Renewable and Sustainable Energy Reviews 94 (2018) 1153–1178

Contents lists available at ScienceDirect

Renewable and Sustainable Energy Reviews

journal homepage: www.elsevier.com/locate/rser

Reducing industrial energy demand in the UK: A review of energy efficiency technologies and energy saving potential in selected sectors

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ARTICLE INFO

Keywords:
Energy efficiency
Steam system
Waste heat recovery
Biomass/waste
Business model
Drivers and barriers

ABSTRACT

Currently UK industrial and manufacturing sectors are facing dual challenges of contributing to national 80% reduction targets in CO_2 emissions by 2050 (compared to 1990 levels) and improving economic competitiveness in the face of low cost imports. Since energy consumption is the main source of CO_2 emissions and directly related to products being manufactured, improving energy efficiency in energy intensive sectors is key to achieve CO_2 targets. Energy consumption is unlikely to meet the targets unless energy efficiency opportunities and technologies are fully explored and timely changes are made to business models and policies This study explores potential energy efficiency improvements from three perspectives: system efficiency of steam networks, waste heat recovery technologies and bioenergy/waste utilisation. Two UK energy-intensive sectors, iron and steel, and food and drink, are selected for analysis and discussion. Potential business models for energy efficiency are also reviewed as there are now a variety of energy service companies who can support adoption of appropriate technologies. Furthermore, drivers and barriers to the adoption of energy efficiency technologies are considered in this paper revealing the factors affecting the diffusion of energy efficient and waste heat recovery technologies and their interactions and interdependencies to energy consumptions. Findings show that it is possible to achieve energy consumption reduction in excess of 15% from a technical point of view, however improving energy efficiency in UK industry has been hindered due to some inter-related technical, economic, regulatory and social barriers. The findings help to demonstrate the significant potential for energy efficiency improvement in two industrial sectors, as well as showing the specific types of technologies relevant for different sectoral processes. The range of business models show opportunities for implementation and for developing innovative business models, addressing barriers, and using enablers to accelerate the diffusion of energy efficiency technologies in UK industry.

1. Introduction

Under the Kyoto protocol, many countries and international communities in general have ambitious targets for the reduction of greenhouse gas emissions and global warming. For the UK, the government committed to reducing the levels of CO_2 and five other greenhouse gases by 12.5% below 1990 levels by 2008–2012. In fact these commitments have been surpassed so far and a new long term target was set to reduce by at least 80% by 2050 (against the 1990 baseline) [1]. Currently, primary energy consumption that fossil fuel represents still dominates in the world's energy consumption and this situation is expected to continue over the next decades. The long-term target is unlikely to be met if there are no substantial changes to policy and technological approaches in the usage of primary energy.

Facing the challenges of carbon reduction, a number of global organisations are working towards an energy revolution that is taking place to tackle greenhouse gas emissions by deploying low-carbon technologies and adopting renewable energy to increase energy sustainability and economic development. The International Energy Agency (IEA), is one of such groups that came up with a tool called the Energy Technology Perspective (ETP) model that presents options for a low-carbon future [2]. It has shown the effect of utilisation of available technologies on the reduction of CO_2 emissions and predicted that the end use fuel and electricity efficiency have potential to contribute 38% in CO_2 reduction, while Carbon Capture and Storage (CCS) and renewable energy technologies could reduce 19% and 17% of the

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https://doi.org/10.1016/j.rser.2018.06.040
Received 9 February 2018; Received in revised form 31 May 2018; Accepted 20 June 2018

Nomenclature

Abbreviations

AD	Anaerobic Digestion
BOOT	Build-Own-Operate-Transfer
BOO	Build-Own-Operate
BTO	Build-Transfer-Operate
BLT	Build-Lease-Transfer
BOT	Build-Operate-Transfer
BF-BOF	Blast Furnace-Basic Oxygen Furnace
CCS	Carbon Capture and Storage
CHP	Combined Heat and Power
EAF	Electric Arc Furnace
ESCO	Energy Service Company
EPC	Engineering Procurement Construction/Energy Performance Contracting
ESC	Energy Service Contracting
ETP	Energy Technology Perspective
FiT	Feed in Tariff
HE	Heat Exchangers
HP	Heat Pumps
ORC	Organic Rankine Cycle
PCM	Phase Change Material
PRV	Pressure Reduction Valve
RHI	Renewable Heat Incentive
RO	Renewables Obligation
TRC	Traditional Rankine Cycle
USCO	Utility Service Company

emissions, respectively. The contributions from other technologies options such as end use fuel switching, power generation efficiency and fuel switching and nuclear are collectively 26% towards the carbon reduction. Most of these values indicate the need for adoption of "energy efficiency" which is broadly defined and covered as the thermal energy recovery and its conversion into usable form of energy, use of low-carbon state-of-the-art technologies and improved energy integration and management. The ETP model also indicates that the reduction of energy use and emissions has already started from the "bottom up" approach, meaning concerns of the effect of emissions and challenges to tackle this in local contexts, which may encourage full utilisation of key technologies to improve energy efficiency of energies' end use, renewable energy and CCS.

Globally, industrial primary energy use and transformation for electricity and heat are responsible for 46% of greenhouse gas emissions [3]. While UK industry consumes about 20% of the final energy consumption of the UK economy (291 TW h in 2011) [4] and generates 32% of the UK's heat-related CO_2 emissions, mostly from fossil fuels [5]. Although UK industrial emissions have reduced in recent years [6], indirect impacts (e.g. the economic crisis in 2008) on carbon-intensive industrial sectors was the largest contributor to falling direct emissions besides some improvement in energy intensity and changes in fuel mix. Even so, UK industrial energy use still directly accounts for around a quarter of greenhouse gas emissions [7]. The majority (73%) of the UK industrial energy demand is for heat [8,9]. Steam systems are responsible for approximately 35% of industrial energy demand [10]. Superheated high pressure steam is usually produced by boilers and is reduced in pressure in the distribution network for use by different processes. Often this pressure reduction is accomplished through a pressure reduction valve (PRV) and energy embodied in the pressure drop is lost. Therefore, there is still a significant space to further improve the system efficiency of steam networks. Furthermore, all heating processes result in significant quantities of waste heat, up to 50% in some cases such as steel and glass making [11], and it is widely acknowledged that there is significant potential for emission reductions through waste heat recovery, estimated at between 10 and 40 TW h/yr which values up to £90/MW h at today's energy prices [12]. Likewise, there is no denying the fact that bioenergy/waste utilisation offers a signification potential for reduction of carbon emissions and grid dependency in industry. In 2016, electricity generation from UK bioenergy was estimated to be 30 TW h [13]. It was predicted that the effective deployment of bioenergy and waste utilisation could contribute to 8–11% of the UK's primary energy demand by 2020 and 8–21% by 2050 [14]. The UK government has embraced biomass strategies to define low-risk pathways that will help to achieve long-term decarbonisation objectives. These pathways include optimum utilisation of end-of-life wastes, use of biomass heating for buildings and industrial processes, use of biofuel in the transport sector and use of biomass for electricity generation [14]. The use of bioenergy and waste for heating and combined heat & power (CHP) generation can not only make a significant contribution to decarbonisation of the industrial sector [15], but also increase sustainability and energy security of the country. Although it is clear from previous studies that steam system efficiency, waste heat recovery and bioenergy/waste utilisation offer greater potential for energy consumption and emission reduction, yet most of this potential has remained unexploited due to technical, economic and organisational factors [15]. Moreover, lack of available business models to address those factors and to diffuse energy efficiency is also posing a barrier to achieve the UK's long-term target. This study will therefore review energy efficiency technologies and energy saving potential in selected sectors.

The aim of this paper is to provide an overview of the energy consumption and emission reduction potential offered by UK industry, especially by the Iron and Steel and Food and Drink sectors, through three different perspectives: improving energy efficiency in steam systems, waste heat recovery and bioenergy/waste utilisation. Besides, the energy efficiency market is reviewed and presented, in terms of business models and drivers and barriers for energy efficiency. Investigation of drivers and barriers (e.g. legislative, technical, socioeconomic, local acceptance) to adopt the associated technologies can deliver additional insights to energy consumption reduction. It is expected that this study will provide information and direction to future research in the development of innovative business models for energy efficiency and will help government, industry and society to engage more in achieving the national targets.

In order to achieve the aim of this paper, recent literature on the subject including journal publications, conference proceedings, Ph.D. theses, subject specific professional web sources, UK Government organisations' reports, industrial federations' and research organisations' reports, international energy agencies' reports, are reviewed and the findings are adapted for UK industry cases. As a first step, the state-of-the-art technologies for improving steam system efficiency, waste heat recovery and bioenergy/waste utilisation in industry, are reviewed. Then, the current state of energy consumption within the selected sectors in the UK is studied from the UK Government sites such as former Department of Energy and Climate Change (DECC) and current Department for Business, Energy & Industrial Strategy (DBEIS) (https://www.gov.uk/government/organisations/DBEIS). The energy saving potential using the various technologies reviewed in this paper is assessed considering the current energy consumption and reported accordingly. At the end, a detailed literature review on energy efficiency markets, different business models and drivers and barriers to energy efficiency is conducted from a global perspective.