shocks or inefficiency to explain departure from efficiency frontier. Similar to DEA, it has been used in health care applications (Meyer, 2015) and less frequently to estimate environmental efficiencies (Reinhard et al., 2000). The specification of the SFA model used is almost as simple as in DEA. The production function for a hospital i is Cobb-Douglas with GWP as a single input (x_i) and standardized revenue as an output (y_i). It uses a log-linear transformation of the stochastic frontier model to be estimated:[15]

$$\ln(y_i) = \beta \ln(x_i) + v_i - u_i$$

[15] We opt not to include a constant term as any output produced has environmental impact. This implies that the efficiency parameter in the Cobb-Douglas model is set to 1.

where

$v_i \sim N(0, \sigma_v^2)$ *is the stochastic shock (noise),*
$u_i \sim N_+(0, \sigma_u^2)$ *is the inefficiency,*
$i = 1, \dots, N$ *are the observations.*

A combined error term is estimated

$\epsilon_i = v_i - u_i \sim A(0, \sigma^2)$, where $\sigma^2 = \sigma_v^2 + \sigma_u^2$ and A is a joint distribution function.

A measure for the asymmetry between the two error term distributions is defined as

$$\lambda = \sqrt{\sigma_u^2/\sigma_v^2}.$$

Using simulated maximum likelihood, the parameters β, σ^2 and λ are estimated. From these parameters, the variance of the stochastic shock and the inefficiency (σ_v^2 and σ_u^2) are calculated using the parametrization shown above. Following (Battese and Coelli, 1988), we estimate the hospital specific environmental efficiencies as $E(\exp(-u_i)|\epsilon_i)$.

3. Results

Both SFA and DEA find a great potential for improving the environmental efficiency in hospitals. Table 6 shows the summary statistics of the environmental efficiency.[16] Our base specification of DEA with VRS calculates an efficiency of 51.5 percent for the median hospital with a minimum of 25.5 percent. The results exhibit considerable variation with a standard deviation (SD) of 23.7 percent. Combining these results with DEA under the assumption of CRS, we can calculate the scale efficiency with respect to environmental impact of the inputs. Median scale efficiency is very high at 99.4 percent. But when looking at the input-weighted mean scale efficiency, it becomes clear that the larger hospitals are less scale efficient. It's the large tertiary care hospitals which are operating at decreasing returns to scale with respect to environmental impact.

Using the full sample of acute care hospitals, the SFA median efficiency is calculated as 53.4 percent with a standard deviation of 19.7 percent. Minimal efficiency estimated using SFA is around 3 percent. This low value is assigned to a small, highly specialized clinic with large environmental impact given its size.[17]

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[16] The terms of the data protection agreement protect the anonymity of the hospitals. Therefore, only summary statistics of the efficiencies can be shown.
[17] Parameter estimates for the SFA model can be found in **Fehler! Verweisquelle konnte nicht gefunden werden.** in the Appendix.

The SFA environmental efficiency estimates for the acute care hospitals allow us to calculate the improvement potential for the 127 acute care hospitals in terms of the GWP. Using the input-weighted mean efficiency and total inputs of 444,861 t CO_2-eq, we find an improvement potential of 136,669 t CO_2-eq.

Table 6. Environmental efficiency for DEA and SFA model

Model	Mean	Input-weighted mean	Median	Min	Max	SD	N
DEA (VRS)	56.8%	68.4%	51.5%	25.5%	100.0%	23.7%	33
DEA (CRS)	38.0%	45.1%	44.5%	17.3%	100.0%	15.8%	33
Scale Efficiency	65.5%	85.6%	99.4%	20.4%	100.0%	22.2%	33
SFA	53.7%	71.5%	53.4%	3.1%	92.3%	19.7%	127

While the overall results are of interest, the data of the survey participants also allow for the estimations of environmental efficiency for the 14 areas for which environmental impact was modeled. Figure 2 shows the distribution of the efficiency values by hospital area. All areas exhibit considerable differences in their distribution of environmental efficiency assessed with the GWP. The environmental efficiencies of heating are concentrated at low levels. 30 out of 33 of the hospitals are below 25 percent efficiency. For the areas heating, catering and waste the maximum efficiency is considered an outlier among the environmental efficiency values calculated.[18]

[18] A tabled version of the results can be found in Appendix Table A.4

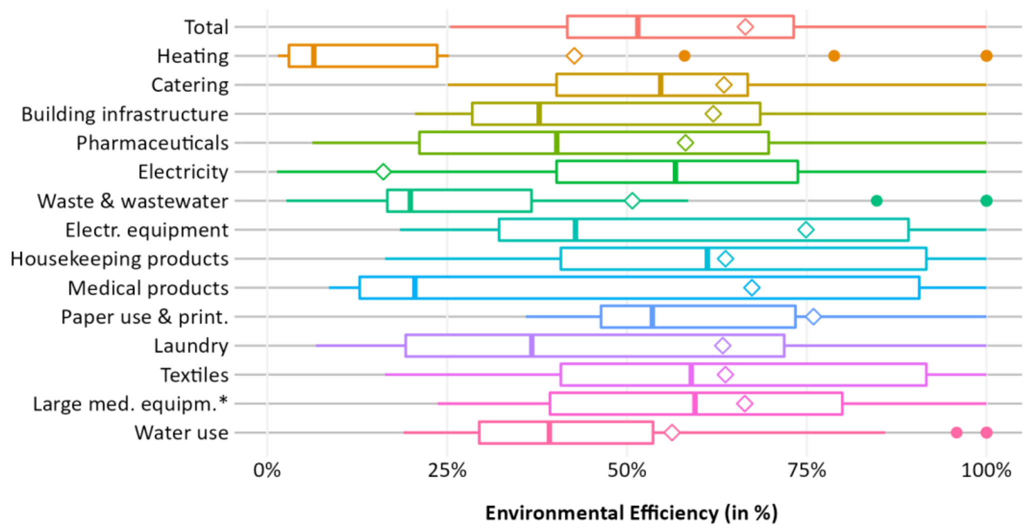

Figure 2. Distribution of environmental efficiency estimates by area and environmental Input. Notes: N = 33; * for large medical equipment N = 31 as the two maternity houses in the sample have no such equipment. The diamonds represent the input weighted mean environmental efficiency across all 33 hospitals.

From a policy perspective, the efficiency of individual areas is less important than the potential contribution of each area to the reduction of a hospitals total environmental impact. This can be calculated by weighting the efficiency of individual areas with its environmental relevance, resulting in a weighted average efficiency. The potential for improvement is largest in areas with a high proportion of total input and low efficiency. This situation is given for areas depicted in the left top corner of Figure 3 that plots efficiency and proportion of total inputs for GWP.

The highest improvement potential is given for the group of areas in the orange rectangle in the upper left corner: heating and electricity. Heating constitutes the biggest improvement potential in the hospital sector. Weighted average efficiency of heating is only 42.7 percent, and it contributes 25.5 percent of GWP input. An improvement in efficiency by one percentage point would reduce overall GWP input by 0.6 percentage points or nearly 1,700 t CO_2-eq. A similarly high improvement potential for the efficiency is present for electricity due to the very low weighted average efficiency of 16.7 percent.

The areas catering, building infrastructure and pharmaceuticals also exhibit considerable potential with respect to overall GWP of 0.3, 0.2 and 0.2 percentage points CO_2-equivalent input per percentage point of efficiency improvement. They are depicted in the green rectangle in the upper right corner of the figure.

All other areas are in the group depicted in a blue rectangle in the lower right corner of the figure. These areas are less environmentally relevant and at the same time show a relative high efficiency. This means that improvements in these areas have the lowest potential to reduce the environmental impact of hospitals compared to the other two groups.

Improving the environmental efficiency of the health sector is a valuable contribution towards reducing the environmental impact of Switzerland from a consumption perspective. To our knowledge, this is the first research project that estimates the environmental efficiency of the hospital sector and additionally differentiates for 14 hospital areas. A direct comparison of our results to similar studies is therefore not possible. Planned internal validation of the results by implementing improvements in partner hospitals and measuring reduction in environmental impact were not possible during the project period[19].

As a measure of the global climate effect of gases emitted GWP can only measure a part of overall environmental impact (Frischknecht & Büsser 2013). We also considered a second more comprehensive single score measure: The method of ecological scarcity (ibid.). It consists of a broad spectrum of 19 impact categories summarized to one key figure and includes the following environmental aspects: global warming; ozone layer depletion; resources; pollution of air, water, and soil; waste and land use. All impact categories are normalized and weighted according to the respective actual emission situation and the national or international emissions targets pursued by Switzerland. However, the efficiency results are comparable and do not change the general conclusion that the potential for improvement in environmental efficiency among Swiss acute care hospital is considerable.

[19] The implementation of a new processes in one chosen area for three partner hospitals in the first half of 2020 was planned. These were measures to optimize a) catering, b) order procedure for pharmaceuticals and medical products, c) cleaning processes. Due to the COVID-19 pandemic, the hospitals had no capacity to adapt processes before the research project ended in August 2021.

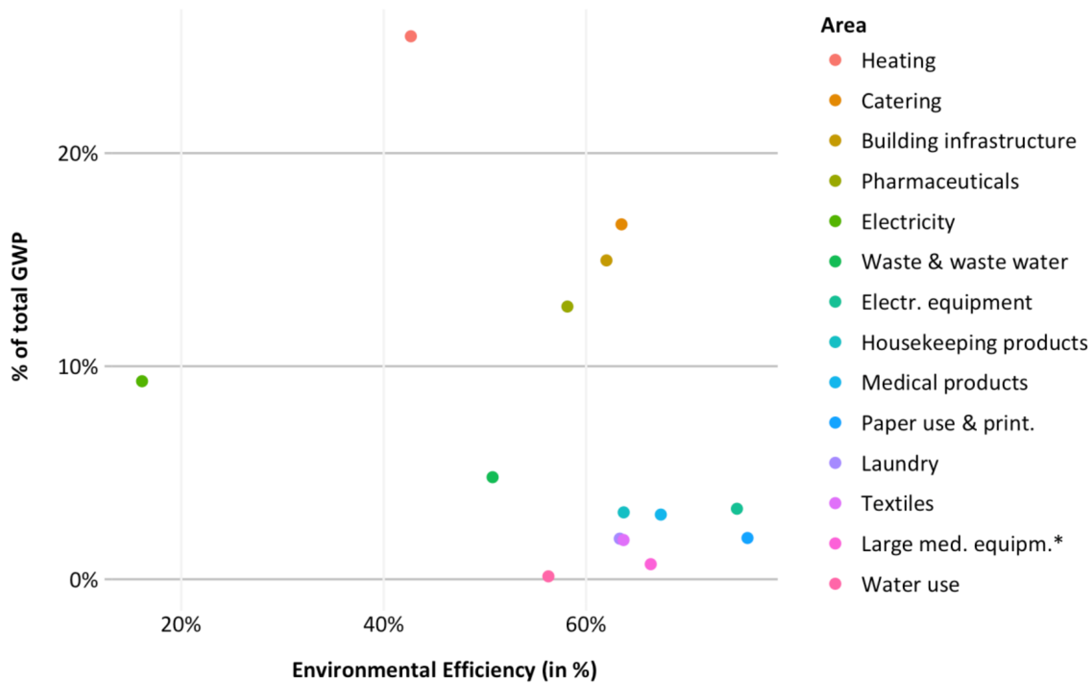

Figure 3. Environmental efficiency improvement potential. Notes: N = 33; * for large medical equipment N = 31 as the two maternity houses in the sample have no such equipment. "Environmental Efficiency" is the input weighted mean environmental efficiency across all 33 hospitals.

4. Conclusion

Using both DEA and SFA, we studied the environmental efficiency of Swiss acute care hospitals. The sample contains 127 hospitals for which we calculate standardized revenue and model the environmental impact for 14 distinct areas. Both DEA and SFA find similar values of environmental efficiency for the median hospital of 51.5 percent and 53.4 percent respectively. The improvement potential of the acute care sector is estimated by combining the SFA input weighted mean environmental efficiency of 69.3 percent with the total input measured in GWP, resulting in a total reduction of 136'669 t CO_2-eq. Efficiency improvements have greatest absolute effect in the area heating and electricity. These were identified by comparing the areas of environmental impact in terms percentage of total GWP with input weighted mean efficiency. In these areas, one percent improvement in efficiency would reduce overall GWP input by 0.60 and 0.58 percent, respectively.

This paper is the first to use a bottom-up life cycle assessment of the environmental impact of hospitals (see Keller et al., 2021) to model the environmental impact of the acute care health sector in Switzerland at a hospital level. It introduces standardized revenue as a simple measure of hospital output in its entirety (inpatient, outpatient, and other services), corrected for differences in operational costs or inefficiency which are implicitly accounted for in the different hospital tariffs. It provides the first estimates of environmental efficiency in the health care sector and shows the considerable improvement potential both for the sector as a whole and disaggregated into 14 hospital areas. As such, this paper is a valuable contribution towards achieving sustainable development in the health care sector.

Our analysis is a first step to understanding the environmental impact and efficiency in the health care sector. The environmental efficiency estimated are specific to the Swiss health care system. The results should be compared to countries where acute care hospitals provide similar health care services and have a comparable hospital infrastructure (e.g. building type), and comparable systems for heating, electricity and catering. Implementing improvements in chosen hospitals would be valuable both for the sustainability of the hospitals as well as for the validation of the efficiency potential. This will be easier to put into practice as soon as the pandemic situation releases resources in acute care hospitals and public pressure for environmental efficiency for services mandates increases.

Acknowledgement

‘Supported by the Swiss National Science Foundation (SNSF) within the framework of the National Research Program “Sustainable Economy: resource-friendly, future-oriented, innovative” (NRP 73) Grant-N◦ 407340_ 172453’. The authors are grateful to Stefan Meyer for helpful comments and Nils Braun-Dubler for insightful discussions.

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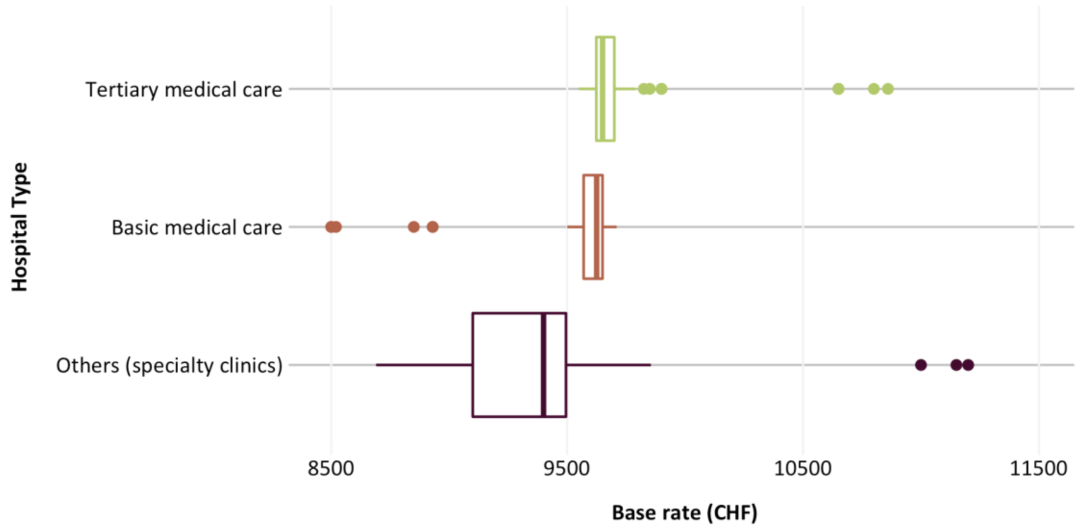
A. Appendix



Appendix Figure A.1. Variation in Base Rate by Hospital Type for 2018. Notes: Tertiary medical care includes the five university hospitals, which have base rates above CHF 10'500 and appear as outliers.

Appendix Table A.1. Amount & Proportions of Hospital revenue by accounting Group and Care Type in 2018. Notes

Accounting group	Revenue (in million CHF)	Outpatient	Inpatient	Long Term	Other	Total
Revenue from medical, nursing, and therapeutic services for patients	15,049.12	0.43%	59.51%	0.49%	-	60.42%
Individual medical services	2,021.67	5.14%	2.97%	0.01%	-	8.12%
Other individual hospital services						
thereof TARMED (TL) [(a)]	2,355.79	9.46%	-	-	-	9.46%
thereof physiotherapy	121.22	0.48%	0.01%	0.00%	-	0.49%
thereof laboratory	382.25	1.51%	0.02%	0.00%	-	1.53%
residual [b]	2,276.50	8.09%	0.98%	0.07%	-	9.14%
Other revenue from patient services	146.02	0.33%	0.23%	0.02%	-	0.59%
Financial income	48.89	-	-	-	0.20%	0.20%
Revenue from personnel and third-party services	730.21	-	-	-	2.93%	2.93%
Contributions from Communities	2.61	-	-	-	0.01%	0.01%
Contributions from Cantons	1,622.49	-	-	-	6.51%	6.51%
Contributions from Federal Government	0.15	-	-	-	0.00%	-
Contributions from corporations, foundations, and private individuals	149.96	-	-	-	0.60%	0.60%
Total	24,906.87	25.44%	63.72%	0.59%	10.26%	100.00%

Notes: N = 141 acute care hospitals; (a) TARMED is the Swiss tariff system for outpatient medical services. (b) The residual of other individual hospital services is not available in the original statistics but can easily be calculated

Appendix Table A.2. Overview of tariffs used for Adjustment of Health Care Revenue by Care Type

Accounting group	Outpatient	Inpatient	Long Term
Revenue from medical, nursing, and therapeutic services for patients	TPVout	base rateacute / base ratepsychic / DRrehab	None (care level unknown)
Individual medical services	TPVout	base rateacute / base ratepsychic / DRrehab	None (care level unknown)
Other individual hospital services			
thereof TARMED (TL)	TPVout	None (no tariff applies)	None (no tariff applies)
thereof physiotherapy	TPVphysio	TPVphysio	TPVphysio
thereof laboratory	None (no adjustment needed)	None (no adjustment needed)	None (no adjustment needed))
thereof residual	None (unclear which tariff applies)	None (unclear which tariff applies)	None (unclear which tariff applies)

Appendix Table A.3. Parameter Estimates of SFA Models.

ln Revenue	**Coeff**	**SE**
Parameters of the environmental efficiency frontier		
ln GWP	0.695	0.007***
Random noise component ln (σ_v^2):		
Intercept of ln (σ_v^2)	-3.025	0.440***
Inefficiency component (σ_u^2):		
Intercept of ln (σ_u^2)	-0.144	0.165
Parameters of compound error distribution		
σ_v	0.220	0.049***
σ_u	0.931	0.077***
λ	4.226	1.113***
log likelihood	-102.375	

Notes: N = 127. "***" implies statistical significance at the 0.01 percent level.

Appendix Table A.4. Environmental Efficiency by hospital area

Area	Weighted mean	Mean	Median	Min(b)	Std. Dev.
Total	66.5%	56.8%	51.5%	25.5%	23.7%
Catering	63.5%	58.8%	54.7%	25.1%	22.8%
Building infrastructure	62.0%	50.1%	37.8%	20.5%	27.3%
Electricity	16.1%	56.3%	56.7%	1.3%	29.4%
Heating	42.7%	22.7%	6.5%	1.5%	33.3%
Pharmaceuticals	58.1%	47.3%	40.2%	6.3%	30.9%
Textiles	63.7%	62.6%	58.9%	16.4%	27.0%
Waste & wastewater	50.8%	34.5%	19.9%	2.6%	31.7%
Electr. equipment	74.9%	57.1%	42.8%	18.4%	29.4%
Housekeeping products	63.7%	62.6%	61.2%	16.4%	27.0%
Medical products	67.4%	44.1%	20.5%	8.6%	37.4%
Paper use & print.	75.9%	62.9%	53.5%	36.0%	21.2%
Laundry	63.3%	46.0%	36.8%	6.8%	34.1%
Large med. equipm. [(a)]	66.4%	58.9%	59.5%	23.7%	24.9%
Water use	56.3%	48.1%	39.2%	18.9%	25.9%

Notes: N = 33; (a) for large medical equipment N = 31 as the two maternity houses in the sample have no such equipment. (b) At least one hospital has an efficiency of 100% per Area. The value is therefore omitted from the table.