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Energy and Offsite Production in the UK Construction Industry:
Zero-carbon Emission vs. Zero-defect Construction

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ABSTRACT:
Greenhouse Gases (GHG) - mainly carbon dioxide (CO2) emissions, the major cause for global warming, have serious economical, environmental, societal, and health implications. Initiatives/ Protocols were launched worldwide such as the Kyoto Protocol to minimise the GHG effect and promote the wider use of renewable energy (RE) sources. As a result, the EU has signed up to binding EU wide targets pledging to meet 20% of its energy needs from renewable energy sources by 2020.

This research adopts a qualitative approach to investigate and explore the potentials of combining RE technologies with offsite produced buildings as means to help meet UK targets with regards to reducing CO2 emissions. There are, arguably, significant barriers to the adoption of RE technologies on the economic, supply chain and technical levels. While, there are a number of successful case studies for employing RE in buildings, their performance have proven to be 'less than anticipated'. This low performance is exacerbated when introducing RE to completed and assembled offsite produced buildings. Integrating OSP and RE technologies within a controlled factory environment would allow combining energy efficiency measures with renewable energy sources in an integrated building system. Hence, improve the renewable energy performance in buildings, and consequently meet the zero-carbon emission target through zero-defect construction.

While, this research may be criticised for being primarily qualitative, the triangulation of sources would increase the reliability and validity of results. Further research is expected to empirically test the qualitative results and to quantify the implications of the post integration/retrofitting of RE technologies into existing building stock in general and into OSP buildings in particular.

Conference Topic: Renewable Energy

Keywords:
Construction Industry, offsite production, renewable energy, zero carbon emission

1. INTRODUCTION:

The whole world in general is facing a major challenge to alleviate the concentration of CO_2 in the atmosphere in order to save the earth from catastrophic implications of the continuous increase of the average temperature. The construction industry and the housing sector in particular, is one of the main contributors to the increased CO_2 emissions.

There are various sources contributing to the Greenhouse Effect. The built environment for example accounts for a large proportion of GHG emissions. The housing sector in the UK, alone, in 2004 accounted for 27% of the UK's total CO_2 emissions. It is estimated that around 225,000 units per year are needed to meet the UK market demand representing only 1% addition per year to the existing stock (25 million dwelling). 88% of the existing stock is expected to be still operational in 2050; representing a major challenge to the reduction of CO_2 emissions. Nevertheless, climate change initiatives predominantly target new build. Offsite production (OSP)/prefabrication of dwellings, through the efficient design principles, controlled manufacturing environment, and integrating RE technologies can help reduce CO_2 emissions significantly. There are currently wide ranges of RE technologies for zero-carbon power production in dwellings on the micro-level. These include e.g. photovoltaic cells (PV), wind generation (GW), and Combined Heat and Power (CHP).

This he paper attempts to shed light on the implications of climate change in general, and to investigate the measures taken by, and the role of the UK construction industry in addressing the challenge of minimising the CO_2 emissions in the atmosphere. This necessitated exploring the potentials of combining energy efficiency measures with RE technologies in existing stock and new build using offsite produced housing.

The paper finally concludes with examples for the successful integration RE with OSP, and outlines measures to be taken into consideration when integrating RE technologies in general and when using OSP in particular.

2. CLIMATE CHANGE AND THE GREEN HOUSE GAS EMISSIONS

The greenhouse (GH) effect is a natural phenomenon which helps regulate the temperature of earth. In the case of the disappearance of all the greenhouse gases, the earth would become much colder and would not support life (EPA, 2009). Human activities' added GHG to the atmosphere contribute to the rise of the earth's average temperature (Figure 1). Climate research concluded that the world's present GH levels are unprecedented for the last 420,000 years, and that carbon and temperature levels are "inextricably linked in a lockstep relationship" (Sweet, 2006). This led to the consensus since early 1990s that human activities contribute 'alarmingly' to the world's global warming (Ürge-Vorsatz et al., 2007; Lisø, 2006).

Human activities' sources for increased concentration of GHG, encompass burning fossil fuels such as coal, natural gas, and oil to generate power for cars, factories, power plants, homes, offices, etc.; in addition to cutting down trees, generating waste and farming (EPA, 2009). The increase in GHG emissions and consequently climate change would result in ocean waters becoming more acidic, sea level rise threatening coastal areas, fiercer cyclonic storms etc. It is warned that increase in GHG would result in change in local habitats to the extent that massive species extinctions could be expected at the end of the century if the situation continues and intensifies (Sweet, 2006; Stern, 2006).

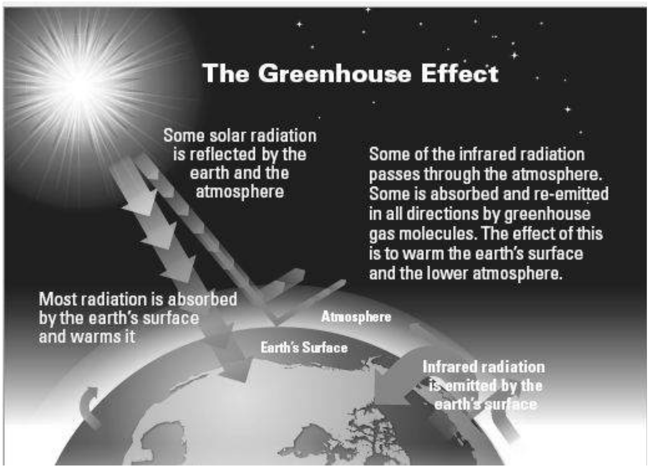

Figure 1: The Greenhouse Effect (EPA, 2009)

GHG emissions increased considerably by 70% between 1970 and 2004 (IPCC, 2007; UNEP, 2009) - Figure 2. These gases encompass mainly Carbon dioxide (CO2), Methane (CH4), Nitrous Oxide (N2O) and halocarbons (a group of gases containing fluorine, chlorine or bromine). CO2 contribute to about 70% of the GH effect (IPCC, 2007; DECC, 2009); where fossil fuel represents the main source for the large concentration of CO2 in the atmosphere. Figure 3, presents a breakdown of the main activities responsible for emitting CO2 (UNEP, 2009).

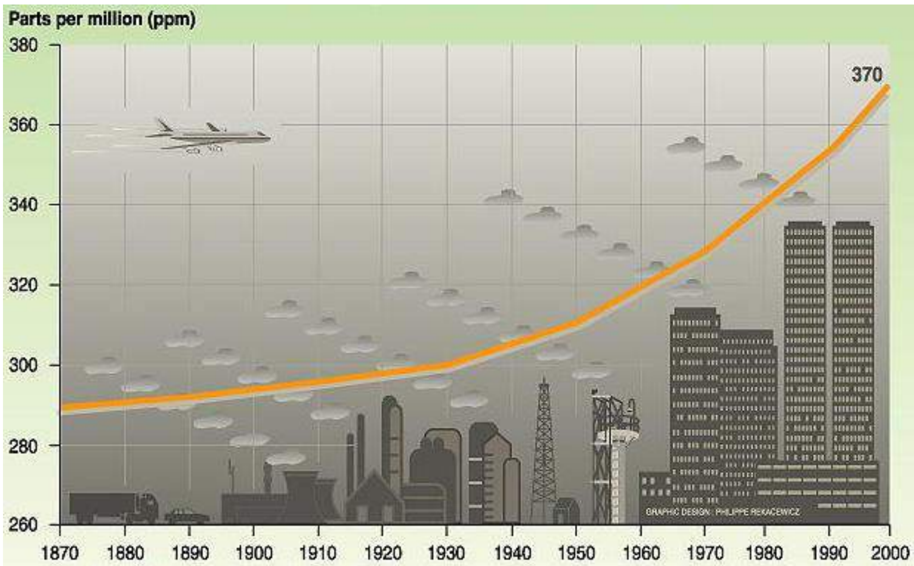

Figure 2: Global atmospheric concentration of CO2 (UNEP, 2009)

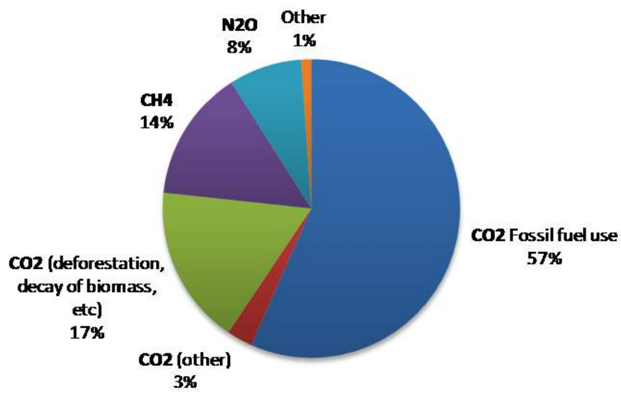

Figure 3: Breakdown of human activities' resultant CO2 emissions

The Kyoto Protocol (launched in 1997) is an international agreement - linked to the United Nations Framework Convention on Climate Change - which sets binding targets for 37 industrialised countries and the European Community for reducing GHG emissions (UNFCC, 2010).

According to the Kyoto Protocol, developed countries are bound to meet certain greenhouse gas emissions reductions by 2008-12 relative to a 1990 baseline. Developing countries, however, were not subject to any emissions requirements in that period. The protocol covers six greenhouse gases produced by human activities: carbon dioxide, methane, nitrous oxide, hydrofluorocarbons, perfluorocarbons, and sulphur hexafluoride.

3. RENEWABLE ENERGY AND ENERGY EFFICIENCY

Renewable Energy is any energy source that is naturally (re)generated and is not depleted through continuous use; these include non-carbon sources such as solar energy, hydropower, wind, tide and waves and geothermal heat, as well as carbon-neutral technologies such as biomass (Verbuggen, et al., 2010). To comply with the Code for Sustainable Home (CSH), the UK Government has set a target that 20% of the energy in the UK be generated from renewable sources by 2020 (DCLG, 2009). While this aspiration was perceived as 'achievable'; the International Energy Agency in Paris, was pessimistic in their prediction that the world by 2030 would still be supplied through fossil fuel resources 82%, whereas non-carbon renewable energy sources would only supply 6% (Ferrey, 2010). The total RE energy used in the UK in 2008, were about 5.90 million tonnes of oil equivalent; with biomass representing 81% use (DEEC, 2009) – Figure 4.

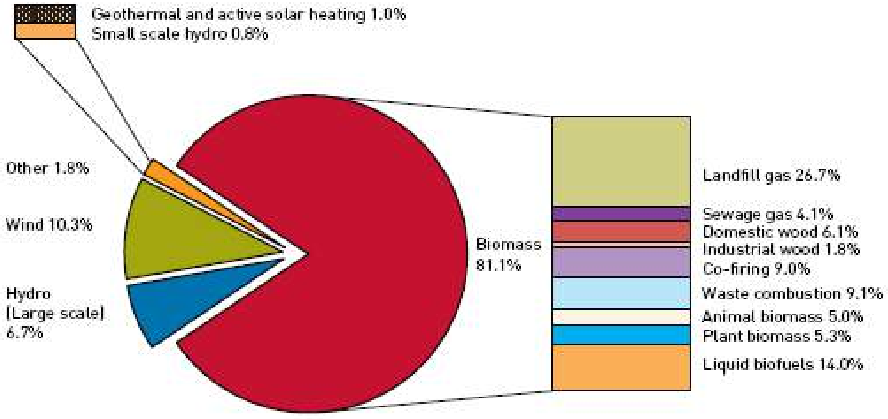

Figure 4: Renewable Energy sources in 200 (DEEC, 2009)

Although there is consensus that RE technologies may help reduce CO2 emissions; it is criticised for being economically and even (in some cases) environmentally unviable (Bradely Jr., 1997; EST, 2005). Supporters of RE, however, argued that the anticipated increase in upfront costs (about 2%) are estimated to result in life cycle savings of 20% of total construction costs, i.e more than ten times the initial investment (Miller and Buys, 2008). According to Figure 5, PV, biomass boiler, and solar hot water are mainly used in smaller developments; whereas bio-energy CHP are commonly used in larger developments. Consequently the use of RE in smaller developments accrue larger costs than in larger developments (UK-GBC, 2008; EST, 2005). Hence, setting constraints on the type of technologies that can be used for the different developments.

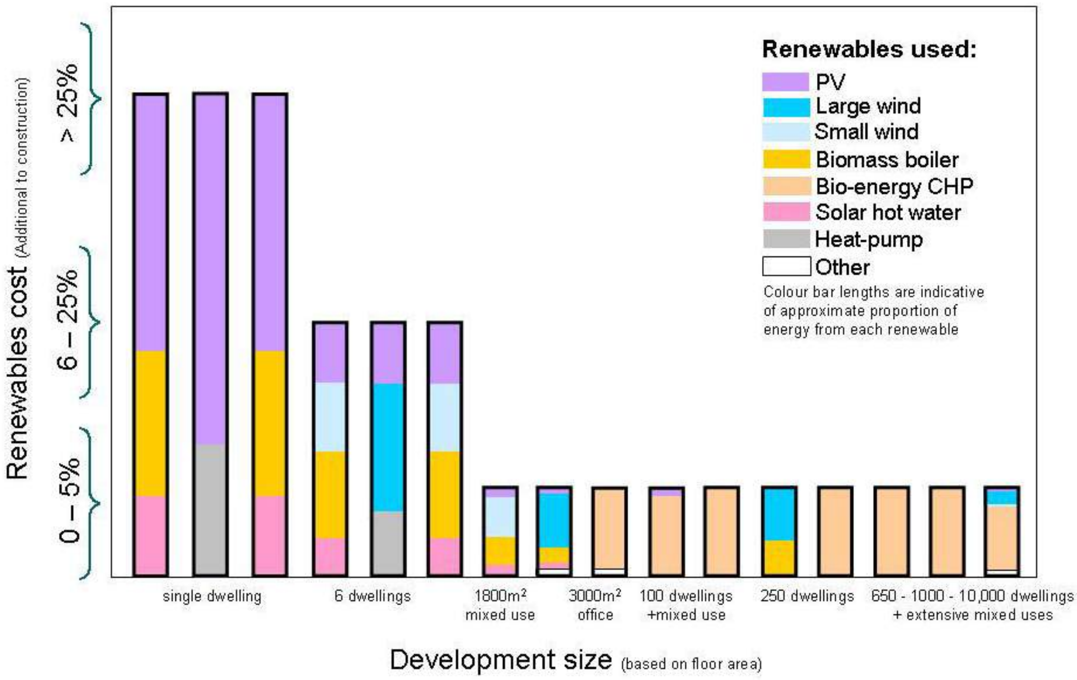

Figure 5: Zero-Carbon Case Studies projecting RE used, cost, and development size

Major barriers to the successful deployment of RE are debated in literature to encompass technological barrier, geographical limitations, economical/financial barrier, reliability, and the availability of various technologies in the market (EST, 2005; Ürge-Vorsatz, 2007; Osmani and O'Reilly, 2009; Verbuggen, et al., 2010). In the same context, Bradley Jr. (1997) suggested that some RE technologies are more economically and environmentally viable than others; arguing that a number of 'once promising' technologies started to be questioned on economic and/or environmental grounds, such as Wind power, solar power, biomass, and geothermal. In addition, other major barriers to the implementation of RE technologies, and thus achieving zero-carbon homes, was the definition used and the uncertainty surrounding the provision of on-site RE (Osmani and O'Reilly, 2009; UK-GBC, 2008).

From an implementation perspective, there is a major concern about micro-renewable being 'bolted-on', as damage has occurred after their installations. This may have contributed to the criticism that the integration of renewable technologies into small scale developments, are currently unreliable, unfeasible to integrate in certain situations; and are therefore believed to be installed to the detriment of profits, with no consideration to space and aesthetic requirements (Osmani and O'Reilly, 2009; RAB, 2007). In order to better appreciate the viability of various RE technologies, EST (2005) mapped the different technologies with regards to their suitability for the various development sizes and housing types (Table 1); where rural housing is more suitable for the majority of RE technologies; as opposed to the other development sizes, where some restrictions may apply.

Table 1: New and renewable energy technologies and their suitability for the various developments (EST, 2005)

	Generates heat	Generates power	High-density urban housing	Low-density urban housing	Distributed suburban housing	Rural housing
CHP	✓	✓	Very suitable	Not suitable	Not suitable	Not suitable
Micro-CHP	✓	✓	Not suitable	Sometimes suitable	Very suitable	Very suitable
Solar water heating	✓		Very suitable with communal heating or CHP	Very suitable	Very suitable	Very suitable
PV electricity		✓	Sometimes suitable	Very suitable	Very suitable	Very suitable
Windpower		✓	Not suitable for on-site generation*	Not suitable for on-site generation*	Sometimes suitable	Very suitable
Wood fuel boilers	✓		Generally suitable with communal heating	Sometimes suitable	Sometimes suitable	Very suitable
Ground source heat pumps	✓		Very suitable	Sometimes suitable for groups of dwellings	Very suitable	Very suitable

According to the Renewable Advisory Board (RAB) (2007), the market for onsite energy technology in 2016 is estimated at £2.3 billion/year at 2007 prices, with a proposed installer and maintenance skill requirements representing a 30 fold increase over the 2006 requirements. Figure 6 illustrates the change in uptake of the 10 top technologies; where PV, biomass CHP, and micro CHP are expected to increase considerably. However, the reported problems with regards to obtaining trained installers and maintenance personnel for low carbon technologies; create a major challenge for providing the installation and maintenance skills requirements in addition to any new skills required by the legislation (RAB, 2007).

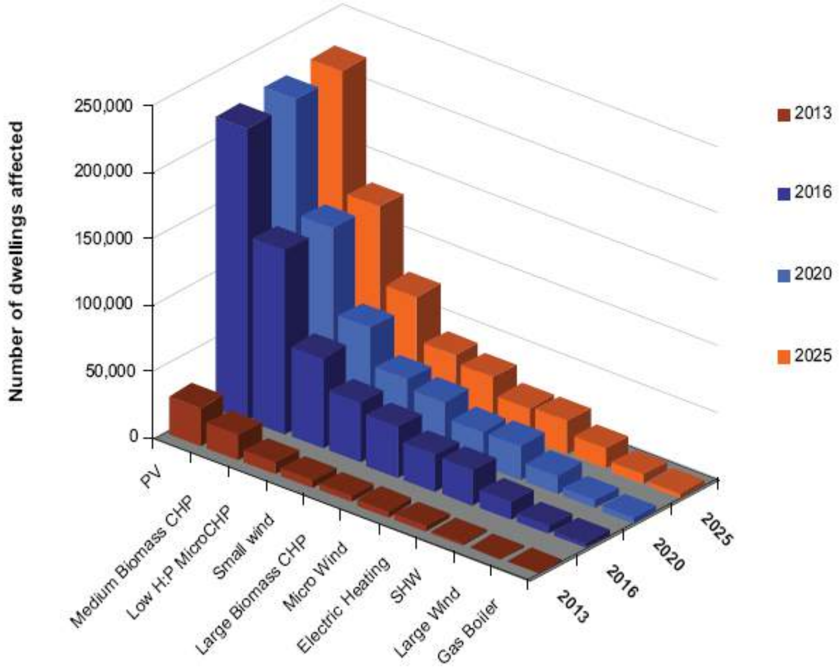

Figure 6: Change in uptake of the 10 top technologies over the period 2013 -2025

The Successful deployment of RE are anticipated to occur when capacity loads are managed, RE technologies are combined with high energy efficiency measures; in addition to good paring of various RE options to provide the requested service (Verbuggen, et al., 2010).

Energy efficiency measures, are aimed to reduce the demand for energy and resources, and are generally perceived as more robust and longer lasting than just depending on the 'supply side' measures such as low and zero-carbon generation technologies (UK-GBC; 2008). In order to help attain energy efficiency, meet the required standards, and reduce cost; housebuilders, advocated the greater implementation of offsite construction in housing (Osmani and O'Reilly, 2009).

4. THE CONSTRUCTION INDUSTRY AND GHG EMISSIONS

The UK construction industry is the second largest in the European Union (EU) - (DTI, 2006), and the sixths largest industry in the UK, generating an approximate output of £65 billion annually (Adamson and Pollington, 2006). In addition to its economical importance, the UK construction possesses a high political as well as social profile due to being a major employer, its key role in providing housing, and consequently it's impact on the environment (European Commission, 2006; SSDA, 2006; Killip, 2008).

The UK construction industry output represents about 52% new work; and 48% repairs and maintenance; where the public sector accounts for 37% of the construction industry business (NAO, 2001; Kirkham et al., 2004; Heimonen et al., 2007; Killip, 2008). Notwithstanding these issues, the UK construction has long been criticised for its levels of wastage and fragmentation (Gonsález, 1999) which adversely affects its performance and productivity (Emmerson, 1962; Banwell, 1964; Latham, 1994; Egan, 1998; EMCC, 2005b; Morton, 2002; 2004; Lambert, 2003; Anumba, 2008). This underperformance of the UK construction industry may, to a large extent, contribute to the increase of the GHG emissions, and consequently the climate change.

Buildings worldwide use about 40% of all energy consumed worldwide, resulting in a carbon footprint exceeding those of all transportation combined (WBCSD, 2009). This was arguably attributed to poor design, inadequate technology, and the inappropriate behaviour of end users (WBCSD, 2009). Homes, alone, in the UK are estimated to contribute to 27% of the UK's total carbon emissions (Killip, 2008; Pérez-Lombard, 2008).

In response to the Kyoto Protocol, the UK Government is targeting the cut the UK carbon emissions by 80% by 2050. This commitment require that all new homes to be zero-carbon by 2016 and all remaining new buildings to be zero-carbon by 2020 (Jha, 2010). There are about 25 million dwellings in the UK (Lowe, 2007), the majority of which (85%) will still be operational in 2050; and hence represent a challenge for achieving CO2 reduction (Ürge-Vorsatz et al., 2007; Killip, 2008; Power, 2008; Jha, 2010) – Figure 7. Despite the bulk of negative environmental impacts are attributed to the large and 'inefficient' stock of existing homes; the Government initiatives predominately target the emissions in new developments - about 9 million homes by 2050 - (Killip, 2008).

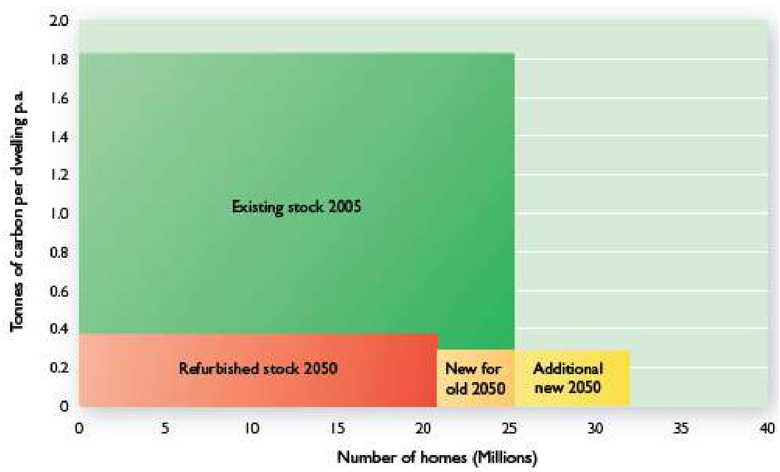

Figure 7: CO2 emissions from refurbished and new-build housing (Killip, 2008)

4.1 RETROFITTING EXISTING STOCK AND THE USE OF RE

Existing Stock is criticised for being inefficient due to energy loss – Figure 8. In order to achieve maximum efficiency, roofs, outer walls, under floors, windows, doors and heating systems need to be well insulated (Power, 2008). In this context, buildability is critical for delivering low-carbon refurbishment; key elements of which are suggested to encompass - among others - practicality, replicability, affordability, reliability, and availability (Killip, 2008). This, however, represents a considerable challenge to achieve; especially that refurbishment work bears high elements of risk and uncertainty (Egbu, 2005). Nevertheless, if done properly, refurbishment/renovation of exiting stock is expected to outperform new build (Power, 2008).

Lowe (2007) advocated that upgrading the whole of the existing UK stock by 2050 is would require about £200 billion (£3.5 – 6.5 billion/year); which represents less than 1% of GDP/year and around 15% of what may be spent on new housing. However, low-carbon refurbishment work is still at its infancy; and depends largely on inexperienced SMEs (Killip, 2008; Power, 2008).

Figure 8: Main building elements and proportions of heat loss due to lack of efficient insulation (Power, 2008)

The suitability for RE on-site solutions to meet the proposed low and zero-carbon legislation depends largely on the nature of the developments being constructed. For example, flats' developments limit access to roof area for roof based renewable; whereas small urban in-fill development is unlikely to have access to a site wide CHP scheme. From a density perspective, the development density would affect the heat load density and therefore the viability of site wide solutions. Furthermore, urban areas affect the viability and output from wind turbines (RAB, 2007).

Economics and feasibility of site-wide schemes for meeting low- and zero-carbon often improve with increased development size (Figure 9). Nevertheless, despite PV technology being one of the more expensive RE technologies, it is connected to around 70% of homes. This was attributable to it being the only RE technology which is accessible to almost all development sizes and house types (RAB, 2007). Generally, RE technologies are commonly combined in pairs for each development size and often include the CHP technology to help meet energy requirements (RAB, 2007).

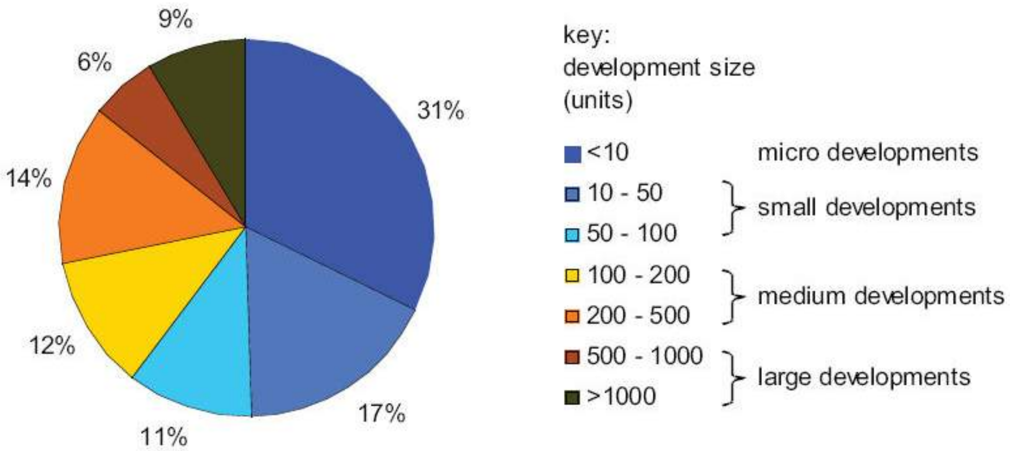

Figure 9: Number of homes by development size (RAB, 2007)

4.2 RATIONALE FOR COMBINING OFFSITE PRODUCTION WITH RE TECHNOLOGIES

While the existing stock represent the real challenge for reducing CO2 emissions, new build should not be neglected. The number of new build homes in the UK in 2005/6 was estimated at 213,700. Figure 9, illustrates the current projections for new households to 2025 to exceed 300,000 (RAB, 2007). The UK Government, however, is seemingly failing to meet housing market demand (Venables and Courtney, 2004). Hence, OSP was perceived as a means to meet housing market demands.

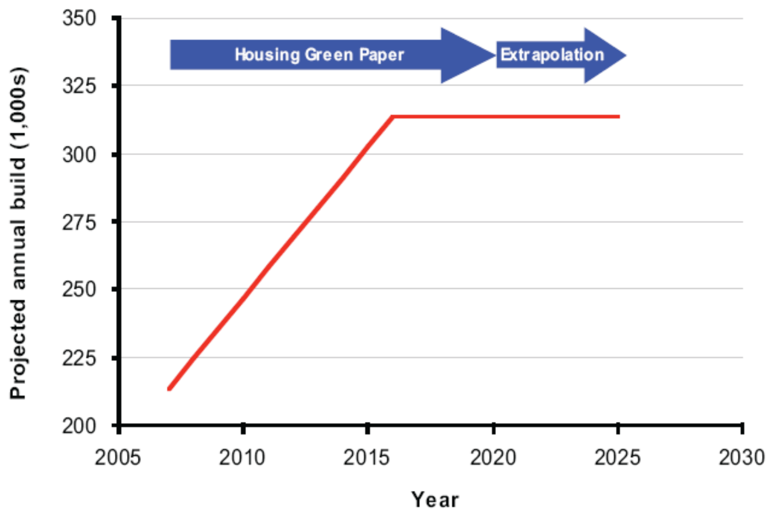

Figure 9: Projected new build to 2025 (RAB, 2005)

Offsite production (OSP) is not a new phenomenon. It evolved as a response to sporadic urge demand for buildings and facilities (Gibb, 1999; Leabue and Viñals, 2003). Despite the, the historic stigma associated with OSP (Hall and Vidén, 2005); there were recent calls for a wider uptake of OSP in the World in general, and in Europe and the UK in particular (O'Brien et al., 2000; Kazi et al., 2007; Ogden, 2007; buildoffsite, 2008). Major drivers cited for using OSP, in addition to alleviating the shortages in housing supply, skills shortage/gaps, low housing quality, was the environmental performance of the final product (NHBC, 2006; NAO, 2005; Goodier and Gibb, 2005). A number of OSP sustainability impacts include better quality, less waste, improved health and safety, improved environmental performance, and greater efficiency in the use of resources (Gorgolewski, 2003; NAO, 2005; DTI, 2004; Egan, 1998; NHBC; 2006; Leabue and Viñals, 2003).

Based on a comparative study, Barrett and Wiedmann (2007) concluded that OSP house out-performs onsite construction house in terms of its GHG emissions due to the light design combined with high levels of energy efficiency. The four major components that contribute to CO2 emissions during the traditional construction of a new home, include material used, contingency and over ordering (an extra of 10%), and consequently waste. As opposed to traditional construction, OSP practices allow more control, fewer material, less waste, less over-ordering and contingencies; and consequently is favoured compared to traditional construction.

5. OFFSITE PRODUCTION AND THE USE OF RE TECHNOLOGIES

The Code of Sustainable homes (CSH) Level 4 for affordable and social housing mandates the use of renewable energy. It is however, warned that RE is more than just ‘slapping’ a few solar panels on the roof of buildings; rather require the integration of complex technologies and specialised skills which may be new to the traditional construction industry (Mtech, 2007). Thus, it is argued that the careful integration of OSP and RE technologies may help achieve substantial sustainable improvements, due to the rigorous inspection/testing regimes in a controlled environment, which consequently is anticipated to reduce time and money (Mtech, 2007).

Due to the controlled working environment, OSP arguably combine both energy efficiency and integrated RE technologies to meet the zero Carbon target, and still be profitable. Seksui Chemical Co., for example, one of the largest PV housing manufacturing in Japan, increased the delivery of their PV solar homes from 46% in FY2003 to 52% in FY 2004 in response to the market demand for high quality sustainable housing (Noguchi, 2005; Sekisui, 2005). In this respect, Sekisui homes benefit from lower utility cost due to superior air-tightness and thermal insulation of the unit (energy efficiency), and through mass production to equip homes with solar electric system as standard provision rather than an option; which further enables the selling of surplus power generated during the day (Sekisui, 2005) – Figure 10. Results suggested that Japanese manufactured housing is about 8% more expensive than the conventional one (Noguchi, 2005).

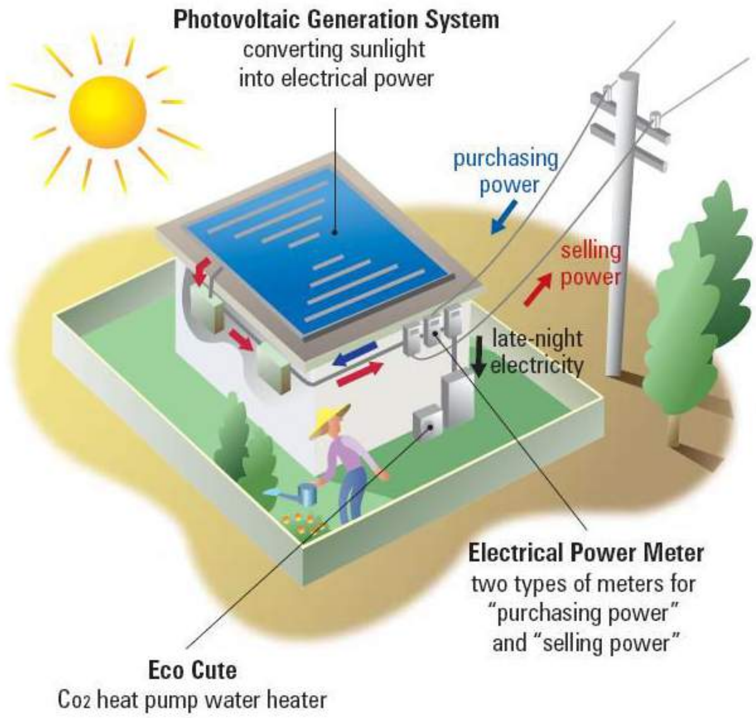

Figure 10: Sekisui OSP homes integrated PV technology (Sekisui, 2005)

While there are successful examples for combining energy efficiency with RE technologies worldwide, some examples were proven to be underperforming due to a number of reasons. In an attempt to evaluate energy performance in six ‘high-performance buildings’ which combine energy efficiency and RE technologies; Torcellini et al. (2004) identified problems that are related to the site and climate - in which buildings are built, and other problems related to the technology itself - such as operational problems as well as occupants behaviour problems. In general although the different buildings studied were perceived as 'good performer', a number of factors have been identified which contributed to the 'lower than expected performance' (Torcellini et al.; 2004); these included:

- Design teams were too optimistic about the behaviour of the occupants towards operating the new system.
- Computer simulations carried out created idealistic controls, however, actual performance varied
- Energy performance was higher and energy production was lower than predicted.
- Thermal bridging was accounted for in models during the design phase, however, construction details and specs were not always installed as designed
- Shading of PV arrays by snow, tress, and adjacent building shadows reduced the performance of the PV system
- Even though all of these buildings were commissioned prior to occupancy, commissioning did not always catch these problems especially that the commissioning does not address the overall performance of the building once it is operational.

It was concluded that design flaws, installation errors, and/or improper maintenance were the main causes for (RE) systems' underperformance (Torcellini et al., 2004). It was further recommended that PV systems should be integrated into the design process as an integral part of the building function (Torcellini et al., 2004). In conclusion, it was advised that RE systems should be designed after the energy efficiency measures are applied to buildings, hence, adding value to the RE systems for offsetting a larger portion of the overall building electricity load (Torcellini et al., 2004).

6. CONCLUSION AND FUTURE RESEARCH

The whole world is challenged to cut CO2 emissions, the major cause for the Greenhouse effect, and consequently the climate change. The UK Government has set a target that 20% of energy in the UK be generated from renewable sources by 2020. While there is general agreements that RE technologies may help reduce CO2 emissions; some authors debated the environmental and economical viability of such technologies.

There is a variety of RE technologies available in the UK market which is evolving rapidly. It is estimated that RE onsite technologies to grow considerably by 2016. However, the successful deployment of RE technologies depends, to a large extent, on the size and type of development. Furthermore, skills shortages have been cited as another major challenge for meeting the set targets.

Although the existing building stock represents the major challenge for cutting the CO2 emissions, the majority of climate change initiatives predominately target new build. The current practice depends on retrofitting RE technologies into existing buildings, resulting in underperformance of the technologies due to installation and maintenance problems. It is argued that the dependence on RE technologies solely is not enough to help meet energy requirements. Hence, the combination RE technologies together with satisfying energy efficiency measures are advised to meet the energy targets. Furthermore, it is recommended that RE technologies need to be incorporated from the outset into the design process as an integral part of the building function (Torcellini et al., 2004).

Drawing on the problems arising to incorporate RE technologies into existing buildings, the need for combining energy efficiency measures with RE technologies, the shortages in installation and maintenance skills, and the lack of proper commissioning etc.; offsite production/ prefabrication is anticipated to help mitigate those problems. This is, to a large extent, attributed to the OSP concept of design-to manufacture-logistics –and-assembly (DMLS) and hence 'treats' the building as a system rather than individual components.

Further research is expected to explore further case studies to empirically test the qualitative results and to quantify the implications of the post integration/retrofitting of RE technologies into existing building stock in general and into OSP buildings in particular.

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