SPANISH AND EUROPEAN ENERGY SAVINGS WITH INCREASED USE OF THERMAL ENERGY STORAGE

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Abstract

Thermal energy storage (TES) is nowadays presented as one of the most feasible solutions in facing the challenge of achieving energy savings and environmentally correct behaviours. Its potential applications have led to R&D activities and to the development of various technology types. However, so far there is no available data on a national scale in Spain and furthermore, on a continental level in Europe, to back up the energetic and environmental benefits attributed to TES usage. This is why, based on a previous potential calculation initiative model performed in Germany, this work intends to provide a first overview of the Spanish and European TES potential. Load reductions, energy savings and CO_2 emissions reductions are tackled for the buildings and industrial sector. A 10-year scenario has been settled with moderate storage implementation rates in order to keep results within realistic margins. Based on the input data and taken assumptions it has been determined that if for instance, 2005 energy consumption and CO_2 emissions are compared with obtained results, energy savings and CO_2 emissions reductions are of 11% and 8.5% respectively.

1. Introduction

Thermal energy storage (TES) potential is gradually growing day by day as a viable solution to energy inefficiency and environmentally disrespectful trends. Some of the advantages TES may provide (such as energy demand balance facilitation, growing range of temperature operation, lower cost in comparison to other energy sources usage, and others) cover a large variety of application fields.

Nevertheless, there are no available data to corroborate all these advantages yet on a national or continental scale as such the case of Germany and Spain. This is why this paper aims to perform TES potential calculations for Spain and Europe, similar to the ones made for Germany [1] (first presented publically at the "Material Development for Thermal Energy Storage" symposium at Bad Tölz, Germany, in June of 2008 by R. Tamme [2]), applying similar calculations criteria and broadening the scope as all the potential may be broken down by categories if enough information is available.

2. Objectives

- To generate data, in similar fashion to that made for Germany, which gathers the required numerical information in order to show the TES potential in Spain and in Europe.
- To corroborate what sort of influence TES systems have got over energetic and environmental matters.
- To extend the scope of the original calculations as additional categories of TES potential may be detected.

3. Methodology

Two main large sectors had been distinguished in the previous study: buildings and industry. The following cases were considered for the buildings sector: seasonal storage, district heating, solar heating, and cold storage. As for the industrial sector the considered cases were: cogeneration, industrial waste heat storage, concentrated solar power storage, and industrial waste cold. Added cases in this study were: cold storage for the building sector; and concentrated solar power and industrial waste cold for the industrial sector. Three parameters have been evaluated for each case: load reduction, thermal/electrical energy savings, and CO_2 emissions reduction.

Potential results cover a ten-year period from now on, with low/moderate projected storage implementation and associated load reductions for both sectors.

3.1 CO_2 emission factors

CO_2 emissions factors (associated to the potential energy savings) have been adjusted based on the national or continental (as it corresponds) primary energy consumption percentages, resulting in a unique factor which could be used for later calculations (Table 1).

Table 1. Determination of the weighted CO_2 emissions factor for Spain and the EU-25.

Primary energy source	**Consumption percentage (Spain)** [3]	**Consumption percentage (EU-25)** [4]	**CO_2 emission factor (g CO_2/kWh_{th}) (Spain)** [5]	**CO_2 emission factor (g CO_2/kWh_{th}) (EU-25)** [6]
Natural gas	22%	24%	204	202
Oil	48%	39%	244	279
Coal	14%	17%	347	351
		Adjusted factor	251	271

The factors associated to electricity are given directly by literature. The factors are of 649 g CO_2/kWh_e [5] for Spain and 476 g CO_2/kWh_e [6] for Europe.

3.2 Building sector methodology

Cases within this sector feature the following input variables: building stock, building yearly rate of renovation and completion [7], and yearly operating hours. Exceptions for this are central/district heating systems, explained later.

Taking the renovation and completion rates as constants during the considered 10-year period, the number of both renovated and new buildings may be known and in assuming a storage implementation percentage, the number of buildings featuring TES may be known. An expected average load reduction value per building has been multiplied by this number in order to calculate the load reduction; then, by knowing the yearly operating hours of the system, the derived energy savings may be obtained and in multiplying these ones by the correspondent emission factor, the CO_2 emissions reductions are known. When working with cold storage, the obtained energy savings are divided by the average coefficient of performance (COP) of air-conditioning equipment in order to obtain the potential electrical energy savings and correspondent emissions reduction. When working with short term systems, once the load reduction has been obtained, it should be multiplied by the average collector area per building and related utilized solar gains (both available in literature) so the energy savings and CO_2 emissions reduction may be calculated. An example is shown in Table 2.

Table 2. Specific input data and main results for the building sector storage systems at the EU-25.

	Potential load reduction (MW)	Replaced energy (GWh)	Average collector area per building (m²/build)	Utilized solar gains (kWh/m²)	Coefficient of performance	Replaced electrical energy (GWh_e)	CO_2 emissions reduction (T CO_2)
Seasonal solar thermal storage	25,287	46,150	-	-	-	-	12,517,676
Cold storage	9,944	18,148	-		2.8	6,481	3,085,135
Short term solar thermal storage	416,180	319,269	15	537	-	-	86,599,153

In the case of central/district heating systems, the yearly operating hours and either the energy consumption or the capacity must be known so that in multiplying the capacity by an estimated or calculated average load reduction percentage, the yearly load reduction may be obtained and in multiplying this one by ten, the correspondent 10-year reduction is obtained, thus also being able to calculate the energy savings and CO_2 emission reductions as described for the previous systems within the sector. EU-25 data are employed as an example in Table 3.

Table 3. Central/district heating storage systems input data and results for the EU-25.

Heating capacity (GW)	Yearly full operating hours (h/yr)	Total heating energy consumption (GWh/yr)	Average load reduction percentage	Potential of load reduction (MW)	Potential of waste heat utilization (GWh)	CO_2 emissions reduction (T CO_2)
1,454	1,600	2,326,182	10%	1,453,863	2,326,182	630,957,558

3.3 Industrial sector methodology

Industrial waste heat and cold systems require a similar calculation method. Necessary input data are the yearly operating hours and final energy consumption, based on which, the respective capacities may be known. In order to obtain the load reduction, capacities were multiplied by a load reduction factor associated to storage usage and by the desired scenario time span. Once done and employing the operating hours, the energy savings and consequent CO_2 emissions reduction are obtained. In the case of power stations the only required input data are the energy conversion losses, which were multiplied by the expected storage implementation percentage and the time span, resulting in the associated energy savings and emissions reduction.

In the case of waste cold storage, an additional required input data is the industrial cooling installations COP, which was to divide the calculated energy savings in order to obtain the electricity savings and therefore the associated emissions reduction. EU-25 data and results are shown in Table 4.

In the case of cogeneration systems, its implementation percentage must be known and multiplied by the number of new buildings along the next 10 years (previously calculated), so the number of buildings featuring cogeneration is known. Other required input data are the installed power per building and yearly operating hours. The potential load reduction resulted from multiplying the installed power per building by the number of buildings featuring cogeneration. The achieved thermal energy production was obtained by multiplying the load reduction by the operating hours. In order to estimate the energy savings or reutilization, an expected storage implementation percentage was applied on the energy production. CO_2 emissions reductions were obtained as done with other previous cases. An example is shown in Table 5.

Table 4. Industrial waste heat and cold storage input data and main results at the EU-25.

	Yearly full operating hours (h/yr)	**Final energy consumption (GWh/yr)**	**Energy conversion losses (GWh/yr)**	**Total potential of waste energy utilization (GWh)**	**Estimated coefficient of performance**	**Replaced electrical energy (GWh_e)**	**CO_2 emissions reduction (T CO_2)**
Waste heat storage	**1,760**	13,238,981	**132,815**	6,659,335	-	-	1,806,289,626
Waste cold storage	**4,380**	7,847	-	31,386	**3.5**	8,967	4,268,512

Table 5. Cogeneration storage systems input data and results at the EU-25.

Total building stock	**Cogeneration implementation**	**Potential of load reduction (MW)**	**Yearly full operating hours (h/yr)**	**Storage implementation**	**Potential of waste heat utilization (GWh)**	**CO_2 emissions reduction (T CO_2)**
195,880,629	10.20%	187,790	4,500	15%	126,758	34,382,153

Finally, regarding concentrated solar power storage systems, only the nominal capacity of those plants presenting storage systems and the storage systems yearly operating hours are needed as input data. As this last one was not directly available, it was adjusted based on two variables, the yearly generated energy by plants with TES (available in literature) and the generated energy by those plants not including TES (adjusted based on a reference plant among those not presenting TES), equivalent to the one they would generate if they held storage systems. The associated electrical energy savings are obtained by multiplying the nominal power by the storage operating hours and the scenario number of years. Emissions reductions are calculated by applying the correspondent factor to these energy savings. Data and results are exemplified in Table 6.

Table 6. Concentrated solar power storage systems input data and results for the EU-25.

Total power for solar plants with TES (MW_e)	**Yearly storage operating hours (h/yr)**	**Generated electrical energy (GWh_e)**	**CO_2 emissions reduction (T CO_2)**
96	2,164	2,077	988,747

4. Results

Final results are summarized in Table 7 for the three available cases. Germany is also presented for comparison. As the German model only considered a 10-year scenario for the building sector and not for the industrial one, values for this sector have been brought up-to-date so comparisons may be made within a unique scenario for all cases.

Table 7. TES potential overview final results.

Energy potential	**Units**	**Germany** (based on [1])	**Spain**	**EU-25**
Load reduction	MW	480,844	541,266	5,854,139
Energy savings	GWh	662,291	826,263	9,527,227
Electrical energy savings	GWh_e	-	3,431	17,526
CO_2 emissions reduction	T	165,572,663	207,670,938	2,579,088,559

As expected, all three cases exhibit large potential within each considered category during the considered period. Observed variables to have exerted the more influence over this potential have been the building stock and the industrial waste energy which may be reutilized by means of TES.

Added cases potential features, as that of the original ones, a direct proportionality with the storage implementation.

For better appreciation of the results magnitude, a graphical comparison of the evaluated parameters is shown in Fig. 1 to Fig. 4.

As results on a European level may be of greater interest, the calculated TES potential benefits for one year are graphically compared with historical values (2005 data [6]) in order to provide a more precise idea of the potential benefits (Fig. 5 to Fig. 7).

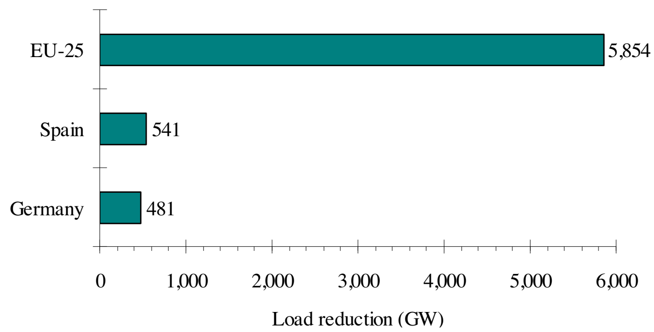

Fig. 1. Potential TES load reduction over ten years.

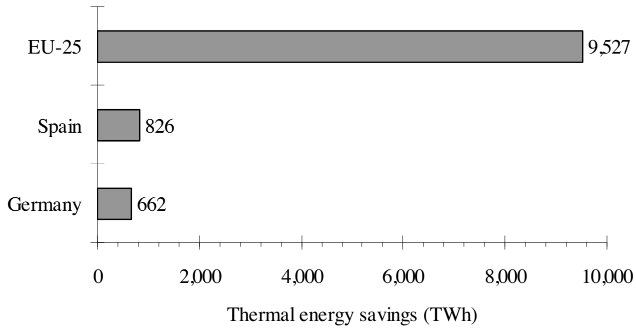

Fig. 2. Potential TES energy savings over ten years.

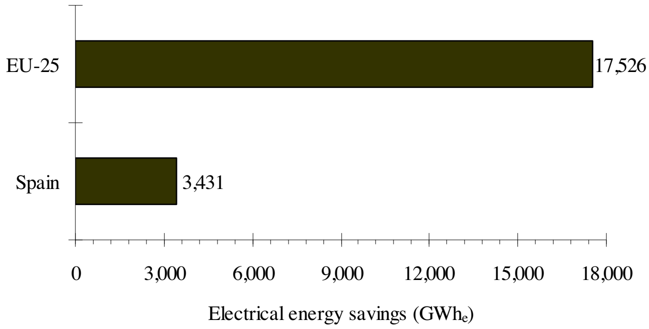

Fig. 3. Potential TES electrical energy savings over ten years.

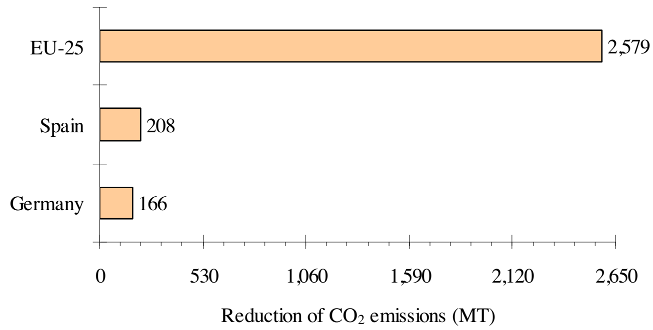

Fig. 4. Potential TES CO_2 emissions reduction over ten years.

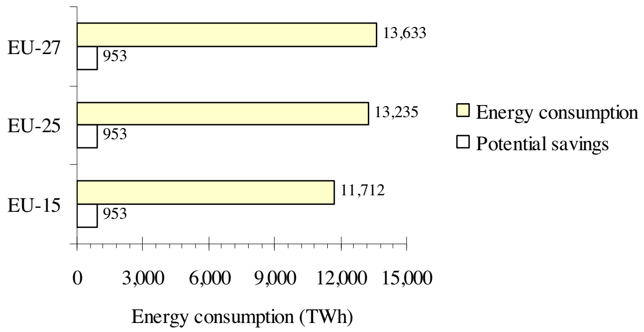

Fig. 5. Potential yearly TES energy savings within the European Union.

Regarding yearly energy savings, calculated values represent an 8% of the consumed energy (EU-15), 7% (EU-25), and 7% (EU-27) respectively.

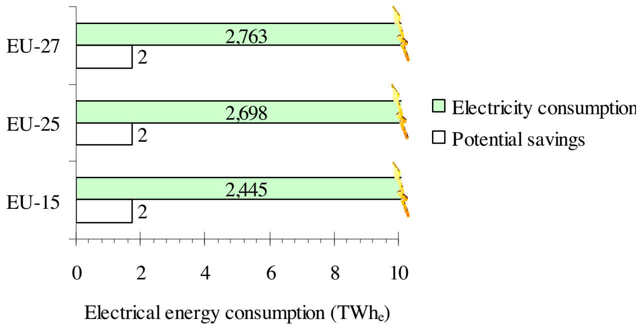

Fig. 6. Potential yearly TES electrical energy savings within the European Union (detail).

Potential yearly electrical energy savings represent only an average 0.1% of the total consumption in the three cases; probably due to the still low implementation of the involved applications themselves rather than the storage implementation.

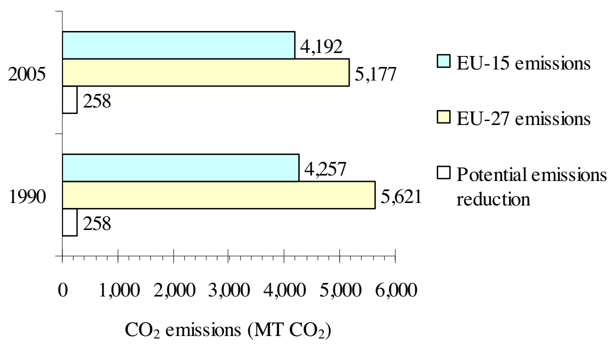

Fig. 7. Potential yearly TES CO_2 emissions reduction at the EU-15 and EU-27 based on historical emissions data.

Both for 1990 and 2005, potential yearly reductions account for 6% of the emissions at the EU-15 and for a 5% at the EU-27. In reference to 1990 levels [8], when emissions measures begun to be taken as a result of the Kyoto Protocol [9], reductions would reach an average 5.5% value.

5. Conclusions

- TES related energetic and environmental advantages associated to the studied 10-year TES implementation scenario are directly proportional to the storage implementation.
- The number of buildings and the industrial waste energy exert a stronger influence over final results than other input data.
- Yearly energy savings in Europe would reach a 7% (taking 2005 levels as reference) of the yearly energy consumption.
- Yearly electrical energy savings in Europe would account only for 0.1% of the yearly energy consumption (regarding 2005 figures).
- In reference to 1990 levels, yearly CO_2 emissions reductions in Europe feature an average value of 5.5%.

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