World fossil energy consumption entirely replaced by biomass as renewable source

Data

In 2011, world primary energy consumption was:

- 4059 Mtonne oil, of equivalent chemical formula $C_7H_{14}N_{0.1}O_{0.1}S_{0.3}$
  (=> molar weight = 110 g/mol), ρ = 0.88 kg/L
- 3 223 Gm^3 natural gas (=2905.6 Mtoe), ρ = 0.7 kg/m^3,
  → take as equivalent to methane CH_4 (=> molar weight = 16 g/mol)
- 7.5 Gtonne coal (=3724 Mtoe), heating value 20 MJ/kg, carbon content 0.5 carbon/kg coal
  (molar weight of carbon = 12 g/mol)

Emissions

1. The oil has a formula with MW=110 g/mol and emits 7 times the amount in CO_2 per mol of oil (= 7 x 44 g/mol = 308 g), hence the weight ratio CO_2-to-oil is 308/110 = 2.8.
In other words, burning 4059 Mtonne oil will emit 2.8 times the amount in CO_2 or
11.36 Gt CO_2

2. We burn 3223 Gm^3 * 0.7 kg/m^3 = 2256 Mtonne gas to CO_2 in a ratio of 1 CO_2 emitted for 1 CH_4 burned, or a molar mass ratio of 44/16 = 2.75, hence burning 2256 Mtonne of methane gas will emit 2.75 times this amount in CO_2, or
6.2 Gt CO2

3. We burn 7500 Mtonne coal * 0.5 Carbon/kg coal = 3750 Mtonne carbon, with a ratio of 1 CO_2 emitted for 1 C burned, or a molar mass ratio of 44/12 = 3.67, hence burning 3750 Mtonne carbon will emit 3.67 this amount in CO_2, or
13.75 Gt CO2

Total year emissions (from all fossil) are thus 11.36 + 6.2 + 13.75 = **31.3 Gt CO_2**
(44% from coal, 36% from oil, 20% from gas)

This is 31.3 Gt CO_2 / 7.1 billion people = **4.4 t CO_2 / person**

12275 Mtoe total primary energy consumption = 514 EJ = **16.3 TW**.yr/yr
(divide by 31'557'600 sec per year)
=> hence **2.3 kW per person** on the planet on average

Replacement

1.
We need 2 * 3724 Mtoe energy equivalent in wood to replace coal (to account for only half the electrical conversion efficiency, 20% instead of 40%) = 7450 Mtoe wood equivalent = 312 EJ = 18.35 Gt wood of 17 MJ/kg heating value. Compared with the yearly wood energy production in forests (32 Gtoe), we would require 1/4th (7.45 Gtoe).

If we can grow 2 kg per m^2 in renewable fashion, this 18.35 10^{12} kg grows on **9.18 10^{12} m^2 woodland**.
To harvest this sustainably, if we assume **a 25 year growth** cyclus, we
then use every year 1/25th of the area, i.e. **3.67 10^{11} m^2 woodland**.

The globe surface is $4.\pi.(6'378'000\ m)^2 = 5.1\ 10^{14}\ m^2$, of which 11% is forest land, i.e. $5.6\ 10^{13}\ m^2$. Hence 0.66% ($=3.67\ 10^{11}\ m^2$ of $5.6\ 10^{13}\ m^2$) of total forest area on Earth would be needed every year to replace coal for electricity.

2.
We need 4059 Mtoe ethanol equivalent (21 MJ/L).

4059 Mtoe = 170 EJ, which is $8.1\ 10^{12}$ L (with 21 MJ/L heating value for ethanol).

This requires $2.7\ 10^9$ hectare cropland (if ethanol yield is 3000 L/hectare), i.e. **$2.7\ 10^{13}\ m^2$** of agricultural land. Total current agricultural land is 3% of the globe, or $1.53\ 10^{13}\ m^2$.
In other words, we would almost need to double the now used agricultural land only to replace oil by ethanol!

3.
We need 3223 Gm^3 gas = $3.223\ 10^{12}\ m^3$ and can generate this from agrowaste at a rate of 2000 m^3 methane per hecare of agricultural land. Hence we need $1.61\ 10^9$ hectare, or **$1.61\ 10^{13}\ m^2$**. Again this alone would use all the current agricultural land!

In total we would need $4.31\ 10^{13}\ m^2$ agricultural land (=8.5% of the planet, i.e. **30% of all land**!) and $3.67\ 10^{11}\ m^2$ woodland. Clearly **liquid and gaseous biofuels are limited**. This is less so with **solid biomass**, due to its bigger energy density and growth density.
In fact, the main bottleneck in energy supply today is liquid fuel for mobility and the world's utter dependence on oil for it as it's almost exclusive source.

Atmospheric CO2 increase (ppm)

Emissions : 31.3 Gt CO_2
Let's express the emission first per m^2 of Earth's surface.
$4*Pi*R^2 = 4*3.1416*(6378000m)^2 = 5.1\ 10^{14}\ m^2$
Therefore : $31.3\ 10^{15}$ g CO_2 / $5.1\ 10^{14}\ m^2$ = 61.37 g/m^2 = **1.395 mole CO_2 / m^2**
(molecular weight CO_2 = 44 g/mole)
At standard conditions (273 K, 1 atm, 1 mole = 22.4 L), this is
1.395 mole * 22.4 L/mole = 31.3 L
(interestingly the exact same number in L as in Gt !! Purely coincidental …)
Since half of this value is absorbed by oceans/land, **15.65 L CO_2** per m^2 of Earth surface are released in the atmosphere every year.
Now we need to know how much air the atmosphere contains above 1 m^2 of Earth's surface.
1 atm = 101325 Pa = 101325 N/m^2 = 10'525 kg / m^2 (divide by g = 9.81 m^2/s^2)
At sea level and standard conditions (273 K), air density is 1.22 kg/m^3, hence

- ⇨ 10'525 kg /1.22 kg/m^3 = 8627 m^3 of air are weighing on 1 m^2 of the Earth's surface, taken at sea level standard conditions.

We now can conclude : 15.65 L of CO_2 are added to 8627 m^3 above 1 m^2 of Earth surface, or
$15.65\ 10^{-3}\ m^3 / 8627\ m^3 = 1.81\ 10^{-6}$ = **1.81 ppm**
If you compare this with the data on the 'Mauna Loa' slide of measured atmospheric CO_2 increase between 1960 and now, this fits very well.