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Ground source heat pump carbon emissions and primary energy reduction potential for heating in buildings in Europe—results of a case study in Portugal

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ABSTRACT

The main purpose of this study is to assess the impacts in the European Union (EU) of a fuel switching strategy focused on the replacement of Natural Gas (NG) boilers by high efficiency Heat Pumps (HPs) supplied by electricity with a fast decreasing carbon content. Additionally, to illustrate the high performance of heat pumps, the experimental results of an advanced Ground Source Heat Pump (GSHP) system installed in a service building in Portugal are presented.

Based on the analysis carried out, it was found that the large scale use of heat pumps for space heating in buildings can contribute to significant primary energy and CO_2 emissions savings, when compared to NG boilers. In Europe, in 2050, through the replacement NG space heating in buildings by high efficiency heat pumps, around 60% of the primary energy required and 90% of the associated CO_2 emissions can be saved. At global EU level, in 2050 the European NG dependency on external suppliers can be decreased to 50% and an additional contribution of 5.6% for Renewable Energy Sources (RES) share in the total final energy consumption can be achieved.

Furthermore, HPs can also play an important role towards exploiting the increasing penetration of renewable electricity generation, effectively contributing to the replacement of fossil fuels and in particular to decrease the growing natural gas dependency of Europe from risky and unstable countries.

Contents

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1. Introduction

The European Union (EU) defined three energy policy targets to meet the challenges related to climate change, security of supply, and competitiveness. The targets to be achieved by EU in 2020 are: a 20% reduction in Greenhouse Gas (GHG) emissions compared to 1990, corresponding to a reduction of about 1100 Mt of CO_2 equivalent (CO_2 eq); a Renewable Energy Sources (RES) share of 20% in the final energy consumption (around 2850 TWh); and an energy efficiency increase of 20% that corresponds to 20% of primary energy savings, meaning that EU primary energy consumption in 2020 cannot exceed 17,140 TW TWh.

The EU is in the process of updating those targets to be achieved by 2030:

- a 30–40% reduction in greenhouse gas (GHG) emissions compared to 1990;
- a renewable energy sources (RES) share of 27–30% in the final energy consumption;
- a minimum energy efficiency increase of 30%.

In addition, ambitious new targets towards 2050 are being projected to mitigate climate change, tentatively aiming to decrease carbon emissions by 80% in relation to 1990 levels.

The European Union has limited oil and Natural Gas (NG) resources and the foreign dependency has been increasing fast, with a projected 70% natural gas imported share of the consumption by 2030. The EU energy dependency is at the top of the EU agenda, now becoming more relevant due to the present political turmoil in Eastern Europe, which has again highlighted the geopolitical risks of imports and the vulnerability of the EU economy. In 2012, the EU demand for natural gas was around 4570 TW 570 TWh with a 65% net import share [1]. Around 30% of the natural gas consumption is imported from Russia, and around half of it crosses Ukraine [2].

The building sector in EU is the main responsible for the increase in natural gas dependency since it is responsible for 61% of the total imported NG. In 2012, building space heating was responsible for 45% of the total final NG consumption and for 29% of the total gross inland NG consumption (this total includes the NG used for electricity generation) in the EU [1]. Therefore, the building sector assumes an important role, not only in the achievement of the EU sustainability targets for 2030 and 2050, but also in the decreasing of the natural gas dependency.

In order to progress towards the EU energy policy targets, the main strategies for buildings include:

- significantly improve the building envelope thermal efficiency (both for new and for in existing buildings);
- drastically improve the efficiency of electricity end-use equipment (e.g. lighting, HVAC and electrical appliances);
- fuel switching through increased use of renewable energies to replace fossil fuels (namely for space and water heating).

To address the latter strategy, high-efficiency heat pumps can be used for space and water heating instead of NG boilers. Additionally, electricity is becoming a cleaner form of energy, since a massive increase of renewable energies (wind and solar) has been observed in EU in the last decade, leading to a progressively lower carbon content electricity.

Denmark is the only EU country that exports natural gas, and it has been one of the most ambitious programs towards sustainable energy and climate targets. Denmark aims to be fully independent of fossil fuels by 2050. In particular, gas and oil boilers are forbidden for new buildings since 2012 and a gradual phase out is planned for these technologies [3].

The latest generation of electric Ground Source Heat Pumps (GSHPs) has the advantage of being a very efficient technology (with one unit of electricity it is possible to produce 4 to 6 units of heating or cooling). Ground source heat pumps can have high efficiency even on the coldest days, since they rely on extracting thermal energy from the ground, which behaves like an approximately constant temperature source.

In this paper the impacts of the large scale penetration of high efficiency Heat Pumps (HPs) in EU will be evaluated, in the following aspects: decrease in carbon emissions; decrease in primary energy consumption; decrease of NG dependency; and the increase of the RES share contribution.

1.1. Methodology

The main focus of this paper is to assess the primary energy and CO_2 emissions savings by switching NG boilers to high efficient HPs for space heating in the EU, including a relevant case study in Portuguese buildings. A scenario where NG space heating will be progressively phased out in EU until 2050 is proposed. Additionally the results obtained in an experimental high efficiency GSHP case study in Portugal are presented in Section 7, to demonstrate the high performance of GSHPs. This pilot was installed within the European GroundMed Project, supported by the Seventh Research Framework Programme [4]. This project aims to demonstrate a measured Seasonal Performance Factor (SPF) greater than five for ground source heat pumps (GSHP), both for space heating and cooling. This technology is being demonstrated in 8 pilot buildings in Mediterranean climate.

The following sections address several key factors necessary to this type of fuel switching analysis (NG boilers progressively replaced by high efficiency HPs) as follows:

- characterization of space heating consumption and respective scenarios of evolution in Europe for the year 2050;
- carbon emissions factor for the electricity sector in Europe for the year 2050;
- heat pump efficiency;
- progressive penetration of HPs in Europe, to achieve full replacement of NG boilers for the year 2050.

1.2. Related studies

Heat pumps have been presented in several studies with different approaches as a very promising technology to contribute to the EU building sector decarbonization and to decrease the primary energy consumption for the heat demand in the EU.

De Almeida et al. have developed a case study in Portugal to evaluate the fuel switching opportunities for the residential sector and concluded that the use of electric air-to-air and air-to-water