# The effect of demand-side measures on the uptake of micro-biomass in domestic dwellings in the UK

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## Abstract
The Carbon Trust Biomass Sector Review suggests that, in the UK, biomass could provide as much as 79 TWh/yr of sustainable energy (from surplus forestry crops, waste wood from industry, agricultural waste and assuming a maximum potential of energy crops). However, the total UK domestic space heating load is 374 TWh/yr[1]. The countrywide implementation of domestic biomass boilers is largely dependant on how the heating demand of the dwelling is managed. TARBASE, a Carbon-Trust funded low-energy building project, has defined several domestic buildings, indicative of the UK building stock, with demand-side refurbishments. With the subsequent reduction in building heating requirements, and scaling up the savings of these individual buildings to the entire stock, it is possible to dramatically reduce the biomass required to heat dwellings in the UK. This leads to the possibility of biomass heating becoming a feasible, and carbon-saving, alternative to fossil fuel heating on a countrywide scale. The improved penetration of micro-biomass in this context is therefore used as a metric to show the effect of demand-side improvements. Other uses of biomass, particularly with regards to transport and commercial buildings, are not considered though it will comprise future work.

## Introduction
TARBASE is a low-energy building project that aims to demonstrate energy-saving interventions in UK buildings that might achieve $CO_2$ reductions of 50 % by the year 2030. One of the areas of study is that of demand-side measures for reducing the heating requirements of buildings. A scenario is taken where biomass is to be used in domestic biomass boilers to meet heating and domestic hot water demands. The extent to which this is possible, on a countrywide scale, will be assessed along with the effect that demand-side interventions can have on the number of homes to be heated by biomass. All demand-side interventions involve building fabric changes as specified by the TARBASE project[2]. In the following discussions, "thermal demand" will refer to both space heating and domestic hot water heating.

## Biomass resources
Based on Carbon Trust (UK) figures[3], the available biomass resources will are quantified in Table 1.

**Table 1 – Present biomass resource and that potentially available in the UK**

| | TWh/yr available | |
|---|---|---|
| | Now | Potential |
| Forestry waste | 6 | 6 |
| Industrial waste | 22 | 22 |
| Agriculture | 13 | 13 |
| Biomass crops | 0.2 | 38 |
| **Total** | **41.2** | **79** |

**Table 2 – Summary of domestic variants with thermal demand reductions**

| Variant no. | Building description | Location | Internal gains (W) | Heating and DHW requirements (kWh/yr) | | |
|---|---|---|---|---|---|---|
| | | | | pre-refurb | post-refurb | % saving |
| 1 | 1946 Semi-detached, brick, filled cavity | Manchester | 669 | 7871 | 4816 | 38.8 |
| 2 | 1900 Terraced, sandstone | Edinburgh | 413 | 10958 | 5777 | 47.3 |
| 3 | 1980 Semi-detached, brick/blockwork | London | 458 | 3749 | 2386 | 36.4 |
| 4 | 1988 Detached, brick, ventilated cavity | Edinburgh | 710 | 13095 | 7726 | 41.0 |
| 5 | 2002 Detached, clay brickwork | London | 708 | 7416 | 5124 | 30.9 |
| 6 | Pre-1900 Detached, brick/blockwork | Manchester | 683 | 18199 | 10999 | 39.6 |

#### FORESTRY WASTE

Woodfuel biomass currently has a very small penetration into UK heating demands[4]. The estimates for forestry residue in Scotland alone appear to deviate wildly depending on the assumptions made – while Scotland's Renewable Resource[5] suggests 356,140 oven-dried tonnes (odt) are available, a Forestry Commission estimate[6] puts the figure at a much larger 1,500,000 odt (where odt has the mass of moisture in biomass removed – this drying process improves the performance of the fuel). However, Carbon Trust[3] produces a more conservative UK-wide estimate of just over 1 million odt currently available, equating to 6 TWh/yr.

#### INDUSTRIAL WASTE

This covers a wide range of wood waste (e.g construction industries). The government organisation WRAP (Waste and Resources Action Programme) estimates that 2 million tonnes of waste wood are produced by businesses every year[7]. Carbon Trust suggest that 22 TWh/yr is currently available for biomass usage.

#### AGRICULTURE

Dry agricultural residue, such as wheat, barley and sugar beet tops, can also be utilised for biomass energy. While 73 TWh/yr of this material is available, much of it, such as straw, is used for other processes. However, an estimated 13 TWh/yr is unused and so can contribute towards energy production.

#### BIOMASS CROPS

The area in the UK available for biomass crops is, again, open to interpretation. Some studies[8] suggest a relatively large figure of 1,509,000 ha of suitable land area (based on 10 % of current grassland and crop area). Carbon Trust suggests a more conservative 680,000 ha (based on land that is currently set-aside and would not require displacement of food crops). This study uses a range of values for the available land area that could be used for biomass production, with an upper limit of 680,000 hectares (quoted in the Carbon Trust report), which is 2.8 % of the entire land area of the UK. To put this into context, approximately 6 million hectares (25 % of total land area) are currently used for arable farming in the UK[9]. While these woody crops (e.g. miscanthus) are not currently grown on a large scale (amounting to just 0.2 TWh/yr in deliverable energy), an area of 680,000 ha could produce in the region of 38 TWh/yr. This is a maximum potential area for use with domestic micro-biomass, used for illustrative purposes only. In reality there will be competition

## Domestic thermal requirements

The TARBASE methodology is to define existing individual buildings (that are indicative of the stock) and apply quantified energy-saving measures. There are six defined TARBASE variant dwellings with specified heating loads. The range of savings for these variants will be used to estimate the range of savings for all UK dwellings.

#### TARBASE DOMESTIC VARIANTS

The variants account for over 28 % of the entire domestic stock in the UK[10] and are briefly defined in Table 2. They are used for consistency with the TARBASE programme and are justified in more detail elsewhere. The internal gains for each dwelling, shown in Table 2, are calculated based on expected occupancy and end-use technology. Further discussion of these buildings can be found elsewhere[2]. From these assumptions, six different thermal demands are calculated, all of which can then be reduced by simple demand-side measures.

#### APPLYING DEMAND-SIDE INTERVENTIONS

The interventions consist of improving the U-value of the glazing, walls and roof and also using improved ventilation with heat recovery (see Table 3). The improved wall U-value is based on implementing external wall insulation (for 40 % of the total exposed area). Table 2 shows the resulting reduction in thermal demand (varying between 31 and 47 %). These figures include the energy requirements for domestic hot water (DHW), which are assumed to stay the same before and after interventions. The kWh figures given are the requirements of each dwelling, so the actual energy consumptions will have to take into account the boiler efficiency.

## Effect of thermal reductions on biomass penetration

#### THERMAL DEMAND REDUCTIONS NECESSARY FOR COUNTRY-WIDE PENETRATION OF BIOMASS

The total space heating requirements of the UK domestic stock has been approximated at 374 TWh/yr[1] (for 25.6 million homes). Also, average dwelling hot water heating requirements can be estimated from the British Gas Formula[11] as being 1649 kWh/yr (for 2.3 people per house) or 42 TWh/yr for the whole stock. Using these figures with the Carbon Trust estimations of maximum energy yield of UK biomass (Table 1), we can calculate the necessary reduction in thermal requirements for this biomass energy yield to satisfy different penetrations. Figure 1 is based on a current UK thermal demand of 417 TWh/yr (heating and hot water) and available biomass energy yield of 79 TWh/yr (being put through biomass boilers with 85 % effi-

**Table 3 – Summary of Tarbase domestic demand-side refurbishments**

| Variant No. | Loft Insulation (mm mineral wool) | | Glazing (u-value, W/m2.K) | | Infiltration (ach) | | MVHR | | External Insulation | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Baseline | Technical intervention | Baseline | Technical intervention | Baseline | Technical intervention | Baseline | Technical intervention | Baseline | Technical intervention |
| 1 | 100 | 300 | 2.75 | 1.4 0 | 0.75 | Interventions that cumulatively reduce infiltration by 70% | 0.8ach met by combination of infiltration and ventilation | 0.8ach met by combination of infiltration and ventilation , MVHR with efficiency of 85% | No external insulation | 100mm of PU on timbe r battens, 10mm of screed or render |
| 2 | 100 | 300 | 2.75 | 1.40 | 0.75 | | | | | |
| 3 | 100 | 300 | 5.10 | 1.40 | 0.57 | | | | | |
| 4 | 100 | 300 | 2.75 | 1.40 | 0.39 | | | | | |
| 5 | 250 | 300 | 2.00 | 1.40 | 0.75 | | | | | |
| 6 | 100 | 300 | 5.10 | 1.40 | 0.57 | | | | | |

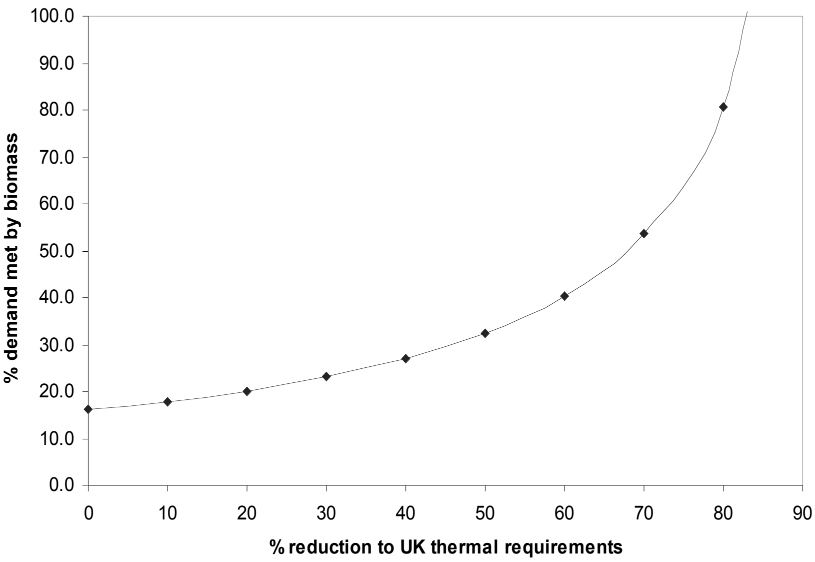


*Figure 1 – Percentage of UK thermal demand met by biomass with reductions to thermal requirements through fabric refurbishments*

ciency[6] – this efficiency assumes a dried fuel, therefore relating to gross calorific value). As already mentioned, this is clearly just one option for biomass (others include biomass-CHP or more efficient pellet boilers). The result suggests that micro-biomass boilers are unlikely to meet total UK domestic thermal requirements – for this to be feasible, the thermal demand of the "average" UK dwelling would have to be reduced by 84 %. However, partial penetration of biomass appears more favourable. For example, reducing thermal requirements by 50 % implies that biomass could be responsible for 32 % of the UK domestic thermal demand. This is discussed later.

## REALISTIC PENETRATION OF BIOMASS FOR DOMESTIC THERMAL REQUIREMENTS

The defined domestic variants are demonstrations of the effect on thermal demand that simple fabric refurbishments can have. It is predicted that thermal requirement savings of between 31 % and 47 % would be possible (based on the refurbishments of Table 3). It is useful to see how such savings, applied across the domestic building stock, will affect the viability of biomass as a domestic fuel. Figure 2 shows how much of the UK thermal demand could be satisfied by biomass, again with an 85 % efficiency boiler, with an increasing area of energy crops. Also in Figure 2 we see how the situation changes for thermal demand reductions of 31 % and 47 % respectively.

It can be seen from Figure 2 that even with no energy crops and without any reduction in demand, over 8 % of UK houses could have their thermal demand satisfied by biomass (from waste wood from the sources mentioned previously). With a 47 % reduction in national demand (i.e. the maximum predicted from Table 2), the proportion of biomass meeting thermal demand, again with no energy crops present, increases to almost 15 %. When the existence of energy crops are added into the calculations, the predicted percentage rises to as much as 28 % (for 0.7 Mha energy crop area) of the UK domestic thermal demand satisfied by biomass boilers, depending on the level of demand-side interventions. Also, by extrapolating the top curve, even with a 47 % demand-side savings, it is estimated that an energy crop area of 4.3 Mha (18 % of the UK land area) would be required to satisfy the entire UK thermal demand.

The interventions ascribed to the dwellings are relatively conservative – it could be argued that even greater savings are possible across the domestic stock than have been described here. Firstly, only 40 % of external wall area has been insulated, and it is assumed that the external wall cladding is the only insulation measure undertaken. The 40 % figure is based on that fact that approximately 20 % of the of the wall area (at the base) would require damp-proofing and so only 80 % might be suiTable for insulation. Of this remainder, there are issues relating to

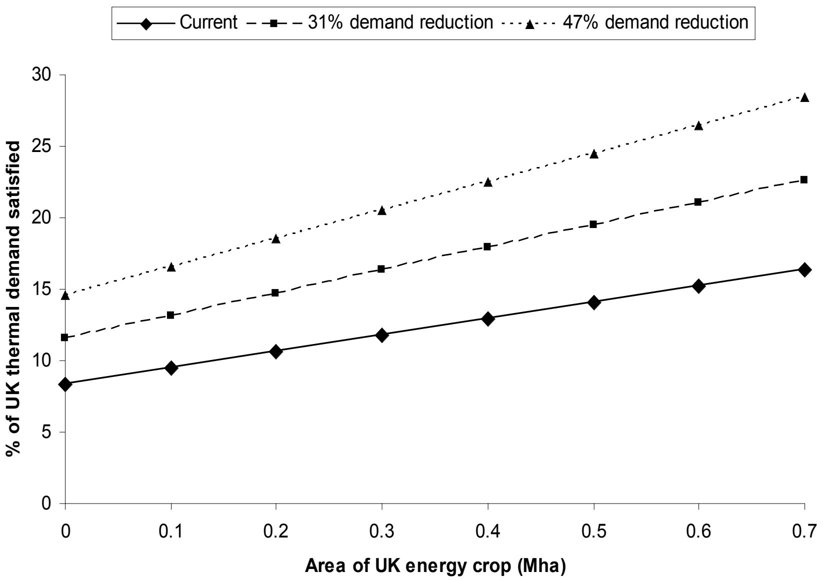


*Figure 2 – Proportion of UK thermal demand potentially satisfied by biomass as a function of energy crop area, with demand-side reductions*

**Table 4 – Estimated $CO_2$ savings (in Mtonnes/year) from demand-side measures and biomass use**

| Energy crop area (Mha) | Demand side measures | | |
|---|---|---|---|
| | None | 31% reduction | 47% reduction |
| 0 | 7.9 | 37.5 | 52.8 |
| 0.1 | 8.9 | 38.6 | 53.8 |
| 0.2 | 10.0 | 39.6 | 54.9 |
| 0.3 | 11.1 | 40.7 | 56.0 |
| 0.4 | 12.2 | 41.8 | 57.1 |
| 0.5 | 13.2 | 42.8 | 58.1 |
| 0.6 | 14.3 | 43.9 | 59.2 |
| 0.7 | 15.4 | 45.0 | 60.3 |

the aesthetics of the façade (particularly at the front), hence the value of 40 % external wall area being deemed reasonable.

Also, all refurbishments are currently achievable– there is no reliance on future technology becoming available. For example, vacuum insulated systems have been shown to have an excellent thermal performance[12], with U-values of around 0.16 $W/m^2K$[13]. The performance of passive houses in Europe[14] would also encourage biomass fuels, with a much less fuel (and therefore less biomass deliveries) required.

## Carbon Assessment

The above energy savings can now be converted into carbon dioxide savings. The carbon intensity of domestic heating fuels (in kg of $CO_2$ per kWh of used thermal energy) is well documented[15,16]. A weighted carbon intensity for domestic heating can thus be approximated, found to be 0.22 $kgCO_2/kWh$ (accounting for gas, oil, coal and electric heating). This, unsurprisingly, is close to the respective value for gas (0.19 $kgCO_2/kWh$), which is by far the dominant fuel for heating homes in the UK. Table 4 shows the estimated carbon savings from introducing biomass and demand-side measures, compared to having no biomass domestic heating (and with the current UK domestic thermal demand). The conventional gas boiler is assumed to have an efficiency of 88 %. For such a situation, the domestic thermal energy consumption (for space and water heating) would be 473.5 TWh/yr, equivalent to 106 Mtonnes of $CO_2$.

Table 4 shows the amount of (mostly) fossil fuel that is displaced for different penetrations of biomass. A biomass fuel $CO_2$ intensity of 0.025 $kgCO_2/kWh$[15] accounts for manufacuring and transport of biomass fuel. The savings vary between 8 and 61 Mtonnes of $CO_2$ or 7 % and 57 % reductions respectively.

## Conclusions

Using TARBASE domestic building variants, with defined thermal characteristics, potential reductions for space heating have been identified as being applicable to the stock. Using these results, it is conservatively estimated that biomass could provide 28 % of the domestic heating load if demand-side reductions of 47 % were performed across the building stock and if there were no other application for the resource. For biomass to satisfy the entire domestic heating demand, it is estimated that an energy crop area of 4.3 Mha would be necessary (again assuming demand-side reductions of 47 %). The associated carbon savings ranged between 7 % and 57 % of the current baseline scenario, which includes the small embodied carbon associated with transport and manufacturing of biomass.

The results suggest that the current UK building stock is not in a suiTable condition for countrywide domestic biomass heating to become established. However, improving the conditions of these buildings makes biomass a more viable alternative to fossil fuels. It could also be argued that district schemes are more suiTable for biomass, with the logistics of transporting the fuel less of a problem. The effect that such systems might have on utilising the available biomass resource is an interesting area for continuing this research, as is biomass-CHP. Other advances in biomass technology (wood pellets, improved efficiency, etc.) should provide further opportunities.

The predictions quoted in this study are an estimation of the maximum potential of biomass based on realistic improvements to the building stock. It is suggested that biomass heating could achieve a substantial domestic market in the UK if other conditions, namely biomass infrastructure and building stock, are improved.

## References

1. 40 % House Report, Environmental Change Institute, University of Oxford (2005)
2. A.D.Peacock, M.Newborough and P.Banfill, "Tarbase – Technology Assessment for Radically Improving the Built Asset Base", World Renewable Energy Congress, Aberdeen, May 2005
3. Biomass Sector Review, Carbon Trust (2005)
4. H.McKay, "Environmental, economic, social and political drivers for increasing use of woodfuel as a renewable resource in Britain", Biomass and Bioenergy, 30, 308-315 (2006)
5. Scotland's Renewable Resources – Volume1:The Analysis, Scottish Executive (2001)
6. Forests for Scotland – Scottish Forestry Strategy, Scottish Executive (2000)
7. Wood – Stakeholder update, Waste and Resources Action Programme, May 2004
8. J.C.Clifton-Brown, P.F.Stampfl and M.B.Jones, "Miscanthus biomass production for energy in Europe..", Global Change Biology, 10, 509-518 (2004)
9. Draft Soil Strategy for England – A Consultation Paper, DEFRA, March 2001
10. House Conditioning Surveys in England and Scotland (1996)
11. R.Lowe and D.Johnston, "A field trial of mechanical ventilation with heat recovery in local authority, low-rise housing", Department of the Environment, November 1997
12. H.Simmler and S.Brunner, "Vacuum insulation panels..", Energy and Buildings, 37, 1122-1131 (2005)
13. T.Nussbaumer, K.Ghazi Wakili and Ch.Tanner, "Experimental and numerical investigation of the thermal performance of a protected vacuum-insulation system…", Applied Energy, 83, 841-855 (2006)
14. V.Badescu and B.Sicre, "Renewable energy for passive house heating. Part I: Building Description", Energy and Buildings, 35, 1077-1084 (2003)
15. The Government's Standard Assessment Procedure for Energy Rating of Dwellings, DEFRA (2005)
16. L.D.Shorrock and J.I.Utley, Domestic energy fact file, BRE (2003)